Governance for increased CHP District Heating diffusion in the UK

Submitted by:

Anthony Granville

To the University of Exeter as a thesis for the degree of Doctor of Philosophy in Renewable Energy
in

May, 2017

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

Signature…………………………………………

DEDICATION

This thesis is dedicated to the one who has given me the opportunity to study, provided the resources and guidance, whom I call Jehovah-Rohl (My shepherd) and Jehovah-Uzi (My strength). “Becuase i fetched my knowledge from afar but ascribed all righteousness to my maker - Jehovah- Eli (My God)” Job 36:3

ABSTRACT

Combined Heat and Power and District Heating technology systems (CHP-DH) is a network-based infrastructure known to offer a more efficient and more sustainable option for meeting society's energy needs with reduced emission production in the face of increasing population and energy demand compared to other forms of conventional thermal plants. Specifically, this brings to the fore the potential importance of these systems, their rate of penetration and what factors are militating against their diffusion.

The United Kingdom (UK) currently exhibits a low penetration of CHP and particularly CHP-DH systems in terms of contribution to both electricity and heat generation profile with the adoption of these systems failing to meet their potential over decades. This is despite Government commitments to meeting environmental targets for emission reduction and 2020 energy targets from renewable energy by introducing several governance mechanisms. This failure suggests that these mechanisms have not fully captured the potential of CHP-DH systems to achieve these targets. Secondly, it is also not clear that the UK has adequately considered heat energy as a critical aspect of the energy vector to meet its energy target, based upon the limited governance infrastructures to facilitate the efficient generation and distribution of heat.

This thesis focuses on investigating the inducing and blocking mechanisms that influence the diffusion of CHP-DH systems in the UK using both a technological innovation system approach and governance theoretical concepts with a view to proposing alternative governance pathways to influence the CHP-DH penetration. Qualitative and quantitative methodologies are adopted here. A wide selection of stakeholders is consulted to identify barriers and assess potential solutions with a view to examining possible strategies for both communities and society at large to harness the potential of CHP-DH in meeting energy, environmental and social targets.

The results suggest several governance options that seek to influence the diffusion of CHP-DH systems in the UK. Summarily, it highlights the roles that hierarchies of governance (State and Local Authorities) can play in influencing the diffusion of the technology, with the state to evolve a joined-up policy portfolio to stimulate investment and growth of CHP-DH systems and the LAs as prime movers of the CHP-DH TIS taking up "doers and enablers" roles in the penetration of the technology. Thereby contributing to the energy policy debate by persuading the hierarchies of governance to see CHP-DH systems through the lenses of a network-based infrastructure and consider alternative governance mechanisms that may ultimately enhance the selection environment of CHP-DH systems in the UK.

# ACKNOWLEDGEMENT

The words of this project were put together by me but it could not have been possible without certain people who God provided to fill the gap and the role of helpers. Though this list is not exhaustive and it's by no means in any hierarchical order but for the purpose of confining myself to this space, I shall start by recognising the academic duo of Dr Peter Connor and Dr Bridget Woodman, who are my supervisors. The two provided the guidance and invaluable support any student would ever wish for, always making sure that I navigate through the academic furnace of PhD and come out with satisfying results without getting burnt, to them I say am grateful.

I would also like to sincerely recognise my fellow PhD and house colleagues, Dr Iyakwari Shekwoyandu and Dr Amos Idzi Ambo who always provided me the succour to keep going even when the mental tide seems ebbing. I will forever remember the lovely companion we had guys.

I also want to sincerely thank the leadership of Redeemed Christian Church of God, Exeter for the continuous prayers and brotherly love extended to me during this programme, with particular mention of Pastor Samuel Olufemi Akinwunmi and Babatunde Abayomi. More blessings brethren.

Finally, my deepest love and heartfelt gratitude to my wife Diema Granville and my great boys, Daniel, Joshua and Abraham for their understanding and perseverance during this programme. Love you all.

To all I say God bless and thank you

Table of Contents

Table of Figures

Table of Tables

List of Appendices

1.0 Introduction

Energy systems are continuously the focus of improving efficiency, security and reducing carbon emissions. Growth in energy demand is expected to continue, as with a recently estimated 30% global increase by 2040 (IEA, 2016). The contribution of energy generation to environmental impacts most notably includes the effects of emissions on global warming. Heat production contributes to over half of the world's final energy consumption with about three quarters of this consumption met with fossil fuels, accounting for one third of the world's CO_2 emissions (IEA, 2014c). While, electricity generation accounts for almost 40% of global primary energy and also contributes about 40% of global energy related CO_2 emission (IEA, 2014d). The combined figure for heat and power accounts for almost three quarters of global energy related CO_2 emission. This underpins the necessity of an efficient integration of heat and power generation technology in abating global warming and presents a long-term opportunity of curtailing the environmental consequences of rise in energy demand.

Combined Heat and Power (CHP) technology (also known as cogeneration) produces electricity and heat simultaneously, allowing the heat to be captured to be used for either space heating/cooling, water heating or process heating. Furthermore, CHP systems can be fuelled by an array of sources including renewable energy sources and low carbon sources to generate both electricity and heat with the opportunity of generated heat to be distributed though district heating (DH) networks. DH networks are also able to receive heat from various heat sources including CHPs and other renewable energy sources of heat (RES-H) technologies. A recent report by IEA (2014a) suggest that 79% of the total DH in OECD countries in 2012 is produced from CHPs indicating the interdependence of CHPs and DH technologies. Therefore, the interconnection or integration of CHP and DH technologies to achieve a mutual goal of generation and distribution of energy vectors is further referred to in this research work as a CHP-DH system. This suggests that CHP-DH systems are network-based infrastructures that produce and distribute public goods/service which have their peculiarities. Such as incremental transition, path dependency, asset specificity, requires huge investment cost, and precipitates sunk cost that ultimately would have political, economic, social and environmental implications on the fabric of the society.

Several studies have shown that the use of an integrated energy system like CHP-DH to simultaneously generate electricity and heat can contribute to higher efficiency and emission reduction of energy production compared to generating electricity and heat separately (Torchio et al., 2009, Genon et al., 2009, Connolly et al., 2014, Rezaie and Rosen, 2012, Haghifam and Manbachi, 2011). Other benefits of CHP-DH system may include economics by reducing energy bills (Shahnaz, 2013), or socially by contributing to mitigating fuel poverty (Hawkey et al., 2013). However, in spite of these benefits only about 9% of the worlds electricity demand is met from CHP with only about 12% of Europe's total heat demand is provided by DH (IEA, 2014a). Considering that the EU accounts for one fifth of the worlds energy use with 80% of its GHG emission emanating from energy use (EU, 2011c). It is suggested that there is a considerable potential for the deployment of CHP-DH systems in the EU in abating emissions and improving energy efficiency.

Consequently, the EU has adopted a strategy for a competitive, sustainable and secure energy system by 2020. This entails a target for 20% GHG emission reduction by 2020 compared to 1990 base levels, increase of energy consumption from renewable energy sources by 20% and a 20% increase in energy efficiency through various action plans (Fabrizio, 2013). This strategy also considers the deployment of CHP-DH systems as part of the key solutions to improve its energy efficiency and sustainable energy goals going forward (EU, 2011c).

Subject to the EU 2020 mandate and subsequent European legislation agreed by member states, the UK is currently legally obligated to achieve a target of 15% of its energy from RE by 2020 through three broad scenarios. These includes 30% of electricity demand, 12% of heat demand and 10% of transport demand from renewable energy sources through several energy efficient technologies. Such as Combined Heat and Power (CHP) and District Heating (DH) Technologies (DECC, 2009). UK Government data suggests that CHP-DH systems have the potential to half emissions from heating and cooling relative to other technologies with a greater potential to reduce further emissions using RES-H on the network (DECC, 2013a). Consequently the UK Government has predicted that DH schemes fuelled by CHPs will play a key role in its heat decarbonisation route to 2050 given that about 72% of existing DH schemes are fuelled by CHPs (DECC, 2013a). This may have informed the Government's suggestion that between 14% and 43% of the UK's heat demand can be provided by efficient heat networks in order to meet the 2050 carbon objectives cost efficiently (DECC, 2016a). Suggesting the potential role of CHP-DH systems might play as part of the solution portfolio to meeting UK's energy goal of energy security, affordability and sustainability (BIS/DECC, 2009, DECC, 2013a, DECC, 2014, Kelly and Pollitt, 2010, Ricardo-AEA, 2013, Ricardo-E&E, 2015, Ricardo-AEA, 2014, Toke and Fragaki, 2008, Pöyry, 2009).

However, despite the numerous benefits, technological maturity and potential role CHP-DH systems can play in meeting the UK energy target, available information indicates that CHP contribution to electricity generation has never moved above 8% (in 1953) with lows of 3% in both 1983 and 1988 (DECC, 2013b). The latest figures indicate 5.9% of UK electricity came from CHP in 2015 (DBEIS, 2016a)**.** The Government also estimates that DH delivers about 2% of the UK's total heat consumption (DECC, 2013a)**.**

The first time an attempt was made to evaluate the national potential of DH systems in the UK was in the 1970s (Russell, 2010) through the Marshall report. The report summarised that without strong government initiatives DH systems would not develop to a significant level (Marshall, 1977). A more recent study, led by Pöyry (2009) for the Government, also suggest that without significant changes to the prevailing energy institutional infrastructures, the potential of DH networks to substantially contribute to national heat demand would not occur. The 2009 study is likely to remain relevant today since not much has changed in terms of market and regulatory conditions impacting positively on the CHP-DH industry. The low penetration of CHP-DH systems in the UK and the conclusions of the Pöyry work suggest that Government intervention is required to influence the rate and direction of CHP-DH diffusion, and the pathways of Government's intervention to facilitate the diffusion of CHP-DH systems in the UK are the focus of this research. The overall research objective is to examine the reasons for the low penetration of CHP-DH systems through three broad based questions and, building on the conclusions drawn for this point, to develop recommendations for alternative governance routes to improve its penetration.

The aims are: firstly, to investigate the dominant governance structures that permeate the UK CHP-DH landscape and the underlying characteristics such as economic and management models, with a view to improve the impacts of these models on the technology diffusion and also unveiling the dominant risks that militates against the development of the system from CHP-DH actor's perspective. Secondly, building on the understanding of the prevailing characteristics and risk profile with the underlying barriers that feed these risks. The research seeks to pose alternative governance pathways to reduce or eliminate these barriers. Alternative roles of local authorities (LAs) as governance hierarchies in the UK were also explored to address these barriers given the potential roles they can play to promote social, economic and environmental wellbeing of their community and being CHP-DH champions globally (UNEP, 2015)**.** Thirdly the research shall explore the impact of the current governance instruments that exist in the UK electricity and heat sectors in influencing the diffusion of CHP-DH systems with a view to propose more impactful instruments.

Therefore, the underlying driver of this research is to contribute to the UK energy policy debate by firstly, exploring TIS and governance theoretical concepts as the analytical tools to empirically offer alternative governance routes that may influence the diffusion of CHP-DH systems in the UK to stimulate the nursing market. Secondly, to contribution to the debate of policy makers to recognise CHP-DH systems through the lenses of a network-based infrastructure that would require governance intervention if energy and environmental targets are to be met at a reasonable cost.

1.2 Research Structure

This research is in seven major parts, as depicted in Figure 1. This shows that the research begins with a discussion on the technological and theoretical concepts that form the knowledge tool set used for the research investigation and as such will be the focus throughout this research. The output of the technological and theoretical discussion will lay the foundation upon which subsequent narration and analysis will be based upon in the following chapters.

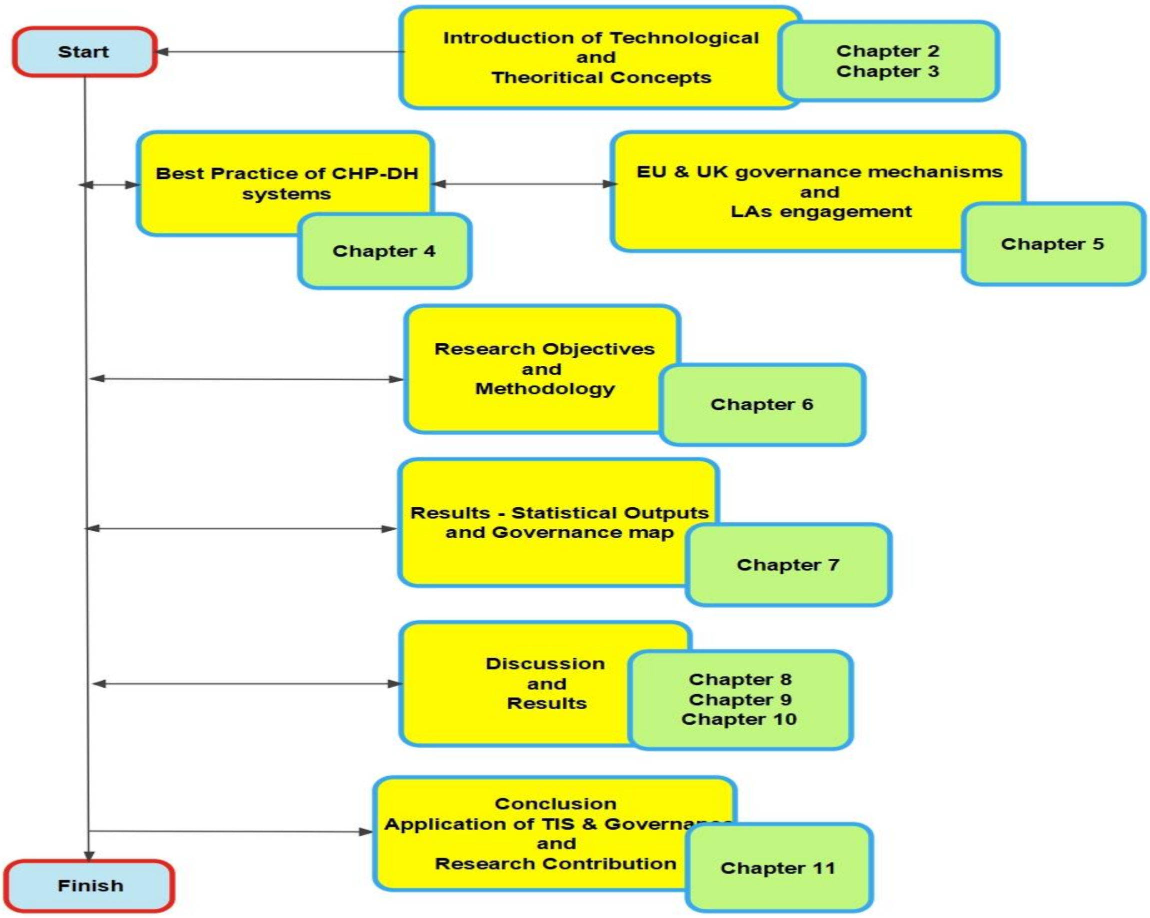

Figure 1: Schematic of research structure

Chapter 2 introduces CHP-DH technology by discussing the connection between CHP and DH systems to unveil the interdependence of both systems and principles of operation. This chapter seeks to capture the performance of CHP-DH systems in the UK and the various significant barriers that have impacted the diffusion of the technology in the UK. Chapter 3 presents the concept of infrastructure and its connection to socio-technical system theories, before narrowing it to the two theoretical concepts that the research is based upon. Firstly, Innovation Systems (IS) theory, which seeks to link innovation to economic growth using an evolutionary approach (Nelson et al, 1982). It suggests that with the entrance of a new product or a new process for an existing product, economic growth can occur (Edquist, 1999) such as new innovative or new ways to govern CHP-DH systems for economic development.

IS theory delineates systems into several areas depending on the focus of interest and the focus of this research is based upon CHP-DH technology penetration within the UK, which the IS theory considers as Technological Innovation Systems (TIS). Therefore the TIS concept was adopted and it is bound around the dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure to influence the generation, diffusion, and utilization of a technology (Carlsson and Stankiewicz, 1991). TIS captures both vertical and horizontal agents that may influence the penetration of the technology (Breschi and

Malerba, 2005 pg:131) and its selection environment. The second theoretical concept adopted is the governance concept by considering the framework of governance around CHP-DH systems in the UK. The governance concept can be largely defined as the interaction and coordination amongst multifarious actors to achieve a collective goal. Governance emerges through four key iterations including: processes, structures mechanisms and strategies (Risse, 2012 pg: 700, Börzel and Risse, 2010, Levi-Faur, 2012 pg: 8). Governance was preferred over policy because the concept of governance stresses the importance of coordination to achieve sustainable innovations which requires social initiatives that are usually outside the remit of conventional policy instruments which often emphasises on top-down approach (Hillman et al., 2011). Therefore, the research analysis draws upon TIS and governance concepts with a view to integrating these two theoretical concepts to provide answers to the research questions and offer possible pathways to influence the diffusion of CHP-DH systems in the UK.

In the concept of system of innovation, systems are not optimal partly because each system is unique and continuously changing; therefore to ascertain if systems of innovation are performing well or not, it is imperative to focus on comparing the differences between systems rather than adaptation (Edquist, 2005 pg:20). Furthermore technological systems are locked into national systems, such that levels of technological penetration are bound to vary between countries as a reflection of demand structures, institutions and incentives (Carlsson and Stankiewicz, 1991). Consequently, chapter 4 focuses on the underlying governance mechanisms that define the Netherlands and Norway CHP-DH systems as some of the best practice governance approaches to CHP-DH systems in Europe with similar market conditions with the UK. Such as huge gas reserve and market competition. This is with a view to benchmarking the benefits of the various governance interventions adopted in these countries.

The fifth chapter discusses the various governance mechanisms from both the EU and UK that permeate the UK electricity and heat sectors, and which may influence future diffusion of CHP-DH systems. This chapter also discusses the context of the prevailing engagement of Local Authorities (LA) in the governance of CHP-DH systems in the UK and the governance structures adopted. Chapter 6 captures the research methodological framework and strategies adopted which involves both quantitative and qualitative approaches. This chapter also outlines the research questions in detail. While chapter seven is the output of the statistical studies derived from the quantitative method through questionnaires.

The discussion on the research questions was embarked upon in chapters 8, 9 and 10, while chapter 11 is the concluding chapter which captures mapping of the TIS function with its strength and weaknesses as derived from the research and proposed possible contributions to the TIS theoretical concept and recommendations.

2.0 Overview of Combined Heat and Power (CHP) and District Heating (DH)

2.1 Principles of CHP-DH

2.1.1 Combined Heat and Power (CHP)

Combined Heat and Power (CHP – sometimes known as cogeneration) technology is the simultaneous production electricity and heat, with the possibility of the heat being used for either space heating/cooling, water heating or process heating. CHPs are known to achieve higher efficiencies to as high as 90% compared to conventional plants which generate power and heat separately at a much lower efficiency of between 30%-37% with combined cycle gas plants having efficiencies of about 50%-60% (IET, 2008, Haghifam and Manbachi, 2011). In part because the heat wasted from conventional plants may reach as high as 40% or above, but CHPs utilises the wasted heat from the generation process for other purposes. Suggesting that it has the potential to exhibit economic and environmental benefits (Shahnaz, 2013) and therefore may be relevant as part of the government energy portfolio to meet its energy targets.

Figure 2 depicts a schematic diagram of the level of fuel efficiency that obtains when generating electricity and heat separately and when generating both forms of energy simultaneously.

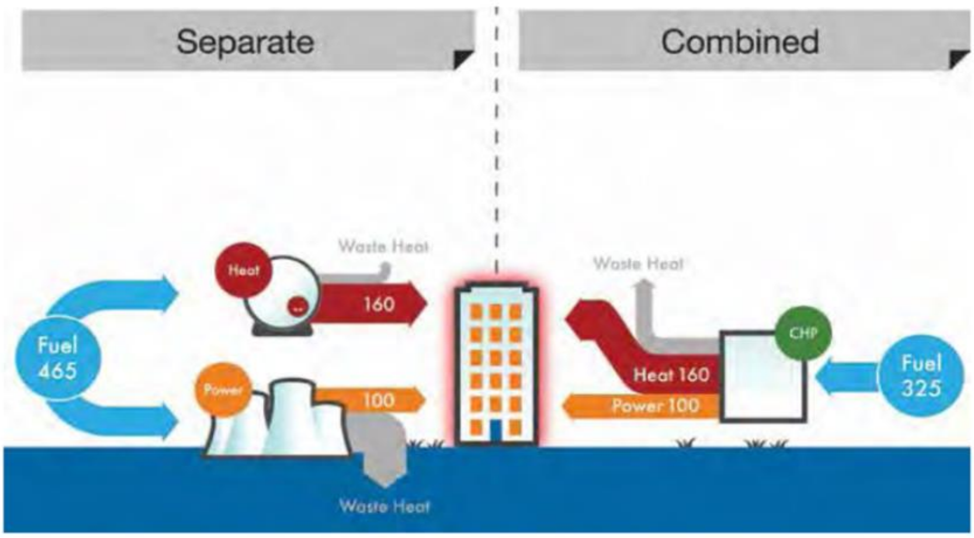

Figure 2: Schematic diagram of separate and simultaneous generation of Electricity and Heat

Source: DECC (2015n)

CHP technology is a combination of three major components which work together to create electrical and thermal energy simultaneously. The components are the prime mover, a generator and a heat exchanger/recovery system. If a cooling effect is required then a fourth component, absorption chillers, might also be required and the addition of this component allows for trigeneration.

Figure 3 below describes in a schematic structure of the overall principle of a cogeneration system, while Figure 4 depicts that of trigeneration system.

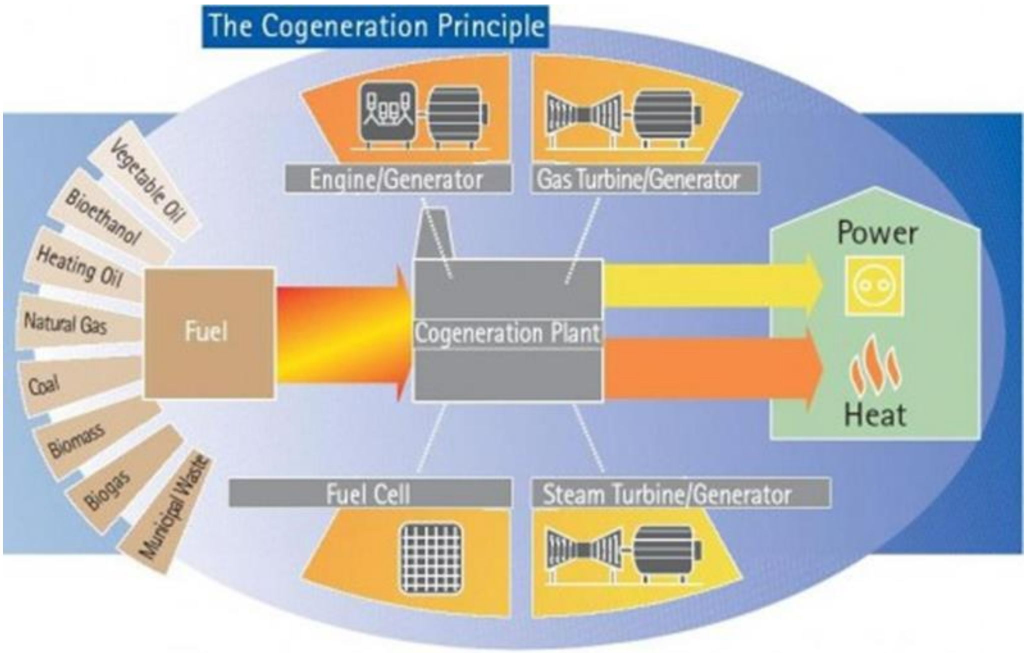

Figure 3: Principle of co-generation

Source: (COGEN Europe, 2013)

Prime movers are devices that convert energy released from fuel into mechanical energy such as shaft power to rotate an electrical generator (steam turbines, gas turbines) or through electrochemical process to convert energy to electricity (Fuel cell – Solid Oxide). Generators are devices that convert mechanical energy to electrical energy while the heat recovery systems converts' heat/thermal energy to mechanical energy or work through a thermodynamic process. Heat recovery systems are generally in two classes: topping-cycle or bottoming-cycle systems, depending on the flow of the energy being used.

If the primary purpose of the energy in the fuel is to generate electricity, this process is known as the **topping-cycle system**. In this system, the waste heat is captured then used for heating or cooling applications, such as, district heating, industrial processes or district cooling (Noordermeer, 2000). Typical examples of topping-cycle systems are steam turbines, gas turbines, reciprocating engines, micro turbines and fuel cells for industrial applications. However, on the contrary, if the primary purpose of the fuel energy is to provide process heat first, this is known as **a bottoming-cycle system**, which is often used for industrial purposes such as metal smelting and glass. In this process the wasted heat is captured and used to drive turbines to produce to electricity. It is noteworthy, that it is also possible that both systems can be integrated to have a system that produces electricity by two separate generators, such as a gas turbine topping cycle and the other part, a steam turbine bottom-cycle system. This process is commonly referred to as combined cycle CHP.

2.1.1.1 Prime movers

Prime movers are broadly characterized into four groups namely: Steam engine, Gas engine, Reciprocating engine and Fuel cell. They differ in many ways, such as fuel type, capacity range, start – up time, electrical efficiency and many more, but the process of generating electricity and capturing of heat for further application is more defining. Further description of the various prime movers that are applicable to CHP systems is under-taken below:

2.1.1.1.1 Steam Turbines

These are turbines (rotating machinery) that don't burn fuel directly or convert fuel directly to electrical energy but require high pressure steam produced in a boiler or a heat recovery steam generator, which is commonly referred to as the Rankine cycle (CRES and ZREU, 1999). They are about the most versatile and oldest of all the technologies used to drive a generator or machinery. They are a mature technology used in various applications. Such as CHP, DH and Cooling, combined cycle power plants and mechanical drives (Darrow et al., 2015). Its strength is the ability to operate at high steam pressures and maximises efficient steam utilization (Onsitesycom, 1999). They can be deployed in topping-cycle, bottoming-cycle and combined cycle systems. Steam turbines for CHP applications are divided into (2) two major categories: Non-condensing (also referred to as back pressure) steam turbines and extraction steam turbines. (Darrow et al., 2015). Both systems work effectively in a CHP application, depending on the quality of heat required, quantity of power and heat required, and economic considerations. They also offer flexibility to various demand criteria such as low grade hot water, low-pressure steam or medium-pressure steam, but particularly deployed where the heat required is more than the power required and are not designed to burn fuel directly but rely on boilers or steam generating equipment like Heat Recovery Steam Generator (HRSG) to deliver the required amount of high pressure steam (Carbon Trust, 2010). Therefore, steam turbines in CHP applications typically have low electrical efficiency between 5 to 40+%, but with an overall CHP efficiency that is close to 80% (Darrow et al., 2017).

Non-condensing (back pressure) steam turbines discharge the entire flow of steam at one or more locations that is appropriate for downstream process equipment. Such as process applications or feed in for lower pressure steam turbine. While, when the casing has one or more openings for extraction of some of the steam to be used for feedwater heating or process heating in CHPs at an intermediate pressure, it is known as extraction steam turbine (Darrow et al., 2015).

Steam turbines have the attribute of meeting more than one heat site requirement (Darrow et al., 2017) and the application of steam turbines in CHP are durable, highly reliable and are better suited for medium and large-scale industrial CHP application with a range from a few MWe to over 100MWe (Carbon Trust, 2010, Darrow et al., 2017). They also have the ability to use a variety of fuel options. Such as coal, nuclear, biomass, various solid waste and by products, such as wood chips, tire-derived fuel, refuse- derived fuel, municipal solid waste, residual oil or refinery gas (Oland, 2004, Onsitesycom, 1999).

However, steam engines have a slow start up, low power to heat ratio and requires a boiler or HRSG to start operation (Darrow et al., 2017).

2.1.1.1.2 Gas Turbine

Gas turbines also known as combustion turbines are used as prime movers for generation of electricity and heat in both topping-cycle and combined-cycle systems. The turbine produces electricity, whilst the useful heat from the turbine exhaust flow is being captured through a heat recovery system. The common components in a gas turbine CHP are air compressor, combustion chamber, heat recovery system, turbine and generator. Gas turbine commonly operates with Brayton cycle principle, which is when there is an intake of atmospheric air as the working fluid from the environment by the compressor only once and forced into the combustion chamber where it ignites the fuel for combustion occur (CRES and ZREU, 1999). The energy released from the fuel during the high temperature combustion process drives the turbine. This system can effectively use the rejected waste heat or thermal energy from gas turbines by recovering the continuous stream of high-temperature exhaust gases and reuse it for process applications to achieve a higher system efficiency of over 70% (Darrow et al., 2017). These recovered heat/gases are used to produce steam or increase the temperature of the boiler feed water, or directly heating other process applications (Oland, 2004). The common fuels for gas turbine are natural gas, synthetic gas, landfill gas, and fuel oils (Darrow et al., 2017).

Two basic types of gas turbines are being applied in CHP; aero-derivative gas turbines adapted from air craft engines and the industrial or frame gas turbines. The application of both systems in CHP are mainly because of the advantages of the ability to switch fuel, low maintenance cost, low initial cost, high availability, high quality heat and high efficiency in large sizes. Therefore, recent developments of gas turbines are targeted at CHP applications with a view to generate electricity and heat simultaneously from a low emission natural gas fuel at a higher efficiency (CRES and ZREU, 1999).

Aero-derivative type of gas turbine are typically more expensive than the frame type but are lighter, thermally more efficient, capable of faster start up and rapid response to changing load with ranges up to 40MW. While the frame types are of higher ranges, of more than 200MW, heavier and better suited for continuous base load operation with longer inspection and maintenance interval (Oland, 2004).

Gas turbines usually have higher electrical efficiency than steam turbines because they operate at higher temperatures and are often designed to operate on cleaner gaseous fuel such as natural gas fuel with usually a stored liquid fuel as a backup (Carbon Trust, 2010). One of the major devices that help to improve the efficiency in a gas turbine is the integration of a heat exchanger into the process, though It also has design challenges as ambient temperature rises and poor efficiency at low loadings (Darrow et al., 2017). They are also expensive, and their cost can normally be justified when a relatively low-cost fuel is being used and the gas turbine has high operating full load hours/year.

The prices of gas turbine CHP applications vary a great deal because of sites, sizes and economy of scale with ability to be scaled up compared to steam turbines. Gas turbines have emissions such as NOx, CO, SO_x, and volatile organic compounds, but abatement methodologies have been provided to reduce these emissions such as the use of Selective Catalytic Reduction (SCR) or catalytic combustion for NO_x or carbon control and scrubbers for reduction of sulphur. While electrostatics precipitators and bag houses are deployed in reducing particulate matter (Darrow et al., 2017).

In summary gas turbines offer operational flexibility as they can satisfy both base load and follow load demands. While the heat recovered from the exhaust gas can be used to generate steam or hot water for DH, cooling or drying applications as demand requires. They also offer the capability of using the shaft power delivered by the turbine to drive a mechanical chiller compressor pump or other types of rotating machinery. Gas turbines are commonly operated in two cycle configurations. Namely: single cycle gas turbines or combined cycle gas turbines.

The single cycle gas turbines are when the compressor and turbine are on the same shaft, often known as single shaft machines and they are commonly used on lower capacity applications, such as less than 25MW (CRES and ZREU, 1999). Whilst the combined cycle gas turbine is a combination of the steam and traditional gas turbine systems. In the combined cycle system, the exhaust heat from the gas turbine is recovered by passing it through a heat recovery steam generator (HRSG) making it a fuel to the steam turbine in a bid to improve the overall efficiency. The combination of the electrical production of the gas turbines through high input temperature and the low output temperature from steam cycle for heat usage, makes it an ideal description of CHP device. The latter (combined cycle) have more flexibility and reliability because of its ability to generate electrical energy and high temperature heat from more than one source, but its drawback is a higher cost than the simple cycle. Furthermore, simple cycle is much simpler to operate, smaller carbon footprint and lower start-up cost. Combine cycle gas turbine is a mature technology that has built in abatement facility for NOx, sulphur and particulate matter emissions with applications often from 25MW and above (CRES and ZREU, 1999). CHP applications gain from the opportunities of a wide range of heat to power ratio provided by the integration of gas turbine with the supplementary firing from steam cycles in a combined cycle system.

Gas turbines are deployed in scales depending on power requirement. A common nomenclature that is a departure in size from the conventional gas turbine is the micro turbine. The underlying difference is often the capacity range, size, lower emissions and fewer moving parts in the micro turbines compared to conventional gas turbine plants. The common fuels used in a micro turbine are natural gas, sour gas and liquid fuels (Darrow et al., 2017). The micro turbines are of smaller capacities, compact and are usually packaged with a microprocessor and a turbine, often from 30kWe and over 300kWe (Oland, 2004). The micro turbines can be deployed in office blocks, factories, or in a distributed generation application due to its flexibility in connection methods.

However, micro turbines have a higher unit capital cost, relatively lower electrical efficiency and they are limited to low temperature applications (Darrow et al., 2017).

2.1.1.1.3 Reciprocating Internal Combustion Engines

Reciprocating engines (or Piston engines) are generally driven by pistons inside cylinders through the conversion of pressure to a rotating motion. There may be more than one piston inside a cylinder with which a variety of fuel, such as gas, diesel can be introduced under pressure and the fuel mixture (air + fuel) is ignited by a spark ignition or heat compression to cause a combustion (thereby attracting the name internal combustion engine). However, when the heat energy required to drive the piston is being applied from outside the piston chamber, it is regarded as external combustion. Reciprocating engines are commonly deployed in locomotives, ships and CHPs (Breeze, 2005 pg:75).

Reciprocating internal combustion engines are of two common types namely the Spark Ignition (SI) and the Compression Ignition (CI). The SI type uses timed high-intensity spark plugs to ignite a compressed air + fuel mixture introduced to the cylinder (Oland, 2004). These types are generally fed with gaseous fuel or vaporised liquid fuels such as gasoline, propane, manufactured gas, landfill gas or natural gas which makes the most popular types of reciprocating engines.

The CI (diesel engines) type uses the heat of compression of the fuel and air which are injected at high pressure into the cylinder to achieve ignition. CI can also be designed to operate in a dual fuel mode using the diesel as the compression ignition pilot fuel. The CI was common on power generation applications due to its high efficiency, but as a result of its higher environmental effect resulting from high pollution, such as nitrogen oxide, sulphur compounds from fuel used, it has limited application on CHP (Breeze, 2005 pg:75). Whilst, SI uses cleaner fuel such as gas which makes it a more favourite choice for CHP application, though all reciprocating engines emit NOx, CO and unburned hydrocarbons. However, modern reciprocating engines have abatement method integrated to reduce these emissions. Such as in SI, a Three Way Catalytic (TWC) conversion is often integrated to reduce the NOx, carbon and hydrocarbons, while in CI engine the wet or dry scrubbers are used to reduce sulphur and an electrostatic precipitator or a bag house is used to reduce the particulate emissions (Oland, 2004). Ongoing technological improvements have seen the growth of reciprocating engines, largely due to improved fuel efficiency and emission abatements with the CI (diesel engines) the most globally installed annually, while SI (natural gas engines) is most popular with CHP applications (Breeze, 2018 pg 9-10).

In using reciprocating engine for CHP applications, common fuel used are natural gas, biogas, LG, sour gas, industrial waste gas, manufactured gas (Darrow et al., 2017).

Reciprocating engines are increasingly becoming popular in the application of CHP because they are readily mobile, high availability (95%), suitable for distributed generation with ability to feed base load and peaking load, fast start-up capability, ability to provide power in an emergency if the battery for black-start is available with minimal auxiliary requirement. It is also economically competitive due to its cost per kilowatt for ranges of capacities (Onsitesycom, 1999). The thermal output from reciprocating engines is usually hot water instead of steam (Carbon Trust, 2010) making it ideal for water heating, space heating, and low temperature process, which can also be suited for driving absorption chillers that provide cold water, air conditioning and desiccant dehumidification. The range of CHP capacities from reciprocal engines are between 5kW to 10MW (Darrow et al., 2017).

Another type of reciprocating engine (but not internal combustion engine) worthy of mention is the Stirling engines - external combustion engines. They are a kind of reciprocating engines that uses the movement of pistons in a cylinder to create motion but in this case, it is caused by externally induced temperature difference and not pressure. This is an external combustion engine that operates in heat led mode. (i.e. they will run when there is demand for heat from the hot water storage tank). These engines typically have low electrical efficiency between 7% and 15% LHV (Hawkes and Leach, 2008a) but high overall efficiency compared to condensing boiler.

2.1.1.1.3 Fuel Cell Engines

Fuel cell engines converts chemical energy to electrical and thermal energy through an electrochemical process without the combustion of fuel directly or any moving parts. This technology uses the reaction between hydrogen and oxygen to produce electricity, heat and water through an electrochemical process and the hydrogen used in the oxidation process could be derived from hydrogen rich fuels such as fossil fuels or renewable energy sources (CRES and ZREU, 1999) . This in effect is the reverse of electrolysis – which uses electricity to separate hydro and oxygen. This technology is similar to a battery system that produces Direct Current (DC) through a chemical reaction that normally happens when you have a cathode, an anode and electrolyte. However, the difference is that fuel cell is a power generator while battery is a power storage system. The electrochemical process begins by extracting hydrogen from hydrocarbons through a process known as reforming, then the hydrogen is separated into electrons and ions. While the electrons flow through the electrolyte to the anode (negative electrode) to produce electrical energy, the ions react with oxygen at the cathode to form water (H_2O) and heat.

There are four potential sources of useful heat for fuel cell. These are: exhaust gas including water condensation, stack cooling, anode off-gas combustion, and reformer heat (Oland, 2004). The heat generated during this chemical process is removed by either liquid or gaseous coolant by passing it through cooling channels in the stack, while the DC generated is converted to alternating current (AC) by an inverter.

Fuel cells have a relatively high electrical efficiency of over 60% HHV of the fuel and around 55-80%% on overall CHP efficiency, with a commercial power generation range of 5kW – 2MW (Darrow et al., 2017). According to Lucia (2014), there are presently eight different types of fuel cells available as shown below and they are defined by the type of electrolyte that is being used. These include:

- **MCFC** (Molten Carbonate Fuel Cell) – Electrolyte is a molten carbonate salt suspended in a porous ceramic matrix.
- **PAFC** (Phosphoric Acid Fuel Cell) – Electrolyte is an anode and a cathode made of a finely dispersed platinum.
- **SOFC** (Solid Oxide Fuel Cell) **-** Electrolyte is a solid ceramic
- **PEMFC** (Proton Exchange Membrane or Polymer electrolyte membrane fuel cell) - Electrolyte is a water-based, acidic polymer membrane and platinum-catalysed electrodes.
- Catalyst on silicon carbide and carbon structure in a phosphoric acid electrolyte.
- **HT-PEMFC** (High Temperature PEMFC) is a PEMFC obtained by changing the electrolyte from a water-based to a mineral acid- based system.
- **DMFC** (Direct Methanol Fuel Cell) – Electrolyte is a polymer membrane
- **AFC** (Alkaline Fuel Cell) - An alkaline electrolyte.

However, only the first four (MCFC, PAFC, SOFC, PEMFC) are commercially available for CHP applications by 2014 (Darrow et al., 2017). Such as in Japan, many homes are currently receiving power and heat from CHP fuel cells (Sharaf and Orhan, 2014). While the UK first fuel cell scheme was launched in 2003 operated by Woking council to provide power for its park lightening, pool and the leisure centre (Carbon Trust, 2010). The fuel cell technology is characterized by several benefits, these includes: ability to be cascaded, efficiency is independent on its capacity, low emission due to no combustion, high reliability due to no moving parts, quiet operation, ability to follow load due to cell in array and produce varying thermal energy levels depending on the electrolyte and the operating temperatures e.g. MCFC and SOFC are capable of producing high pressure steam for CHP applications (Mekhilef et al., 2012).

However, fuel cells require long time duration to start up compared to other prime movers, therefore they are useful for feeding baseload but not ideal for peak load or standby service (Oland, 2004).They also currently have high initial cost outlay, a limited service history, limited operational capacity, low power density per volume, short life spans of fuel cells due to demand and gas impurities (Mekhilef et al., 2012). Others are immature hydrogen infrastructures, hydrogen safety concerns, delicate heat and water management (Sharaf and Orhan, 2014), and the least commercially mature among all the prime movers in the CHP spectrum.

COMPARISON OF CHP PRIME MOVER TECHNOLOGIES

Technology	Reciprocal Engine	Steam Turbine	Gas Turbine	Micro Turbine	Fuel Cell
Electric Efficiency (HHV)	27 - 41%	5 - 40+%	24 - 36%	22 - 28%	30 - 63%
Overall CHP Efficiency (HHV)	77 - 80%	Near 80%	66 - 71%	63 - 70%	55 - 80%
Effective electric efficiency	75 -80%	75 -77%	50 -62%	49 - 57%	55 - 80%
Typical Capacity (MW_e)	.005 - 10	0.5 - several hundred	0.5 - 300	0.03 - 1.0	.002 - 2.8
Typical Power to Heat Ratio	0.5 1.2	0.07 - 0.1	0.6 - 1.1	0.5 - 0.7	1.0 - 2.0
Part Load	ok	ok	poor	ok	good
CHP Installed cost ($/$kW_e$)	1,500 - 2,900	670 - 1000	1,200 - 3,300 (5 -40MW)	2,500 - 4,300	5,000 - 6,000
Non-fuel O&M Cost ($/$kWh_e$)	0.009 - 0.025	0.006 - 0.01	0.009 - 0.013	0.009 - .013	0.032 - 0.038
Availability	96 - 98%	72 - 99%	93 - 96%	98 - 99%	>95%
Start - Up Time	10 Sec	1Hr - 1dy	10min - 1hr	60Sec	3hrs - 2days
Fuels	Natural gas, biogas, LG, sour gas, industrial waste gas, manufactured gas	All	Natural gas, synthetic gas, landfill gas, and fuel oil	Natural gas, sour gas, liquid gas	Hydrogen, natural gas, propane, methanol
Uses for thermal output	Space heating, hot water, cooling, LP steam	Process steam, district heating, hot water, chilled water	Heat, hot water, LP - HP steam	Hot water, chiller, heating	Hot water, LP - HP steam
Power Density (Kw/m^2)	35 -50	>100	20 - 500	5.0 -70	5.0 - 20

Table 1: Comparisons of CHP Prime movers

Source: (Darrow et al., 2017)

CHP systems can be further enhanced with the addition of an absorption chiller to produce cooling for buildings in a trigeneration system and a thermal storage to improve its overall efficiency. Figure 4 below depicts the schematic of a trigeneration system

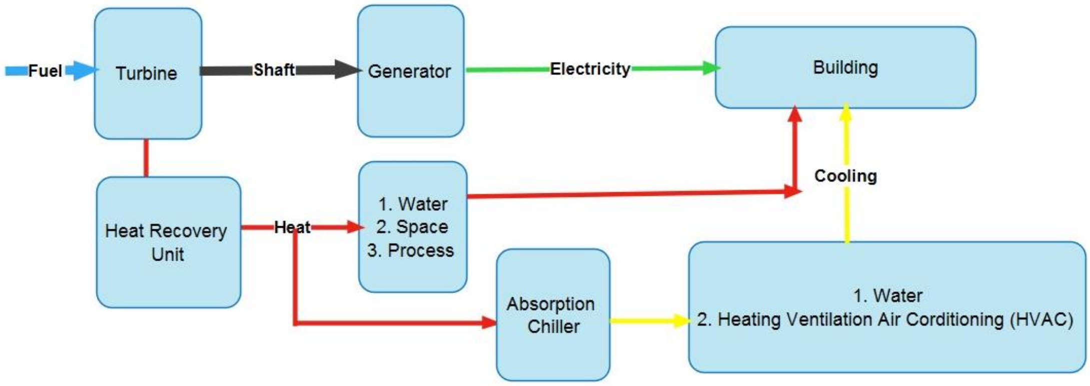

Figure 4: Principle of a trigeneration

Typically, CHPs can be operated in various modes via a despatch or operational strategy. These are typically heat-led mode, electricity-led mode, or least cost/prime operating mode.

- **Heat-led mode:** In heat- led modes the CHP would attempt to primarily meet the heat demand of the site, providing the thermal base load of the site directly from the CHP with an integrated boiler to provide the balance peak load as in the Aberdeen DH (Kelly and Pollitt, 2010). In this mode, dumping of heat is always avoided as the location's heat demand determines the heat to power ratio of the CHP plant which often runs on full load except for normal maintenance shutdown (EEA, 2008)

- **Electricity-led mode**: Here the CHP aims to meet the electrical peak demand as closely as the economics allow, bearing in mind the cost of import and export of electricity at different times of the day. So its main aim would be to reduce the net cost of electricity consumption; while it may consider dumping un-utilised heat or storing it with heat accumulators within the system to be used later, as for instance in the Woking and Barkantine DH schemes (Kelly and Pollitt, 2010). This system may also use an integrated boiler when it is not economical to produce electricity or when heat demand exceeds CHP capacity (Hawkes and Leach, 2007).

- **Least cost/prime operational strategy**. This option is primarily on best economic generation of both sources (heat and electricity) at any point for an unlimited time. In this mode there is no priority of any output but the minimal net cost of providing both the electricity and heat demand bearing the prevailing technical constraints and electricity import or export would depend on operational cost. In contrast to the two mentioned above, this strategy will benefit from increased revenues from selling larger quantities of electricity during the summer and meet heat demand during the winter, for instance in Southampton DH scheme (Kelly and Pollitt, 2010). Thermal storage may not be required here unless the excess heat requires storage and be discharged on a cost benefit basis (Hawkes and Leach, 2007).

2.1.2 District Heating (DH)

District Heating (DH) delivers heat at various points of consumption or generation through pipes using steam or hot water as the transmission medium; it's sometimes referred to as heat network (HN). DH mainly consists of pipes and heat interface units with additional consideration for thermal energy storage (TES) for operation and economic objectives. The early pipes were mainly made of concrete, but most recent pipes are pre-insulated pipes made of polymers to improve efficiency and ease of deployment.

Most UK DH networks deliver heat between 90 -120^{0}C and with an exit temperature at 40 – 70^{0}C (DECC, 2013a). The Government estimates that around two thousand heat networks are operational in the UK, supplying only two percent of domestic, public and commercial heat demand through 210,000 homes and 170,000 commercial and public buildings (DECC, 2013a). The largest CHP-DH system in the UK is the Olympic energy park centre with about 16km of community energy networks (Cofely, 2016, Roelich et al., 2013).

District heating supplies heat via a local distribution system in which consumers are often locked to a single supplier. This is generally different from the markets for natural gas and electricity, which are supported by national transmission grids connecting all producers and consumers. The absence of physical linkage between distribution areas makes the district heating markets look like natural monopolies, each characterised by a group of heating consumers captured most often by a single producer which brings to fore the concern of efficiency in heat distribution.

2.1.3 CHP and District Heating Relationship (CHP-DH)

CHP-DH system is the inter-connected system of production of electricity and heat and distribution of heat from CHPs through DH networks, whilst using the electricity generated for consumption or sales. CHP-DH systems have stronger inter-linkages between production and distribution compared to other energy systems like gas or electricity. In part because the return temperature of the water in the DH network affects the economic performance of the CHP plants such that the lower the return temperature, the more improved overall economic performance of the CHP plant due to higher electricity production (Söderholm and Wårell, 2011). Similarly the separation of production and distribution activities makes it significantly more difficult to operate a cost-effective district heating system (Söderholm and Wårell, 2011).

The integrated nature of CHP-DH systems leverages on the economy of scale of linking production and distribution of two critical energy vectors (electricity and heat) to capture economic, environmental and social objectives. Furthermore, CHPs can be fuelled by various sources while DHN can also receive heat from various heat sources including CHPs and renewable energy sources of- Heat (RES-H).

CHP-DH systems offer several benefits; such as their efficiency which means they are relatively low in emissions for both electrical and heat generation, suggesting it's a useful option for heat decarbonisation. For instance in a recent study, the Government suggests that CHP-DH systems have the potential to half emissions from heating and cooling relative to other technologies with a greater potential to reduce further emissions using RES-H on the network (DECC, 2013a)..

2.2 Trends in CHP-DH Development in the UK

The earliest large CHP-DH scheme in the UK can be traced to a city centre power station supplying steam to nearby office blocks and factories by Manchester Corporation in 1911 (Russell, 1993, Kelly and Pollitt, 2010) and later the Boots company CHP-DH site beside the River Trent in 1919 (Jarvis, 1986). However various literature recognised that the CHP-DH system in London by Pimlico is considered as one of the first successful large schemes to showcase the technology on the back of supplying heat to housing estates (Martin and Thornley, 2013, Roelich et al., 2013, Diamant and McGarry, 1968 pg 172, Jarvis, 1986). In part, because hitherto there was the deep cultural place of open heating by coal as opposed to centralised heating resulting in lack of interest by municipal electricity utilities in CHP-DH systems (Rüdig, 1986). Which led to the unpopularity of DH networks in cities but more in the industrial sector where there was demand of steam or heat plus power (Sievers et al., 2005). Available data from government archives on the development pattern of CHP-DH systems from the 50s to 2014 as shown in Figure 5, reveals that CHP contribution to electricity supply in the UK has never risen to 10% with 1953 as the year with highest contribution of about 8%. While 1983 and 1988 are seen as the years with the lowest contribution with about 3% of net electricity supply.

This seemingly poor historical performance compared to some western countries such as the Netherlands can be traced to amongst other reasons. Such as, the unsure position of government on the technical and economic viability of the technology (Russell, 1993) and cheap cost of town gas from coal for heating. This was reinforced by the failure of a few earlier CHP-DH systems due to pipe corrosion like the Gorton scheme in Manchester and poor costing as with the Duddeston scheme in Birmingham (Diamant and McGarry, 1968 pg 171-172).

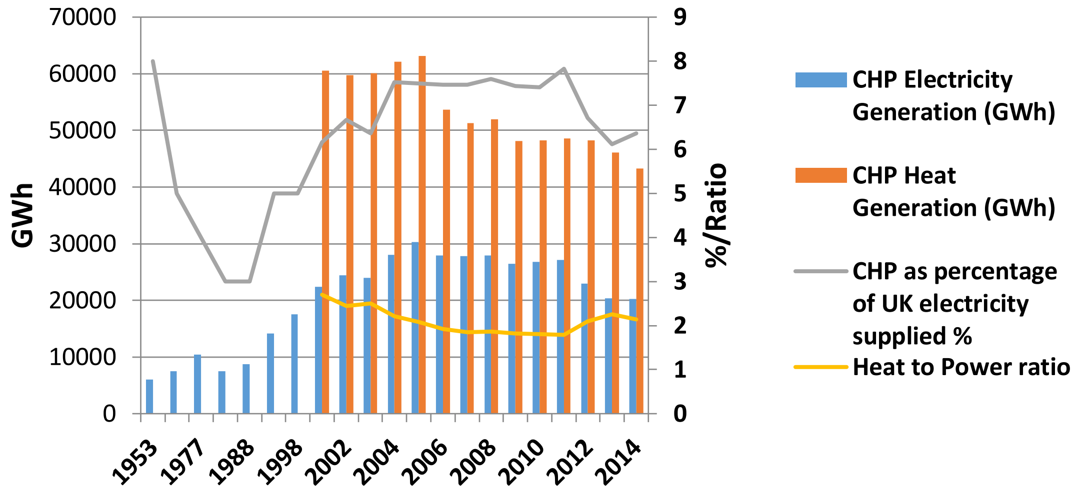

Figure 5: CHP technology growth profile

Sources: Graph created from government data (DECC, 2014e, DECC, 2013b, DECC, 2013k, DECC, 2010d, DECC, 2007, DECC, 2005, DECC, 2006, DECC, 2015c)

Based on Government data the heat to power ratio of CHPs in the UK shows a downward trend, indicating a decline in the heat output relative to electricity. This was largely due to the gradual displacement of coal steam turbines by gas turbines and reciprocal engines as shown in Figure 6. Furthermore, the refocusing of the UK economy from industrial to service economy may have also contributed due to high industrial heat demands that gave way to lower heat demand from the industrial sector.

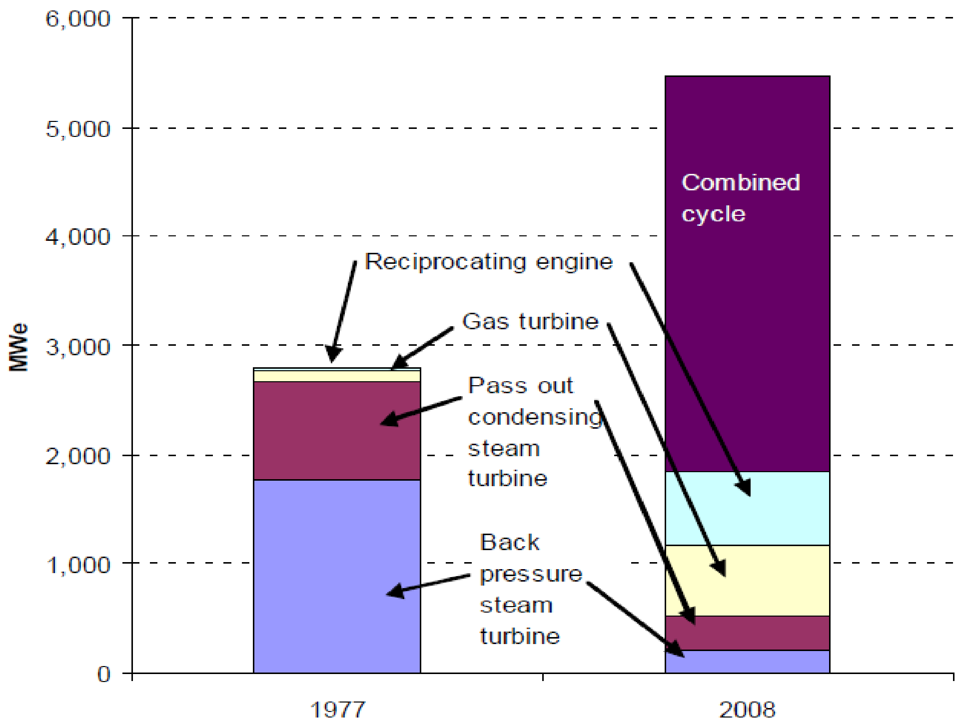

Figure 6: CHP technology profile in 1977 and 2008

Source: DECC (2013b)

The debate on the development CHP-DH systems in the UK received national prominence in the 70s when the national potential of DH systems was assessed in terms of public cost and benefits through the Marshall report (Russell, 2010, Kelly and Pollitt, 2010), influenced by the oil shock of the early 70s (Babus'Haq and Probert, 1996).

The Marshall report aimed to investigate the techno-economic role of DH systems in the UK energy mix and identify the barriers to its penetration and make necessary recommendations. The report suggests that the strength of DH systems was its energy saving ability and fuel flexibility. However they cautioned that competition from natural gas, the structural challenges within the electricity supply industry, high cost of DH systems and government's energy policy preference for free market forces were inimical to its growth (Marshall, 1977). Therefore, the report recommended that without strong government initiatives CHP-DH systems will not develop to a significant level in the UK, key of which is a road map to unravel the potential of CHP-DH systems and the formation of a new organisation known as the "National Heat Board" (NHB) to regulate the heat industry. However, the NHB recommendation was ignored by the Department of Energy (DOE) partly because the government felt that it should be private sector driven if the economics was right. Subsequently DOE hired a consultant, Atkins & partners, to conduct a prefeasibility of CHP-DH systems to investigate the socio-economic and environmental implications of its deployment. (Atkins, 1982, Russell, 1993, Babus'Haq and Probert, 1996).

The mandate of the Atkins contract from DOE was to identify the locations with significant heat density and socio-economic benefits to make business case in collaboration with the local authorities (Atkins, 1982). Suggesting that the participation from both the local authorities was desirable. After the assessment by both DOE and Atkins, nine local areas were favoured for DH systems (Belfast, Glasgow, Liverpool, London, Sheffield, Tyneside, Edinburgh, Leicester and Manchester) but Belfast, Edinburgh and Leicester were selected to benefit from the DOE £750,000 grant under the Lead City Scheme (Babus'Haq and Probert, 1996), while Sheffield, London and Newcastle decided to pursue CHP-DH through the private sector. The Belfast scheme was later abandoned due to a payback period of twenty years (Taki et al., 1993).

The Atkin's report was followed by the Electricity Act of 1983, which many consider as the first CHP-DH friendly UK legislative milestone (Budden, 1988, Babus'Haq and Probert, 1996). Prior to this act, individuals or companies other than the electricity area boards were not allowed to sell electricity to the area boards or local authority, because it was considered not their main business. This was a significant barrier to the growth of CHP-DH systems because CHP owners were locked to their own demand; the 1983 Electricity Act repealed such rules and allowed private generators to buy or sell electricity from/to the local electricity board and also allowed prospective CHP developers to use the national transmission and distribution network for export of its power (Pearson and Watson, 2012).

Another governance instrument of note was the Electricity Act of 1989 which ushered in the privatization of the electricity sector from 1990. This bill was thought to have brought some consolation to the CHP-DH industry as it now allowed local authorities to embark on the sale of electricity as long as it was produced simultaneously with heat thereby encouraging the development of CHP-DH systems (HM Government, 1989). However there were other actions that pulled CHP-DH systems in the opposite direction such as the failure of government to establish a market for heat and the changes to the tax system which meant that natural gas used in power stations was taxed at higher rates than natural gas used for heating in homes, therefore disadvantaging CHP-DH systems (Kelly and Pollitt, 2010, Pearson and Watson, 2012). Additionally, power companies couldn't internalise the waste heat from their plants due to the dominant electric heating (Kelly and Pollitt, 2010), lack of heating governance structures and the uncertainty of the price of natural gas on CHP-DH investment did not help as well (IET, 2008). All these may have culminated in the dash for gas by power stations not translating into growth of CHP-DH systems.

Another significant milestone was the report by the Royal Commission on Environmental Pollution, "Energy - The Changing Climate", which advocated a long term decarbonisation target of 60% reduction in UK emissions by 2050 relative to 1990 as part of an overall energy policy. Importantly, It also advocated a robust regulatory policy to encourage the use of CHP-DH systems and its role in emission reduction instead of technologies that generate power alone. (RCEP, 2000). The Royal Commission's report was influenced by a growing concern as to the impact of energy on the environment and the global position on environmental pollution by the United Nations through the Kyoto Protocol; this could be argued as a turning point in the UK's energy policy to incorporate environmental concerns. As part of government's response, it set a target via the Climate Change programme to double the (electrical) capacity of CHP by 2010 (DETR, 2000), but capacity improved without reaching its target as the capacity of CHP in 2000 was 4.7GW (DECC, 2005) and by 2011 the capacity was 6.1GW (DECC, 2012c) as the prevailing conditions earlier highlighted were still very much around. CHP contributed about 5.9% to UK electricity generation in 2015 with average of electrical and heat efficiency of twenty-four percent and forty-eight percent respectively (DBEIS, 2016a).

The climate change programme heralded several schemes such as the 2001 Community Energy Programme (CEP) through a grant of £50m to encourage the development of DH networks (DECC, 2003, DEFRA, 2004). Subsequently, the energy review of 2006 and energy white paper of 2007 all acknowledged the contribution of CHP-DH systems to the energy and environment debate (IET, 2008).

In 2008, the Climate Change Act can be argued as the governance instrument that sought to set the scene for the linkage between the environment and energy demand in energy policy debate by setting a target of 80% emission below 1990 level by 2050. This culminated in several other policy documents amongst which is the future heating strategy in 2012 that seeks decarbonisation of heat generation and the Energy Act of 2013 that introduced the Electric Market Reform (EMR), which sought to provide secure, cheap and low carbon electricity. It also led to the formation of heat network delivery unit by DECC to facilitate the developments of DH systems.

2.3 Challenges of CHP-DH penetration in the UK

In spite of the technological maturity of CHP-DH technology, UK market penetration remains low, providing only an estimated 2% of heat consumption in the UK via DH network (DECC, 2013a). Many CHP plants are being mothballed such that in 2014 alone 42 schemes were removed from the register and CHPs contributing only 6% to the electricity consumption (DECC, 2015g). This suggests that CHP-DH systems may be experiencing challenges in the UK that may require attention. Hence the discussion of some inherent challenges being experienced by CHP-DH systems in the UK

2.3.1 Electricity Market

A key determinant for the development of CHP-DH systems is the ability to sell both electricity and heat outputs but given the uncertainty in the heat market due to heat largely being treated as a waste/by-product, the sale of electricity becomes crucial in the development of CHP-DH systems.

The electricity market has been driven by competition through economic regulation, Ofgem admits that the market is still fraught with lack of competition, rising profits and distrust of the dominant energy suppliers without satisfying customer expectation (Ofgem, 2014). The 1990 privatisation led to the fall of electricity export prices and generators to negotiate their price with their local RECs. This resulted in small generators like CHPs entering the market under poor contract terms because many lacked the requisite skills to negotiate and resources to hire one. The result was that by 1991 small generators that were hitherto receiving 75% of the commercial sales tariff was now receiving 60% and new entrants only about 25% (Sievers et al., 2005).

In 2000, New Electricity Trading Arrangement (NETA) covering England and Wales only were formed from the pool regime and later in 2005 the transmission networks in Scotland were integrated to form the British Electricity Trading and Transmission Arrangement (BETTA) (Tovey, 2005) but with essentially the same rules. The NETA/BETTA regime operated a more competitive, complex arrangement, and offered greater choices to market participants; however CHP generators and distributed generators in general were paid against a measure of wholesale power prices with a discount to the supplier's cost and imbalance risk. Shortly after the take-off of the NETA regime CHP generators received 17% lower price than earlier received in the pool prices as wholesale electricity prices dropped between 20 – 25% for the first three months, subsequently 60% of output from CHP plants was lost within the first year (Ofgem, 2001). This was reinforced by increased gas prices which raised their cost and the complex requirements of being part of the newly introduced the balancing and settlement code (BSC) (Cornwall and Littlechild, 2008).

The System Operators of the grid – NGET – used the "balancing mechanism" under the BSC to buy or sell power to maintain the energy integrity of the grid. BSC sets the rules for balancing mechanism and its framework is managed by Elexon. Elexon also manages the settlement process by resolving any issues arising between generators' actual output and suppliers' actual demand and clearing debts or credits of market participants. In a study by Cornwall and Littlechild (2008) suggested that most CHPs, who are considered small generators because of their predominantly lower than 50MW capacity, were found to have difficulty in accessing the market partly due to lack of patronage from major suppliers and the burden of imbalanced risk. Suppliers passed this risk to the CHP developers resulting in high market transaction costs and many opted for short term off-take agreements. CHP generators had to also persuade suppliers to take up power by signing contracts that shared their embedded benefits such as Levy Exemption Certificates (LECs) when they export power (DTI, 2005). It can be concluded that from its inception the NETA/BETTA arrangement was not designed to encourage distributed generation but rather to emphasise competition and reinforce lock-ins of the large generators leaving many CHP generators at a relatively disadvantaged position on market entrance (Smith and Watson, 2002; Woodman and Baker, 2008; Wood and Dow, 2011).

Another issue within the electricity market framework that militated against CHP-DH development was the licensing regime. Under the UK Electricity Order 2001, electricity generators under 5MW threshold were exempted from generation, distribution and supply licences, stipulating that generators of electricity can only supply not more than 2.5MW to domestic customers and 5MW to business customers without having a supply licence. This was known as the class order exemption 2001 (DTI, 2005, Ofgem, 2008a). This effectively limits how much a CHP-DH operator can self-supply electricity through a distributed network operator without a supply license. However, if the electricity supply is through a private network, no restriction applies. Secondly, if the CHP-DH operator procures the services of a supplier it usually cost a discount of about 10-20% of the wholesale electricity market price, which typically constitutes the cost of trading, balancing cost, administrative cost, long term risk and profit margin (Handley, 2013). This was exemplified by the collapse of a Leicester citywide district-heating scheme when it failed to secure a supply contract for the sale of its electricity (Kelly and Pollitt, 2010). This restriction of electricity supply of 5MW indicates the adverse consequence of electricity licensing regime on CHP-DH operators.

However, in 2009, licence lite (LL) licence was introduced to encourage small distributed generators like CHP generators to supply their customers directly but with a caveat that they would still require the services of a standard licence owner. Currently there are three main routes to be licensed to supply electricity, which are Licence Lite (LL) license, Standard Supplier License and white label providers. LL licence “junior electricity supply licence” allows a small scale electricity supplier to supply through a third party who has a standard supplier license and a BSC registrant so that it can transfer the compliance obligation on codes. Such as BSC to the standard supplier if the generator is going through the public network. It protects the LL licensee from embarking on the technical and financial implications of a standard supplier, such as high start-up cost, operational complexities and higher market risk associated with a standard licensee (IPPR, 2014). The white label routes introduced in 2013 are for organisations that want to supply electricity or gas using their brand names to retail electricity to customers. This also has to have a third party agreement with a full supply licence for compliance of the industry codes and standards (Ofgem, 2015a). While the third one is the full electricity standard supply licence with condition to comply with all codes and standards as required by the licence conditions. Nonetheless, electricity generators such as CHPs without a standard licence will have to sell their electricity at a discount due to imbalance risk introduced by the NETA/BETA regime.

2.3.2 Heat Market

In spite of the advantages of CHP-DH systems in energy efficiency and social objectives such as reduction of fuel poverty (Hills, 2012), the heat market in the UK is neither a top-down model nor market based competition. It differs considerably from the market for electricity largely due to the fact the large majority of heat produced is consumed locally (on site) or wasted, the volume of heat supplied to third parties is negligible. Secondly, there is no heat grid as in the electricity industry to facilitate widespread heat transaction and thirdly, the UK is still without national heat governance infrastructures.

2.3.3 Policy and Regulatory risk

Markets are created by policies and regulatory mechanisms, the stability of these mechanisms in the long term determines how investors react to the market (Foxon et al., 2005). One risk that investors find difficult to manage or judge is policy/regulatory uncertainty. At best, they will find an alternative route by investing in lobbying or be patient till the regulatory tide calms down (Grubb and Newbery, 2008 pg. 297). Therefore uncertainty over future regulation within the energy sector has the effect of limiting long-term investment and encourages conservative short-term, quick profit decision-making (Kelly and Pollitt, 2010) or investors will adopt a wait-and-see position since they will not invest speculatively (Webb, 2014). Policy/regulatory uncertainty can also emerge from political uncertainty arising from change of political guards at the governance hierarchies. For instance, the CHP industry lost a major financial stream when in 2010 the treasury under the new coalition government initiated a reform of the climate change levy regime. This was with a view to remove the previously enjoyed levy exemption certificate (LECs) on electricity exported from CHPs with effectiveness from the 1st of April, 2013, but still retained the LECs for only site consumption electricity (HMRC, 2010).

2.3.4 Public Perception

Early problematic experiences of the performance of CHP-DH systems in the UK may have affected public support (Sievers et al., 2005) precipitated by the failures of some early schemes due to pipe corrosion after installation and poor design leading to cost overruns. For instance the early DH system at Gorton and Blackley in Manchester in 1919 was abandoned due to pipeline corrosion. (Diamant and McGarry, 1968 pg. 171-172). A study by Larsson (2006) on the perception of CHP-DH systems in UK, suggested that in addition to the earlier mentioned design and management issues, there are contracting problems when the companies providing the DH services are not able to give the appropriate guarantees to the customers. The poor hindsight that these early systems may have left and the perception that CHP-DH systems is not considered an integral part of the energy system in UK but rather an appendage, may all have fuelled the negative perception it has. (Russell, 1993).

2.3.5 Investment/Finance

CHP-DH infrastructure is characterised by high initial capital and low marginal return that makes the investment fully recoverable after many years, which makes it less attractive to investors (Balcombe et al., 2013, Kelly and Pollitt, 2010, Aronsson and Hellmer, 2009). CHP-DH systems produce two energy vectors with different characteristics in terms of infrastructure, regulatory institutions and determinants. Secondly the losses in electricity is largely determined by the volume of power and demand, while heat loss is largely determined by the ambient temperature and pipe insulation (Orchards, 2013).

The intersection of these variables with the recovering of a huge sunk cost on infrastructure makes financing a challenge. Furthermore, the regulatory signals of the UK energy system feed the investment risk of CHP-DH systems. For instance, the perspective with which energy assets are regulated in the UK are based on return on capital invested with little or no consideration to political economy, which dis-incentivises the development of CHP-DH systems in spite of its socio-economic gains (Webb, 2014). Simply put, the recovered heat from a CHP-DH system which displaces additional carbon emission in the energy supply chain at a cheaper cost is only considered as a by-product suggesting heat supply as an additional risk. Therefore, these additional institutional and economic risk attracts additional cost to the capital, which impacts on the viability of the schemes.

The methodology for financing of CHP-DH systems is typically derived using a life-cycle costing method, which analyses the cost based on justified benefit from the system over the economic life of the system known as discounted cash flow (DCF). This is consistent with a recent EU Energy Efficiency Directive Article 14, which mandates all CHP-DH (thermal or electricity generation) installation above 20MW threshold to show evidence of a cost benefit analysis statement since 2014, except for CHPs with less than 1,500 hours of operation per year (DECC, 2015v). This method of DCF is used to determine the viability of the scheme by discounting the cash flow of the project by a factor over the period to determine the present value. The rate of return used to determine the output of DCF analysis is known as the discount rate. The discount rate selected will determine the level of financial return to the investor as the higher the discount rate the higher the financial return due to reduced cost over time, but the UK recommends a discount rate of 3.5% for social analysis with estimates for heat network to be between commercial rates of 10% to 20% (Hawkey and Webb, 2016 pg:122). Suggesting that for CHP-DH systems to be attractive to the market, it’s likely to have a rate of return above 10%, which many Heat Network Delivery Unit (HNDU) facilitated schemes seem not to have (King, 2016). The Heat Network Delivery Unit – HNDU (England and Wales) is an initiative since 2013 to support CHP-DH schemes through provision of grants for feasibility studies in England and Wales with focus on LAs schemes.

There are two main ways CHP-DH systems are financed in the UK, on-balance-sheet financing or off-balance-sheet financing. This suggests either debt with equity finance or through equipment supplier and operating leasing. The choice as to financial route is usually dependent on how much the parties are risk averse and the desired return on investment.

2.3.6 Transmission and Distribution Infrastructure

The early grid networks in the UK were constructed to lock in centralised and large generation, leveraging economies of scale and many of them presently nearing the end of its design life (Hammond and Waldron, 2008). Ofgem (2009a) estimated expenditure of £53.4bn will be needed between 2009 and 2025 to reinforce the electricity grid amidst the changing generation profile to accommodate more distributed generation, as this is critical to the overall energy strategy. The grid has been slow in meeting its obligation as there is increased demand for connection of distributed generation, partly due to the required high investment for grid reinforcement and long lead time in completing transmission and distribution reinforcement projects. As a result, the grid is experiencing bottlenecks and difficulty in granting access to distributed generation, for instance there is restricted power flow of about 2.2GWe from Scotland to England (Hammond and Pearson, 2013). The increased difficulty for the connection of distributed energy, including CHP, naturally constituted a major barrier to grid access as long queues of application would wait for wider system reinforcements to be completed before connection (Wood and Dow, 2011).

However, Ofgem and the DNOs had introduced several schemes to reduce the impact of this challenge, such as the Transmission Access Review (TAR) in 2008 that introduced “connect and manage” approach to accelerate new connections and allowing the generator to choose any point of connection but on the long term, generators will have to provide financial commitment to guarantee long term access. Others are the Low Carbon Network Fund (LCNF) in 2010, which made available about £500m from 2010 to 2015 with the aim of challenging distribution companies to come up with innovative ideas in the form of pilot projects to improve network challenges (Ofgem, 2010a). This was subsequently succeeded by the Network Innovation Competition (NIC) scheme to run from April 2013 – March, 2021. NIC is an annual competition amongst network companies to compete to access an annual maximum amount of £27m for delivery of innovative projects that would impact on grid management and operation (Ofgem, 2013i). Lastly, the incentive regulation of the RIIO (Revenue = Incentive + Innovation + Outputs) to stimulate innovation in network connections through price control, which seeks DNOs to capture sustainability and best customer service in their business plans from April 2015 to March, 2023. (Ofgem, 2013i). However, from the available information, it’s still not clear how it has impacted on better CHP grid access.

Nonetheless, grid connection issues for distributed generators (DG) are far from over. Primarily because in the UK there is no regulation that grants distributed generation and CHPs in particular priority access to the grid as obtainable in Germany and Denmark and the non-socialisation of reinforcement cost as practised in Denmark (Simonds and Hall, 2013). Rather it is on a first come, first served basis with guaranteed network access only after a connection agreement has been signed. Some DGs are still struggling to connect their plants to the grid as a result of high connection cost quotations which largely depends on location and non-standardisation of connection process amongst the DNOs. In addition to these challenges are the high variance amongst DNOs in terms of timelines and consistency as there is no fixed timescale for connection and opacity of connection information from the DNOs (Simonds and Hall, 2013).

2.3.7 Spark Spread

Around two thirds (67%) of CHPs in 2014 were gas fuelled (DECC, 2015g), suggesting that price volatility of natural gas would greatly impact on the viability of CHP-DH development from a spark spread perspective. Spark spread is the gap or difference between the wholesale gas price used for electricity production and the cost of electricity sold to domestic consumers as shown in Figure 7. Spark spread usually acts as an investment pointer to let the CHP-DH developers know if they can recover the investment over time through the sale of electricity or the financial viability (Bonilla, 2006). The graph in Figure 7 indicates how the gap between these indices are getting further apart as the years forward and the resultant would mean lower financial hurdles for CHP-DH developers. As the rate of increase in electricity price out paces the rate of increase in the gas price, then the financial viability of CHP-DH systems improves, because of this, others have argued that a more accurate measure for the competitive viability of CHP-DH systems is the difference in price between gas sold for domestic use and gas sold for the generation of electricity, or what some may define as the domestic-wholesale gas price spread (Kelly and Pollitt, 2010). Nonetheless, spark spread continues to be critical to the investment decision process of CHP-DH development, even more so in places where the spark spread is not consistent like the US, where they are varying spark spread depending on the region (CODE, 2010).

Source: (DECC, 2014d)

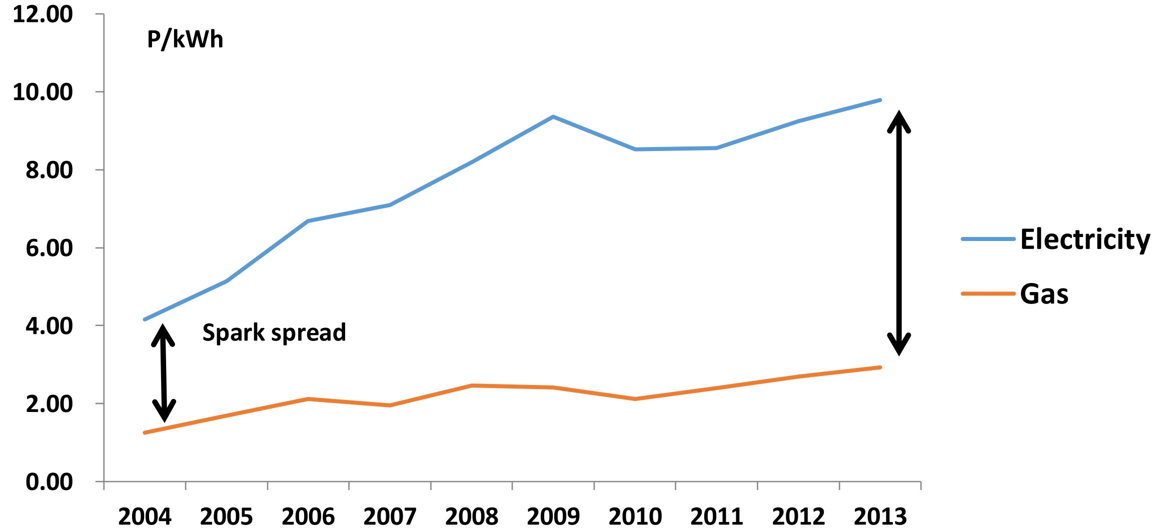

Figure 7: Average prices of fuel for non-domestic customers in the UK

A study by Streckienė et al. (2009) suggested that the electricity and natural gas price impact most on the NPV of CHPs, therefore spark spread is a vital risk indices for CHP-DH developers .

2.3.8 Planning Systems

A further constraint on CHP-DH penetration in the UK is planning. Planning is a governance mechanism used by the state or LAs to control processes (Teisman and Edelenbos, 2004 Pg. 176). This control and steering is achieved through the production of rules of engagement with non-hierarchical actors seeking to engage in infrastructural development. These rules are often rigid and obligatory which also exhibits the extent of the rights of actors and options to exit, else actors may be denied interaction with the locality (Brousseau and Raynaud, 2006). It is therefore always in the purview of hierarchical governance, either by the state or municipal/LA to evolve planning rules for engagement with non-hierarchical actors. In the UK it is also a route to compensate those whom the development has affected through communal compensation.

Planning in the UK as it relates to CHP-DH scheme is divided into two major sections, firstly planning for construction of a DH network and secondly planning rights for the CHP plants to be built and discharge its electricity. The development of DH networks falls under the Town and Country Planning Act 1990 rather than the permitted development rights as electricity, gas and water networks which don't require planning permission (GLA, 2014a). However, in spite of DH heating networks not being part of the permitted development rights, there are other ways that DH networks can get approval to be developed as indicated under the national planning policy framework. The routes could be permission under a wider development, adoption of a local development order, electricity undertaker permitted development rights, LA permitted development right and De Minimis treatment of heat networks (GLA, 2014a).

To discharge its electricity, CHPs would require application for larger capacity CHP plants (>50MW) in England and Wales to be approved by the planning inspectorate and while lower capacity will be approved locally. Similarly, plant sizes (>50MW) in Scotland will be approved by the Scottish Government and lower capacity plants will be approved locally. This suggest that the entrance of large capacity CHP (>50MW) would still go through the more bureaucratic state approval structures even as the smaller plants still experience a common hurdle of long decisions on planning locally (Wood and Dow, 2011). Therefore the impact of the planning approvals is significant on CHP developers, since it feeds into the grid connection offer as a prerequisite which is usually time bound ranging between one and six months at the distribution levels (Simonds and Hall, 2013). While at the transmission level the grid connection offer expires after 90 days (Klessmann et al., 2008), indicating the importance of timely planning approvals.

The dominant instrument of engagement with CHP-DH developers by LAs is through Section 106 (S106) agreements which stipulates the rights and exit options. S106 agreement was designed to ensure that developers contribute to the cost of the development of local infrastructures but the agreement can only be reached if the condition of local planning policies such as implementing CHP-DH systems in designated areas is adhered to. However, S106 agreements has been criticised for the undue delays it brings to projects due to how long it takes for LAs to firm up these agreements, in part due to the negotiating skills of all parties (Bottini et al., 2013). Therefore planning permission and procedures are vital to the success of any CHP-DH system. For instance the Thameswey Energy (an ESCO wholly owned by Woking Borough Council) identified difficulties gaining permission to lay pipes as a significant barrier to their DH project in Melton Keynes (Hawkey, 2009).

The first notable example of where planning policy was used to incentivise the adoption of renewable technologies and by extension, CHP-DH systems in the UK was the introduction of an innovative planning system by the London Borough of Merton in 2006. It demands that all new non-residential developments above 1000m^2 should incorporate the allowance of providing at least 10% of its energy requirements from a renewable energy source (TCPA, 2006). This is what is now commonly known as the “Merton rule” which many LAs, for instance Blackpool (CLASP, 2011), have adapted in signposting developers to CHP-DH systems.

2.3.9 Asymmetric Information

Information is a vital instrument in driving government policies and it’s often used in deciding the fate of policies (Peters, 2012b pg. 117), since actors would use information to determine market entrance. A study by Jaffe and Stavins (1994) to generate an s-shaped diffusion curve with an 'epidemic model", using the spread of information regarding the existence and profitability of the innovation. They suggested that one obvious source of potential market failure affecting adoption decisions is lack of information about available technologies. This is further reinforced by Pindyck and Rubinfeld (2001) which stated that markets can fail because of asymmetric information and high information transaction cost. Since information is vital to investment and government is a critical information node because of its capacity to pool and keep data to direct policy and citizen behaviour, therefore role of Government cannot be relegated in this arena (Peters, 2012b pg. 117) in making sure information is available to all market participants and other actors.

Currently, a complete database of CHP-DH systems in the UK is scarce as only limited information is held by DBEIS (Department of Business, Energy and Industrial Strategy) (formerly DECC) and ADE (Association for Decentralised Energy). There is also no registry of CHP-DH data in UK, which can attract an additional transaction cost to obtain. The information landscape may soon get clearer as it’s begin to benefit from the Heat Network (Metering and Billing) Regulations which came into effect in December 2014. The Act which was the Government’s response to the EU Energy Efficiency Directive mandates all DH systems to be registered by April 2015. However, the law only permits registration of systems after commencement of operation as indicated in Section 3 paragraph 2b of the Act. (UK Legislation, 2014). This means that collation of data of systems under development will still be a challenge, because businesses wishing to plan future schemes will still face a transaction cost to get information of on-going systems.

2.3.10 Retrofitting of CHP-DH system in developed areas

The UK built environment contributes about 46% to UK emission (Davies, 2010), largely due to the poor energy performance of existing building stock. For instance, a not too recent report estimates that for homes built before 1996, the average net space heat demand for the building stock in 2050 is 9,000kWhr/year, while homes built after 1996 will be 2,000kWhr/year (Boardman et al., 2005). Considering that about 80% of the homes that will exist in 2050 have already been built (CR, 2017), the contributions from existing buildings to the ambition of 80% reduction of UK's emission by 2050 compared to 1990 may be significant. Therefore, the EU, through the energy performance directive had directed member states to undertake major renovations in buildings and consider other alternative low carbon energy sources, in a bid to improve the energy performance of existing stock (EU, 2010a). Furthermore, member states are to determine new minimum energy performance levels for new buildings so that all new buildings will be nearly zero energy level by 2020. However, while new buildings will have energy efficient measures integrated at design stages, existing buildings will have measures that can be adopted which includes refurbishing of windows, doors, roofs, walls and floors, and the adoption of alternative low carbon sources of energy to the existing buildings, such as CHP-DH systems.

As iterated in the earlier sections, the benefits of the deployment of CHP-DH are numerous, such as lowering of energy bills, reducing carbon footprint and so on. However, the conditions that are prevalent in deploying CHP-DH systems in a new build are totally different from deploying it in an existing built environment. For instance, most new builds that deployed CHP-DH systems, did it as an integrated part of the infrastructure provided which often considered the thermal behaviour of the buildings and heat appliances required at the design stage. Therefore, in developing the CHP-DH system in a new build sufficient space would have been acquired for the CHP units and right-of-way for the DH pipes. However, the same cannot be said for deploying CHP-DH systems in an existing built environment because of the several factors that will impact on the deployment. One of such is a reduced ratio between DH network heat loss and heat consumption by the existing buildings for the optimal technical and economic operation of the system by having a reduced supply and return temperature (Brand and Svendsen, 2013). Therefore, to meet the desired temperature for the optimal operation of a CHP-DH system, several measures are sometimes taken such as renovation of the building stocks or internal heating appliances (Brand and Svendsen, 2013, Østergaard and Svendsen, 2016). Both measures are expensive with the renovation of internal heating appliances a faster and cheaper route and thus a challenge to the adoption of CHP-DH system on existing systems.

There are other notable barriers that deploying a CHP-DH system on an existing built environment often experience, such as laying of DH pipes in the streets and roads. Laying of pipes on hard digs are more expensive than soft digs such as grass verges or undeveloped areas and laying of pipes on congested streets with existing utilities even attracts additional cost (Arup, 2011b). Other inhibitions to the deployment of DH pipes includes physical constraints such as highways, cemeteries, waterways and railways. Laying of DH pipes across these structures may be expensive or not even permitted. Furthermore, meeting the right noise and air pollution for the locality during the construction can also be a concern. Another consideration in retrofitting a CHP-DH system in an existing environment is acquiring enough space of land at the right location for the energy centre that would house the CHPs to feed the DH networks. This also constitute a challenge due to the extent of development.

Therefore, the enormous considerations in retrofitting a CHP-DH system in an existing built environment attracts significant additional cost that impacts on the technical and economic performance of the system. This constitutes a significant barrier to its deployment, though there a few recent examples of retrofitted CHP-DH systems in an existing built environment in the UK. Such as the Aberdeen heat and Power in Scotland (Ian, 2013) and the Bunhill Heat and Power CHP-DH project undertaken by the Islington Council in London (Islington, 2013).

3.0 Introduction

This chapter shall seek to explore the conceptual framework for investigating CHP-DH systems in the UK as an infrastructure using innovation systems with a view to improve its diffusion through governance process with emphasis on the role of the hierarchies of governance (state and Local Authority).

This chapter shall traverse three theoretical concepts that has potential to conceptualize CHP-DH system as an infrastructure and advance reasons for the selection of Technological Innovation Systems as the preferred option for the analysis. The three are Large Technical Systems (LTS), Multi-Level Perspective (MLP) and Technological Innovation Systems (TIS). Furthermore, the concept of Governance shall also be discussed and how it can complement the TIS concept with a view to compensate for its weaknesses and create opportunities to reduce the effect of the blocking mechanisms to the diffusion of CH-DH system in the UK.

A broad and generalised discussion of the TIS theoretical frameworks shall be undertaken to gain a better understanding of how the various activities of the hierarchies of Government and other actors impact on CHP-DH systems in the UK and to set the scene for an empirical assessment of the roles these actors can play further in the growth of the system. This chapter also sets the scene that leads into further in-dept discussion on how the overall research objective/questions are discussed.

3.1 Infrastructure Overview

Infrastructure is a widely used term to represent various meanings, such as collective inputs, artefacts, public utilities, institutional setups and so on, therefore it has a broad representation but with no universally accepted definition. However, some authors have considered it from various perspective such as, Star (1999) saw it as an output of inseparable relationship between actions, tools and the built environment, but Smith (2005b) considers it as collective resources for production that would require investment decision. While Guy and Marvin (2016) examines it as a physical construct of a constant flow of technological innovation in a production arena to meet demand sustainably. The common consensus though is that infrastructure possesses several inherent characteristics such as technical, economic, social and political that would determine its functionality. These characteristics are also in a seamless web with the organisational and institutional structures that supports the infrastructure. Therefore, there must be a balance of action on these factors for an optimal performance of the infrastructure resulting from complex interaction of characteristics. Hence, analysing infrastructure from a system perspective (Markard, 2011).

Finger et al. (2005) argues that infrastructures exhibit key features, which includes: (a) they are physically network based, that contribute to economic importance by being a conduit for goods and services. (b) Because they precipitate positive and negative external effects, increasing returns and networks effects, which often adopted traditional market failure approach cannot address, thus, often constituting a challenge to institutional governance. (c) It provides a service that meets social objectives and has a significant economic and political impact. These features suggest that infrastructures would require huge investment and precipitate sunk cost, asset specificity – investment in assets that cannot be efficiently relocated and exhibits social dependencies, which would all constitute barriers for structural change. Therefore, infrastructures are impossible for sudden transition, but rather they have tendencies for incremental change (Frantzeskaki and Loorbach, 2008). They also have path dependencies – changes along established paths (Bolton and Foxon, 2015) and the change could be caused by endogenous or exogenous factors. Endogenous factors may include environmental effect or persistent underfunding/underinvestment, while the exogenous factors could be state policy priorities, macroeconomic changes or reduced funding from/to the local authorities (Markard, 2011, Markard and Truffer, 2006). Infrastructural changes which can lead to penetrative or transformative capacity take place through three broad routes (Jonsson, 2005, Frantzeskaki and Loorbach, 2008): Firstly, system improvement – enhancement aimed at efficiency achieved through new/hybrid designs often from a top-down intervention. Secondly, system synergies – enhancement of production through coordination of different systems and scheduling i.e varying with the rate of usage of the infrastructure. Thirdly, social innovation – satisfying the needs of users through new processes or new social forms and its often a bottom-up intervention.

Infrastructures have been broadly divided into three categories by Jonsson (2005) and Frantzeskaki and Loorbach (2008) namely: Distributive systems – Linking users from a central node, for instance, television, radio, water and electricity, Accumulative systems – process flow in opposite direction, i.e from users to a central mode such as sewer and waste disposal. The other is Communicative systems – multidirectional flow, for instance, telecom, transportation systems and mail systems. Drawing upon the taxonomy above, CHP-DH system can be considered a distributive system as it's an infrastructure-based system consisting of nodes (CHP plants) and linkages that connect these nodes (DH networks) to supply electricity and heat energy (Loorbach et al., 2010). Furthermore, these infrastructures function under organisational and institutional structures. Such as laws, market structures, regulatory and legislative frameworks, governance structures and role of public authorities. Therefore, the integration of these elements with the hardware component (infrastructure) function together to deliver the electricity and heat to the public. Suggesting that infrastructures would require governance to function to achieve its purpose.

However, firstly, governance of infrastructure often emphasises on the asset specificity of the technology, rather than being part of a system (Finger et al., 2005). The consideration for governance of infrastructure as part of the system is borne out of the socio-political significance it may hold as a public goods/service provider. This means that infrastructure provides good/services that should be affordable, reliable and accessible to all within the geographical coverage. Thus, suggesting the necessity of a partial or direct involvement of the hierarchies of governance (state and LAs) in the operation or management with a view to determine the desired social or economic objectives. This also suggest the reason why infrastructures are often strongly regulated, which impacts on the transformation (Markard, 2011), though (Finger et al., 2005) has argued for three different types of coordination mechanism. They include: centralized coordination – top down approach, decentralized coordination – distributed decision making from various actors and lastly, peer-to-peer coordination – self coordination through self-selected actors or bilateral contracts. Secondly, under market failure conditions private investment is often scarce for infrastructures, because of the presence of free riders that may benefit from the infrastructure without payment or unaccounted market benefits and the constant demand for expansion due to increase in demand (Finger et al., 2005). Thirdly, the usual framework of analysis of infrastructures is often either considered as technological or institutional problem. Therefore, to properly conceptualise an infrastructure such as CHP-DH system with a view to fully capture the various characteristics to be able to analyse its performance or diffusion, the various components - technological (hardware) and institutional (software) factors, must be considered together as a system. (Markard, 2011, Künneke et al., 2010).

The interaction of the varying components (hardware and software) to achieve the desired goal of an infrastructure has been commonly conceptualised to mean sociotechnical systems but the study of how the penetrative and transformative capacity develops has been explained from broadly three holistic approaches of science and technology literatures. Namely as Large Technical System (LTS) (Jonsson, 2005, Loorbach et al., 2010, Joerges, 1988, Hughes, 1993, Hughes, 1987, Mayntz and Hughes, 1988, Van der Vleuten, 2004, Giikalp, 1992), socio-technical transitions – Multi-Level Perspective (MLP) (Bulkeley et al., 2014, Bolton and Foxon, 2015, Geels and Schot, 2007, Elzen et al., 2004b, Geels et al., 2004, Geels, 2002), and Technological Innovation Systems (TIS) (Bergek et al., 2010, Smith, 2005b, Bergek et al., 2015, Markard et al., 2015, Hekkert and Negro, 2009). Consequently, a broad discussion on these three theories shall be undertaken below, with a further comparison to determine the analytical framework to take forward.

3.2 Large Technical Systems (LTS)

The concept of Large Technical Systems (LTS) has been developed to capture the features and dynamics of infrastructures as a socio-technological system that evolves over a long time arising from a seamless web of various components and also seeks to specifically separates its analytical framework from other social systems. For instance, the LTS framework shares similar insight with the Social Construction of Technological Systems (SCOT) which places more emphasis on history and sociology, while LTS places more emphasis on system analysis and on material infrastructures – sometimes referred to as infra-systems (Ewertsson and Ingelstam, 2004 pg:293-294). A leading influence on the LTS framework was Thomas Hughes, a historian of technology, who attempted to see the electricity sector from the lens of

LTS because he considers technological systems as complex systems that are constructed and shaped socially. In part because, LTS is developed by human construct and made up of systematic interaction of not only the technology but the non-physical artefacts. Such as regulations, investment bank, environment, business cultures, organisations, political actors and so on (Hughes, 1987). The LTS concept models the technological system to evolve through a life cycle of invention, development, innovation, transfer, growth, competition and consolidation, though not in any order.

Hughes (1987) conception of the causal analysis of the structural tension within a technological system that may inhibit or induce growth or expansion is seen from three perspectives, namely: Load factor, Reverse salient and Momentum. Load factor seeks to explain system growth from a techno-economic perspective, for instance the rate of return on investment. Reverse salient are critical problems that emerge within the system, often unexpectedly as the system expands, such as technical /institutional/organisational anomalies, which requires intervention for system growth. When the problem cannot be resolved or addressed its considered a radical problem that may require a new or competing system. While, momentum is the concept associated with systems that have grown and consolidated over time (critical mass), acquired velocity (rate of growth) and direction of growth, but appears to be autonomous – out of control. He opines that mature systems appear to be institutionalized "inertia to motion". In part because of the path dependencies of actors or system culture, but in practice the direction of the acquired momentum could be redirected by external forces, such as political or environmental. Therefore, load factors and reverse salient are considered as mainly internal dynamics, while momentum reflects external effects (Joerges, 1988)

Another critical concept of LTS is the system builder, who is the dominant actor rather than the designers (Joerges, 1988). These system builders could be entrepreneurial professionals, politicians or regulators that play the core role of increasing the size of LTS due to their ability to coordinate all actors and bring them to the same page with a view to foster unity of purpose within the system and address system problems by providing the link between system performance and system goals (Hughes, 1987).

The LTS concept has been applied by various authors on different types of infrastructures. Such as Davies (1996) for Telecommunication sector and Markard and Truffer (2006) who examined the effect of liberalization in the electricity supply system and suggested that liberalization as an external stimulus triggered a radical innovation process in the electricity sector. They also went ahead to mention four selection environment that can trigger a radical innovation in LTS namely: external and internal developments, reverse salients and government policies. However, (Markard, 2011) argues that LTS framework is not sufficiently equipped to explain the likely disruptive effects and how the sector would respond to external pressures. Such as selective pressures resulting from oil crisis that would impact on input prices or technological discontinuity - adopting new technologies to change market position. Such as in the application of gas turbine in the electricity generation which was first applied in the aircraft industry. Furthermore, Magnusson (2012) also attempted to analysis the current and future trends of the Swedish DH sector using the LTS framework, but cautioned that LTS lacks the capacity to fully distinguish the system growth potentials of different grid based systems. He argues that LTS may suffice for electricity and gas networks as they can grow over distance due to low energy losses but that is not the case for DH networks, which exhibits high heat losses of 5-10% and to even as high as 30% in lower density systems. In part because, losses in electricity is largely determined by the volume of power and demand, while heat loss is largely determined by the ambient temperature and pipe insulation, which has a significant impact on expansion decision due to the cost and efficiency (Orchards, 2013, Persson and Werner, 2011). Therefore Magnusson (2012) opines that the conceptual narrative from LTS of systems interconnectivity resulting into national or international systems like the Nordic grid, which hinges on system geographical growth to new areas to meet demand and gain from economies of scale may seem impossible on DH systems.

Further challenges of the application of LTS have been enumerated by Ewertsson and Ingelstam (2004). These include: a) The strong focus of LTS on heroic actors such as system builders at the detriment of less visible actors whose action may have influenced the development of the system. b) The desire of LTS to portray the development of a system as well-controlled in an orderly manner with little attention to the inherent chaos or uncertainty in system building. c) The fluidity of system boundaries in LTS, as it considers the system boundaries to be constantly changing and thus difficult in delineating system boundaries.

3.3 Socio-technical Transition - MLP

Lately, any innovation process of an infrastructure is bound to exhibit the following characteristics. Such as economic growth, technological change, societal benefit and environmentally sustainable. This has become another lens which policy makers look through to formulate policies, given the concern that diffusion of technologies may mean diffusion of side effects and what is the relationship of this growth to the environment and natural resources. Hence, Misa (1994) argues for a framework for integrating the social shaping of technology and the technological shaping of society, thus the evolution of concepts like the socio-technical transitions.

Transition theory is an alternative framework for sociotechnical systems, which seeks to capture not just the technological changes but changes in other elements that make up the system. Such as regulations, demand, institutions, social networks and so on. The concept of transition was originally used to describe changes in phases, such as going from solid to liquid to gas, but has been further applied to describe shifts in qualitative state and recently applied in ecology, psychology, technological studies, economics (Loorbach et al., 2010).

Therefore, transition theory combines research from technical, social and historical analysis to understand past and future technological changes of a sociotechnical system based on interaction at three different levels: Socio-technical regimes, technological niches and socio-technical landscape (Foxon et al., 2008a, Rotmans et al., 2001). They summarise the functionality of these levels as follows: Landscapes (macro level) entail the physical infrastructure, non-physical elements, such as political culture, socio-cultural values, macro economy, institutions and natural environment. Socio-technical regimes (meso level) refers to the set of rules, shared assumptions and beliefs that govern interactions of the various elements imbedded within the socio-technical system. While the technological niches (micro level) refers to the actors, local practice and technologies. Hence, transition framework seeks to explain technological changes and how to anticipate and manage future transition processes by investigating the dynamic interaction at these three levels (Greenacre et al., 2012).

There are three common variants of the transition theory, which includes: Multi-Level Perspective (MLP), Transition Management and Socio-technical Scenarios, but the broader and more widely adopted approach is the MLP approach (Bolton and Foxon, 2015, Smith et al., 2010). The early proponents of MLP are Dutch scholars who combined studies from institutional theory, sociology of technology and evolutionary economics to apply hierarchical levels of innovation through a multi-level perspective to explain the past and future dynamics of socio-technical change (Geels, 2004a pg:33, Rip and Kemp, 1998, Rotmans et al., 2001, Geels and Schot, 2007)

The MLP emphasises on the interaction of three system levels. Namely, micro level niches, meso level socio-technical regimes and macro level landscapes. A broad discussion of these levels is undertaken below.

Micro Level Niches: This is considered the source where radical innovations are generated and are often carried out by small networks of dedicated actors which are typically outside or fringe actors e.g environmental activist (Geels and Schot, 2007). At this level, the niches (e.g technological projects, emerging technologies), which are initially unstable and with low performance act as the change room of the socio-technical system or incubation rooms for new technologies or social practice. Hence, they are protected spaces for experimentation against normal market selection pressures or enable emergence of radical innovations (Schot, 1998, Kemp et al., 1998). Small networks of actors provide protection because they are willing to invest in the development of new technologies which would create spaces for crucial internal processes like learning processes – learning-by-doing, learning-by-using, and learning-by-interaction and building of social networks, (Verbong and Geels, 2007). Transition of technology and market share do not only happen at this level but other elements of the socio-technical systems evolve as well such as infrastructure, networks, and regulation (Greenacre et al., 2012). Resulting in niche accumulation that would enable diffusion to increase market share which will eventually compete and overthrow the incumbent (Geels and Schot, 2007).

Meso Level Socio-Technical Regimes: These are the stable structures that govern the interaction of actors, institutions and other elements of the sociotechnical system with a view to provide stability and reinforce the existing system. The aligned activities due to interaction between the elements that span the production – consumption divide, such as scientist, engineers, policy makers, investment, normative, users, usually trigger incremental innovation to provide stability (Geels and Schot, 2007). Therefore, the regime level places more emphasis on optimization rather than transformation since incremental innovation is being generated at this level. The stability in the regime precipitates path dependency and lock-in due to the interlinked trajectories of firms. However, firms may not share similar cognitive routines, such as technological search, problem definitions, belief systems, guiding principles, which may lead the trajectories of technological change to be misaligned and precipitate tension resulting in instability in the regime (Geels, 2004a pg:34, Greenacre et al., 2012). Socio-technical regimes typically consist of three nested elements (Verbong and Geels, 2007): (a) network of actors and social groups, (b) rules that govern interaction - formal (regulations, standards, laws), normative (value and norms pattern), cognitive and (c) tangible elements - physical infrastructures.

Macro Level Landscapes: These are the external environmental factors that usually represents the broader political coalitions, socio-cultural values, macro-economic and institutions that form deep structural trends of a society (Foxon, 2011). They are heterogenous factors that can influence the niches and socio technical regimes with the potential to cause shock and surprises to the system, such as wars, rising oil prices, environmental problems (Geels, 2004a pg:34). These factors exert slow changing effects on the sociotechnical system which could take decades and therefore more resistance to change. However, if changes occur in the system, it starts from the niche level and expands through regimes and possibly leading to landscape transformation (Greenacre et al., 2012).

The application of MLP is conducted through the interaction of the aligned activities at these three levels (macro, meso and micro) to provide a global map of the entire transition process of the infrastructure. Geels and Schot (2007) summarized how transitions are introduced through the interactions of the levels in MLP framework. (a) Internal momentum is built up by niche innovations through the processes of learning, improvement of price/performance and supports from networks. (b) a downward pressure is created on the regime by landscape, which destabilizes the regime to create opportunities for niche innovation to compete and displace the incumbent regime. Therefore, the beginning of transition is often when the regime begins to show serious problems that would trigger key innovations at the niche to allow for transition of the technology to take place and the end of the transition process is when the new regime has taken hold or socially embedded and this process usually takes decades (Genus and Coles, 2008).

The concept of MLP has in no doubt broaden the conceptualisation of transitions of infrastructures (and other artefacts) to new socio-technical systems drawing on contributions from various levels that constitute the framework of its existence and technological change. Such as cultural patterns, markets, economy, political, environment and social activist. However, it has not been without its criticisms. For instance MLP has been generally criticised for the inconsistent conceptual framing, the relative neglect of agency, the over emphasis on niches as drivers of system change, and less attention on plurality of niches (Genus and Coles, 2008, Berkhout et al., 2004, Smith et al., 2010) and more importantly the silence on cost and economic factors or business strategies on technological innovation (Foxon, 2011, Alkemade et al., 2011). For instance, in a study by Fouquet (2010) on 14 past energy transitions in the UK, which includes the heating, power and lighting sectors. He notes that the dominant drivers for energy transition in the UK were cheaper price and better service.

In particularly, the key driver for the heating sector for technological change was cheaper price while better service was the main driver in the power sector. Suggesting that economic factors could be critical for adoption and diffusion of technology, which has been given less emphasis in transition studies than social groups (Fouquet, 2010).

Other scholars have also opined that lack of consensus on the functional distinction between the levels make the perspective extremely difficult to operationalize (Genus and Nor, 2007). However, Geels and Schot (2007) argues that both regimes and niches have similar kinds of structure depending on the scale and stability, since both (regimes and niches) have features of community interaction or organisations. Nonetheless, Bulkeley et al. (2014) notes that since the socio-technical regimes are considered to be operating at the national, while niches are considered to be at the local, where the management, negotiation and contestation will take place is vague, considering that the concept regards them to be in continuous interaction. Furthermore, they opine that since niches are considered to be in bounded and protected spaces within the regime, the MLP concept de-emphasises the extent of political tension that may ensue in practice due to conflicts and contestation. Suggesting that similarity does not mean the same. Geels et al. (2008) also agrees that MLP has not sufficiently captured the socio-political processes between governance hierarchies. A not too distant example is the introduction of an energy policy by London Borough of Merton in 2003 requiring all new non-residential developments above 1000m^2 to make provision for at least 10% of its energy requirement from a renewable energy source, but the state initially considered it an affront to its role in pivoting energy policy (Keirstead and Schulz, 2010).

Furthermore, on the operationalization of the levels in the MLP concept, Geels (2004a pg:35-36) notes that the structuration of activities of niches are localized, vague and loose, because of the weak coordination of the multitude of experimentation by niche actors, but with stronger coordination at the regime and strongest coordination at the landscape. However, with respect to CHP-DH systems, a recent report by UNEP (2015) suggests that Local Authorities are in the best position to be global champions to facilitate the diffusion of DH systems. In part because of their frontline role to promote social, economic and environmental wellbeing of their community. Additionally, DH systems are geographically localized centralized heating system with typically no national interconnectivity due to efficiency and heat losses. Therefore, the demand for strong coordination of multifarious actors locally is imperative for the diffusion of CHP-DH systems. This suggest that the operationalization of MLP on the diffusion of CHP-DH systems may be less practical. This is further collaborated by Winskel et al. (2012) when they argue that MLP has more emphasis on the nature of the technology development and technology systems in their socio-historical context rather than technical or economic imperatives.

Finally, in a recent summary by Smith et al. (2010) of a workshop by network of researchers on the MLP concept. They concluded that the MLP concept is still vague on a number of issues. For instance, how would niche actors perform as political actors in such a way that they can shape the space so as to prosper through ways like, technical standards, finance, regulatory frameworks and engaging with agendas of public policy. This is in addition to other multiple challenges like impact of geography (territorial or boundary jurisdictions) on transitions or governance of transitions. Concluding, it recommended that the MLP concept is still work in progress that requires further work to capture more cross disciplines that influences transitions of socio-technical systems.

3.4 Innovation Systems

Economists like Lundvall (2007) and Saviotti (2005 pg:181) tend to agree that innovation theory can be traced back to Schumpeter's "Theory of economic development" (Schumpeter, 1934) that established that the major drivers behind economic development are organisations or entrepreneurs who create competition by using new processes, raw material, industrial structures and markets to implement or deliver new products thereby creating the difference between what is popular and what is new. Edquist (1999) further clarifies that in as much as innovation may lead to the entrance of a new product to the market, it could as well be the introduction of a new process for an existing product. This definition could include new and innovative ways to govern CHP-DH systems for economic development.

Innovation systems draw from the field of evolutionary theories in economics, which is characterised by two major strands that describes its concept. Firstly, that within an economic structure, elements change with time, suggesting that they are dynamic and are renewed randomly. Secondly the long-time growth of the economic system is crucially determined by technological change, institutional change and financial market (Dosi and Nelson, 1994). Therefore, innovation system is a concept that links innovation to economic growth using an evolutionary approach (Nelson and Sidney, 1982), which seeks economic growth through creation of industrial structures, competition amongst firms, and products. This process is underpinned by the interaction of institutions through shared knowledge that is often bounded by regulations and laws (Carlsson, 2006, Metcalfe, 1997) and can be used as a practical tool to innovate policies (Lundvall, 2007).

Innovation systems could stimulate economic growth and it typically captures three vital components that interact together to achieve innovation, these includes actors, networks and institutions (Bergek et al., 2008b, Hekkert et al., 2007b, Jacobsson and Bergek, 2004).

Actors: These are organisations, firms, entrepreneurs, or agents that are technically, financially or politically relevant to the extent of influencing the development and diffusion of the technology (Jacobsson and Bergek, 2004). For instance, in the case of CHP-DH systems in the UK, they may include universities, hospitals or other site owners, developers of CHP-DH systems, DH pipe suppliers, or CHP suppliers.

Networks: These are opportunities and routes created amongst the constellation of actors to transfer knowledge and experience to shape the process and diffusion trajectory of the technology. They are often built around markets but sometimes non-markets as well to share information with a view to influence actors decisions and setting up of institutions to guide the process (Jacobsson and Bergek, 2004) and they are also more informal than formal (Carlsson and Stankiewicz, 1991). An example of a network within the UK CHP-DH system is the Association for Decentralised Energy (ADE), UK District Energy Association (UKDEA) or Creative Finance Network

Institutions: These are the umpires or arbiters of the system who stipulate the rules and regulate the interactions between actors with a view to either influence the direction of the rate of diffusion through incentives or through demand structures (Jacobsson and Bergek, 2004, Edquist, 1999). They also provide mitigations against conflicts, apply sanctions and gauge the system dynamics through feedbacks from both the actors and market, and can provide incentives to signpost actors and define selection environment (Carlsson and Stankiewicz, 1991, Carlsson et al., 2002). Therefore, they may take several forms depending on their role in the system in stimulating development or diffusion. These include political institutions, market institutions, economic institutions or trade institutions (Edquist and Johnson, 2005 pg:50), for example in the UK CHP-DH context, the UK energy regulator, the Office of Gas and Electricity Markets (Ofgem).

Innovation is not spontaneously generated by the components or generated in isolation but rather by the interaction of the components within the structure, suggesting that it possess the capacity to change over time depending on the relations between the components. Innovation systems are characterised by a number of vital features. Firstly, learning processes – learning is at the heart of innovation systems and can encompass various modes of learning, including:

- learning by searching – learning through formal education and research and development (R&D) (Edquist, 2005 pg:16);
- learning by doing – reduction of unit cost of production resulting from market growth (Winskel et al., 2012, Smith, 2000);
- learning by using – Increase in experience in using by consumers/demand instigating increase in productivity and diffusion (McWilliams and Zilbermanfr, 1996); and
- learning by interaction – interaction between demand and supply actors to innovate production (Edquist, 2005 pg:16). Learning processes emphasis on knowledge transfer and development processes to foster innovation which is a key ingredient for the system to survive over time by reducing uncertainties and increasing diffusion.

Secondly, Innovation systems are holistic and strongly interdependent with other components or agents within as they depend on the interactive and complex relations, allowing for inclusiveness of the litany of actors such as social, political, institutional or organisations actors (Edquist, 2005 pg:17).

Thirdly, the agents are rational but are bounded by their limitation and capabilities to perceive future technological growth, which means the innovation system will be characterised by uncertainty because of the unknown solutions to the techno-economic problems (Carlsson and Stankiewicz, 1991, Ehrnberg and Jacobsson, 2005 pg:322)

The components of innovation systems interact to deliver outcomes depending on the performance of the various elements within the system. The combination of the performance of these elements could determine if the system has stimulated innovation or not. This suggests that these elements could reveal that the system is not performing, and a system failure may have occurred which may warrant Government/policy intervention (Edquist, 1999, Smith, 2000). However, Governments often intervene on technological change with governance mechanisms and policies based on market failure by focusing on removal or reduction of market barriers (Metcalfe, 1995, Nilsson et al., 2007). For instance, in responding to the challenges of the heating industry in the UK, the government suggest that its primary concern is to eliminate the market barriers by developing the right framework to facilitate entrance to market by reducing transaction cost (DECC, 2013a).

This market failure approach to address infrastructural challenges has been severally criticised for not sufficiently appropriating the externalities such as knowledge generation which are not reflected in market transactions but attracts a cost as the market is driven by competitive prices (Smith, 2000). This means that the market will not allocate the right volume of resources to stimulate the required innovation to steer technological change. In part because infrastructures are known to be large scale capital goods producer with multiusers that often requires public provision or intervention (Smith, 2005b, Finger et al., 2005). Suggesting that market alone cannot provide the resources required for development of infrastructure to create economic development due to its the public good attribute (Metcalfe, 1995). Thus, the essence of an innovation system failure framework that may warrant Government/policy intervention based on the socio-technical peculiarities of an infrastructure. Drawing upon Klein Woolthuis et al. (2005) and (Foxon, 2007 pg:131-133) system failure framework, the four major characteristics of a system failure are:

- **Infrastructural Failure**: These are the failures of the physical infrastructures that actors within the system require to function, such as communication (ICT, broadband) energy systems (energy networks and supply), road, transport and sciences (knowledge and possibility for knowledge transfer). These infrastructures are usually of a scale that requires substantial capital outlay and long operational periods that the private sector may not be attracted to invest in due to low returns so may require public intervention to meet actors demand. For instance, the grid bottlenecks which is restricting power flow of about 2.2GWe from Scotland to England makes it difficult for CHPs to get connection offers on time (Hammond and Pearson, 2013).

- **Institutional Failure:** These may be in the form of either formal institutional failure (regulatory frameworks and agencies from both the private and public) or informal institutional failures (political culture and social values that implicitly informs the behaviour of actors). These institutions shape the economic behaviour and interaction of actors and therefore can block the stimulation of innovation and offer the rationale for policy intervention.

- **Network Failure:** Network failure could result from either a weak or too strong interaction between actors in a network. A too strong interaction of actors in a network could result from path dependency due to asset specificity, high switching cost or market dominance leading to lock-in by incumbents. While weak interaction may arise from poor alignment between the technology and institutions. Therefore, the extent of dominance of either the incumbents or the technology may provide the impetus for policy intervention to allow for new entrants within the same technological system.

- **Transitional Failures:** These failures are associated with existing firms, especially with small firm's failure to adapt to technological changes and market demands due to limitation in terms of capabilities and competencies since their core focus is usually on the technology with which they are experienced and skilled in. Therefore, public intervention may help these firms to overcome such barriers.

3.4.0 Types of Innovation systems

Several commentators have proposed various versions of innovation systems to depict demarcations depending on the purpose of study. The common versions are national systems innovation, regional systems innovation, sectorial systems innovation and technological system innovation. Below are broad discussions on each type of innovation system outlining the perimeter for each mode.

3.4.1 National Innovation System (NIS)

National Innovation systems arose as a result of the concern of innovation system failure to address the lack of emphasis of the measure of leaning activities amongst the array of institutions in a national economy as a whole. This is as a result knowledge resulting from patents and number of R&D, considering that countries have varying technological change pattern. Therefore it may be pertinent to capture innovation systems at a national level with a view to access and compare innovations of the elements within the innovation process of an economy or country (Patel and Pavitt, 1994, OECD, 1997). The key demarcation is capturing innovation between elements of innovation structure that share common geographical boundaries, culture, language, history and socio-political institutions (Breschi and Malerba, 2005 pg:130)

Literature is rich in providing explicit definitions of NIS from various commentators such as Freeman (1995), Lundvall (1998), Metcalfe (1995), Patel and Pavitt (1994) and many more. However this research identifies with the definition by Patel and Pavitt (1994) which stresses the importance of a geographical boundary of a country in a NIS structure *"the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change-generating activities) in a country*." (Patel and Pavitt, 1994).

However, others have criticised the NIS for not being sufficiently capable of comparing countries systemically (Balzat and Hanusch, 2004) due to its greater focus on firms and technology, which Groenewegen and Steen (2006) has suggested that it may need to be more focused on socio-political institutions and their dynamism. Hekkert et al. (2007b) also suggested that mapping the dynamics of NIS may be difficult due to the complexity and size of actors, network relations and institutions.

3.4.2 Regional Innovation System (RIS)

Regional innovation systems can be likened to NIS except that in RIS innovation and diffusion results from interaction of actors in a local technological system. Another point of comparison is that the actors in both NIS and RIS share similar socio-cultural and political institutions but in RIS, it's delineated in a technological cluster within a country or local geographical area. This concept is largely attributed to the work of Cooke and his colleagues in the late 1990s who argued that territories smaller than a state sharing similar socio-cultural, political institutions and economic cohesiveness, that differentiates them from the other regions could gain from geographical proximity to reduce transaction cost of innovation and limit uncertainties through local learning networks (Cooke et al., 1998).

The distinctive feature of RIS is the formation of geographic clusters or industrial areas resulting from collective knowledge of firms that are in the same or related technology. This precipitates fast information flows, coordinated investment and knowledge spill over to increase the rate of diffusion of the technology which is underpinned by shared culture and values (Ehrnberg and Jacobsson, 2005)

However, RIS may exhibit potential for strong networks (Ehrnberg and Jacobsson, 2005) or too strong interaction of actors which may precipitate lock-in resulting from path dependency leading to the failure of the system to innovate (Foxon, 2007 pg:132, Klein Woolthuis et al., 2005). Maskell (1996) also argues that it's difficult to reproduce the economic environment partly due to knowledge embeddedness.

3.4.3 Sectorial Innovation System (SIS)

The concept of sectoral innovation systems (SIS) was developed by Franco Breschi and his colleagues in the late 1990s (Lundvall, 2007) in an attempt to capture innovation between industries of the same technological regime. The concept of SIS distinguishes itself through more focus on vertical interaction and less on actors outside its cluster of industries (Carlsson et al., 2002). Therefore, there is little focus on interdependence of actors but rather industries with similar technological opportunities, capacity and knowledge trajectories seek to interact, irrespective of geographical location and compete amongst themselves or inter-regional competition. In order words geographical proximity often plays little role in fostering innovation amongst industries since knowledge is standardised and codified systematically for knowledge transmission and access to actors (Breschi and Malerba, 2005 pg:137). This characteristic of clustering of innovators at a much higher geographical scale than the regional concepts may have led to the suggestion that it is the bridge between RIS and NIS (Cooke et al., 1998). SIS has been used in a variety of conditions (Malerba, 2005, Malerba, 2002, Breschi and Malerba, 2005).

3.4.4 Technological Innovation System (TIS)

This concept was championed by Carlsson and Stankiewicz (1991) in the early 1990s to focus on a particular techno-economic area or industry, as with CHP-DH technology in this research. They defined TIS as a dynamic network of agents interacting in a specific economic/ industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology (Carlsson and Stankiewicz, 1991). Secondly TIS captures both vertical and horizontal agents that play a role in the development and diffusion of the technology (Breschi and Malerba, 2005 pg:131). Suggesting the inclusive recognition of social-political actors in addition to the techno-economic actors in innovative activities and influencing the selection environment. Nonetheless the number of actors, networks and institutions in a TIS is usually smaller than in an NIS even if both have geographical and cultural proximity due to the greater complexity and interaction of NIS it has more agents in the innovation system component than TIS (Carlsson and Stankiewicz, 1991, Hekkert et al., 2007b). Early applications of TIS had captured the systems dynamics of matured infrastructures and whole sector technological systems that impact on socio-economic growth, such as telecommunication industry, Pharmaceutical industry, electronics and computer technology (Carlsson, 1997).

TIS captures two key determinants of the interaction between agents. Firstly, the economic competencies of the agents – the ability of the agents to take opportunities that the market provides, and this competency is cumulative. Secondly, the economic competencies are acquired through the knowledge network - learning processes, which permeates the industry in a view to impact on the adoption and diffusion of the technology. This indicates that market formation is a key driver of the TIS processes amongst the structural components bringing to fore the essence of technology push – market entrance of firms and demand pull – market formation by user/consumers within the institutional infrastructure which will shape the processes and couple the technology with the market (Hendry et al., 2008 pg:114). Therefore, activities or barriers that may hinder technologies from taking advantage of the opportunities that the market provides may be considered a market failure.

Drawing on the market failures that can be deduced from an innovation system by Jaffe et al. (2005), the low rate of diffusion of CHP-DH systems in the UK can be attributed to a number of market failures/barriers as enumerated in chapter 2. These also includes: firstly, the unpriced value of carbon reduction in the process of energy generation compared to other conventional processes which CHP-DH offers as a public good drawing on the negative externalities of GHG on the climate. Secondly is the selection environment the energy system impacts on CHP-DH systems. Such as lack of heat grid(s), mature gas grid used for domestic heating, heat governance structures and barriers to electricity grid connection, all of which favour the incumbent technologies. Thirdly, the asymmetry of information in the UK CHP-DH industry - where there is not even a complete database of CHP-DH systems - seems to inevitably lead to increases in transaction cost for new entrants. The removal of market barriers to perpetuate economic growth is a vital ingredient of innovation, including other non-market failures that are inherent in the system such as network or institutional failures which the TIS seeks to provide a systemic view of entire process of innovation. Therefore, TIS seeks to capture the production – consumption wide elements that influence the transformation of a specific socio-technical system, which compliments the general challenge of policies deduced from IS approach, that focuses more on the optimization of institutional environment of the innovation process of firms (Weber and Rohracher, 2012).

The structural components of TIS is usually characterised by dynamics that interact with internal and external factors to influence the adoption and diffusion of the technology (Bergek et al., 2008b pg:88-89). For instance, institutional change arising from the Treasury's removal of the CCL tax exemption on exported electricity earlier enjoyed by CHP is an example of an internal structural factor that can influence the diffusion of CHP-DH systems. While the seemly regulatory capture of the highly organised 'big six' energy companies on the energy market, such as the formation of codes through Elexon, which the 'big six' seeks to perpetuate their market dominance is an external factor that may impact the selection environment for CHP-DH systems. This suggests that actors in the TIS not only compete in the market but also compete to influence the institutions to enhance their survival, locking in their technology to the detriment of new entries (Bergek et al., 2008b pg:82). However, Markard and Truffer (2008a) argues that in delineating the system boundary, TIS framework considers the interaction of components within the system as more intense than the interaction between the system and the environment. This was further elaborated by Geels et al. (2008) who notes that TIS approach draws little distinction between internal and external factors since it views the system as an integrated system, but stresses that the role of external factors such as emission reduction targets, are very strong on sustainable energy systems. Coordination of policy activities has also been mentioned as a shortcoming of the innovation systems, as coordination is mainly referred to as the coordination of R&D actors, with less attention to coordination of horizontal and vertical policy activities/levels (Weber and Rohracher, 2012). Suggesting that TIS has not fully captured socio-political processes, since diffusion of technology is not only driven by market and legitimacy but also by socio-political processes between hierarchies of governance (state/LA) (Geels et al., 2008, Kern, 2015). Therefore, TIS is known to have analytical difficulties in terms of governance of sustainable technologies, especially as it relates to the effect of the dynamic interaction of exogenous factors to the core of the system (Smith et al., 2010).

3.5 Rationale for choice of Theoretical socio-technical framework

CHP-DH systems as a network-based infrastructure that provides electricity and heat to the society, places it as systems that are crucial to the socio-economic fabric of the society. Not least because energy is the bone of industrialisation and economic growth, which contributes to the social being of any society. For instance, watching football matches with family and friends via televisions or warming our homes uses both electricity and heat energy. The unique features of CHP-DH system also played a crucial role in the selection of analytical concept. Such as DH networks are not typically scalable to have national or intercontinental connectivity like the electricity network, but the CHP system has the capacity to be a distributed and flexible electricity generation source. Suggesting its integrated features and the ability to use array of renewable sources of energy and low carbon fossil fuel like natural gas compared to coal, may have contributed to its consideration as part of the energy systems to contribute to UK's energy sustainability ambitions. Additionally, CHP-DH system is a matured technologically but not commercially matured in the UK due to its poor penetration.

Three approaches had been discussed with a view to capture insights on their suitability for offering analytical framework to answer the research objectives of this work. Namely: Large Technical Systems (LTS), Multi-Level Perspective (MLP) and Technological Innovation Perspective (TIS). All three have the capability to investigate infrastructures as socio-technical systems and capture the linkages of the heterogenous (technical and non-technical) elements within the system to effect technological changes. However, Geels (2004a pg:31) notes that's LTS framework focuses on technological changes on emergence of new technologies but little on diffusion. More importantly, Magnusson (2012) had cautioned that LTS lacks the capacity to analyse DH systems because of the difficulty to conceptualize it as a local or centralized system with little or no national and international connectivity due to the inherent heat losses in expanding heat networks.

Generally, both MLP and TIS seek to promote innovation in infrastructures that promote technological change, economic growth and sustainability, but their key policy focus differs (Alkemade et al., 2011). MLP policy objectives is concern with solving societal problems at an aggregated level, such as, climate change, energy systems, water management, transport, while TIS is more focused on improving the performance or penetration of specific technology with a view to contribute to economic growth (Weber and Rohracher, 2012). Secondly, MLP often seeks to replace the incumbent regime through a regime shift (change of existing production and consumption system), often resulting from niche accumulation through radical innovation in the micro/niche level. While, TIS policy often focuses on competency enhancement of selected technologies and strengthening of existing regimes (e.g regulations, standards or institutions) that would make such regimes more sustainable through incremental innovation (Alkemade et al., 2011).

Even though all concepts (LTS, MLP or TIS) have been used extensively on various infrastructures. They all have been considered insufficient or evolving by various scholars. Such as LTS (Geels, 2004a pg:31), TIS (Markard et al., 2015, Kern, 2015) and MLP (Smith et al., 2010, Geels, 2011). Hence, they can be considered work in progress. Therefore, the analytical choice is not of conceptual stability but rather on best fit because the conceptual choice shall mainly depend on the overarching objective of the research. The conceptual choice shall possess a diagnostic and exploratory characteristic to investigate the dynamic pattern of the penetration of CHP-DH systems in the UK with a view to have insights into the barriers and drivers to its diffusion and utilization. Suggesting that, diagnosing, incremental innovation and enhancement of competencies is at the centre of the analysis considering that CHP-DH as a matured technology, generates electricity which already has a regulatory institution overseeing matured electricity and gas grids but no heat regulation in UK. Furthermore, a system failure framework is sought that would investigate the poor penetration of CHP-DH systems and low market share in the electricity and heat sectors in the UK despite it being initially deployed decades ago. The essence of system failure framework is to justify the intervention by the hierarchies of governance.

Therefore, drawing on narrative on the key characteristics of this research mentioned above, the TIS approach is alluring because it meets the desire of the research and will be adopted as the analytical framework going forward. This approach is simply heuristics, since it does not claim to offer a perfect solution to the status of CH-DH in the UK considering its analytical challenges. However, the TIS shall be complimented by integrating it with governance concept and this would serve as an integrated approach to provide insights into the attributes to its current state and potentially present governance measures that can influence the penetration of CHP-DH in the UK.

3.6 Conceptual Framework for Governance

In conceptual terms, the debate about governance cuts across various spheres of study ranging from public administration, political science, economic development, international relations, sociology, organisational management and many more, hence its proliferated definitions (Jessop, 2001, Rhodes, 2007, Offe, 2009, Börzel and Risse, 2010, Bevir, 2011, Rhodes, 2012, Levi-Faur, 2012, Peters, 2012). The absence of consensus on the definition of governance largely depends on the discipline or debate the narrator leans on (Stoker, 1998, Jessop, 1998). However, many institutions have attempted to adopt governance concept in their activities to address collective concerns. For instance, the EU's governance white paper sees governance as a way to strengthen "*openness, participation, accountability, effectiveness and coherence*" amongst members of the union (EU, 2001). The world bank defines governance as "*the manner in which public officials and institutions acquire and exercise the authority to shape public policy and provide public goods and services" (WB, 2007)*. In navigating through various definitions of governance, the underlying recurrent has been that governance largely refers to the interaction and coordination amongst multifarious actors to achieve a collective goal.

This research draws upon the definition of governance by the Organisation for Economic Co-Operation and Development (OECD) because of its emphasis on the impact of interaction and coordination of the activities multifarious actors on innovation to achieve economic growth. The OECD defines governance as a process to broaden the role of government in innovation policy to capture more independent actors with a view to achieving more socio-economic growth (OECD, 2005a). It suggests that governance of innovation policy entails improved interaction and coordination between government and non-governmental actors since non-technological changes are as potent as technological changes in innovation policy (OECD, 2005a).

The concept of governance emerges from four key iterations: processes (modes of social coordination of interaction and steering functions), structures (formal and informal Institutions and actors), mechanisms (Instruments of compliance and control) and strategies (design and adaptation of institutions and mechanism) (Börzel and Risse, 2010, Risse, 2012 pg:700, Levi-Faur, 2012 pg:8). The modes of coordination may be hierarchical such as top down decision making, inter-organisational, inter-personal network, inter-systematic steering, (Jessop, 1998), or non-hierarchical such as negotiation, persuasion, social learning (Risse, 2012), and value chain integration (Griffiths et al., 2007).

The discussion of governance typically revolves around three broad perspectives (state, market and society), as proponents struggle to out debate their opponents on the most appropriate type of governance to adopt. Firstly, governance can be seen from the position of the market, where market forces drive economic growth (Best, 2001, Streeck, 1991). Lindblom (2002 pg:4) argues that all societies use markets, so the coordination of activities can be done through transactions. This is sometimes known as market-led governance, where the role of the state in decision making is limited and the transactions are governed by a market superintendent (Waarden, 2012 pg:358). The second perspective is state-led governance, where the state takes a steering role (gathering of information, making of ground rules and enforcement) and rowing role (service delivery, distribution and taxes) (Levi-Faur, 2012 pg:14, Osborne, 1993) in governing the market and society. Proponents of state-led governance suggest policies will be more effective if they emanate from the state, especially in the present era of globalisation and global threats, largely due to the huge capacity of the state to make and enforce rules (Offe, 2009).

Thirdly, others see the state as not capable of formulating public policies and as such they advocate “unravelling” (Hooghe and Marks, 2003), or “unbundling” (Pollitt and Talbot, 2004) of the state to allow for only rowing. Some refer to this as the “hollowing out” of the state, suggesting the devolution of state powers horizontally to non-hierarchical actors, such as networks, non-governmental organisations or vertically to regions, local authorities and political institutions (Jessop, 1998, Stoker, 1998, Rhodes, 2007). However, this form of governance reinstates a great deal of authority on the state in as much as it recognises the importance of non-government actors. This form of governance is sometime referred to as “big governance” (Levi-Faur, 2012 pg:13) but often referred to as “governance networks” (Jessop, 1998, Rhodes, 2012 pg:33-35, Rhodes, 1997, Kersbergen and Waarden, 2004, SØRensen and Torfing, 2009, Torfing, 2012 pg:99-106)

The concept of governance networks emerged because of the desire of scholars to understand the role of the state in governance, given the failure of state and market-led governance systems by incorporating actors from the private sector to participate in governance (Rose, 1996 pg:43). The key variance between state-led governance (the hierarchical control of the state), market-led governance (competitive regulation of the market) and governance network (regulated self-regulation) (Torfing, 2012 pg:105, Jessop, 2001) is the degree of relationship between actors and mode of compliance. State led governance is known to have a unicentric command and control relationship with actors, while market led governance has multicentric relationship that makes it difficult for competitive markets to evolve but governance networks has pluricentric relationship (Kersbergen and Waarden, 2004). This suggests that the relationship between actors in governance networks involves more independent interaction of actors which entails a lot more negotiation and compromise to produce public goods. Compliance in the state-led governance is through legal sanctions, while in market-led governance, its often through economic sanctions, but compliance is achieved through trust, political obligation and jointly developed rules and regulations in governance network, thereby creating a sense of ownership amongst actors (Nielsen and Pedersen, 1988, SØRensen and Torfing, 2009).

Governance networks are also credited as having more potential for proactive governance to collective problems and mitigations as market and state-led governance are considered too rigid and reactive, largely due to the complexity and multi-layered fashion of society (SØRensen and Torfing, 2009). Furthermore, governance networks entrench governance through regulatory instruments (Levi-Faur, 2012 pg:13), it also encourages the development of technological innovations via actors internal capabilities, resources (Griffiths and Zammuto, 2005) and legitimacy (Börzel and Risse, 2010).

However, in spite of its attractive contributions to governance, governance networks may exhibit risk of governance failure as networks are not formed spontaneously and may lead to undesired outcomes such as uninformed or wrong decisions (Torfing, 2012 pg:107). Furthermore, they may have potential to undermine political competition, since there is no equal representation of actors but rather representation from a given sector or area, thereby making political and policy processes more open to capture (SØRensen and Torfing, 2009).

The implementation of governance activities requires action and compromise by both the state and the market, since both lack capacity to achieve systemic economic growth (Offe, 2009). The state will have to give up some of their steering powers, which is top-down authority, while the market will have to give up some economic decision powers to achieve the desired systemic economic growth (Jessop, 1998). However because of the need to make and ensure the implementations of socially binding decisions, such as energy efficiency targets by LAs, this function best resides with the state and LA through corporation and coordination with other multifarious actors (Offe, 2009).

Furthermore, no actor can regulate the economy and society singlehandedly, partly because all actors are limited in capacity and knowledge (Torfing, 2012 pg:100).

Therefore Government/policy intervention may fail for a variety of reasons such as firstly, Government activities are enclaved in human relations which can be unpredictable (Jessop, 1998). Secondly the complex bureaucratic procedures, information asymmetries, political short sightedness and demarcation between the policy makers and policy benefactors can all offer recipe for a failed Government/policy intervention (Metcalfe, 1995). Therefore, the application of governance networks through interaction with horizontal actors which possess large knowledge resources to compliment the decision-making process can be the antidote to failure of Government/policy.

Furthermore, in order to also harness the financial and knowledge capacity of non-hierarchical actors, and the vital role of governance network in social regulations (Torfing, 2012 pg:99), the governance network perspective seems the preferred governance option as it captures the plurality of actors within the TIS of CHP-DH system in the UK and will henceforth be referred to in this research as just governance.

3.7 Theoretical Analytical Framework

3.7.1 Functions of Innovation Systems

Innovation systems has been characterized to be analysed using a system failure framework, which seeks to be an alternative to the market failure approach in addressing infrastructural failures adopted by government/policy makers by capturing the components of the system that impacts on the system behaviour. The system failure approach typical depicts the failure of a socio-technical system into four distinct categories namely: infrastructural failure, network failure, institutional failure and Transitional failure (Klein Woolthuis et al., 2005 pg:131-133, Foxon, 2007). However, this approach has often been criticised for only capturing the structural element of the system (actors, networks and institutions) and not paying enough attention to the system dynamics that determine the performance of the system which can be offered by the functional perspective of TIS (Bergek et al., 2008b, Bergek et al., 2010, Hekkert et al., 2007b). The TIS functional analytical approach seeks to capture both the structural and functional processes and seeks to explain how the socio-technical system work and performs in relation to the structure rather than how the system is composed (Markard and Truffer, 2008b).

Innovation does not occur in isolation largely due to the fact that it emerges over time under the influence of several factors (Edquist, 2005 pg:1) and in a complex interaction between the agents in the components, suggesting that it emerges through dynamic processes. The dynamic processes involve several activities which determine the outcome of the system innovation. However the outcome of the innovation processes such as high diffusion of technology is not the only criteria that determines if the system is functioning well or not (Hekkert and Negro, 2009). Since system innovation is not just about product innovation but also about process innovation in understanding the system as whole.

Therefore, the TIS tool to assess the dynamic activities of the internal structures of the system (actors, networks and institution) is described as the system functions, which seeks to bridge the gap between performance of the system and the structure (Bergek et al., 2008b pg:83). This functionality can be categorised into seven different functions or “activities” which are capable of influencing the performance of the system either positively or negatively so as to allow for insight of the impact of the various contributors on performance (Hekkert et al., 2007b, Hekkert and Negro, 2009, Bergek et al., 2008b, Bergek et al., 2008a). This functionality pattern can be deployed for various types of innovations system irrespective of the system delineation whether it is NIS or TIS, since the strength of the functionality framework lies more with the role of institutions (macro level) than the actions of the firms (micro levels) (Hekkert et al., 2007b). The seven amalgamated categories of functions as discussed by various authors (Hekkert et al., 2007b, Hekkert and Negro, 2009, Bergek et al., 2008b, Bergek et al., 2008a) are detailed below:

Function F1; **Entrepreneurial Activities**: Technology (or rather technology companies) seeks to permeate the market via actors taking on risk in the midst of market uncertainties to ensure that the technology is diffused and utilised. These actors are often entrepreneurs undertaking entrepreneurial activities which will leverage knowledge, networks and market to explore new business opportunities. They may be new entrants that have seen new market opportunities or incumbents that change their business models with a view to capture new business opportunities (Hekkert et al., 2007b, Bergek et al., 2008b). This may include established large utilities that have ventured into CHP-DH systems or renewable energy generation.

Function **F2**; **Knowledge Development and Diffusion**: Knowledge is at the heart of innovation and the most critical way of acquiring knowledge is through learning activities (Lundvall, 2007). Therefore, the development of knowledge and how actors receive it plays a major role in how a system innovates. A common way to develop knowledge is through research and development (R&D), while it can also be diffused to ensure market growth through various other processes of learning such as “learning by doing” or “learning by using” (McWilliams and Zilbermanfr, 1996). These processes may instigate market growth from cost reduction through learning-by-doing or be the driver for market growth through learning-by-research (Winskel et al., 2012). Others have also argued that knowledge spill over also contributes to the technology diffusion since innovation in a technology industry can arise from innovative activities in another organization, industry or country (Clarke et al., 2006).

Function **F3**; **Influence on the Direction of Search**: Function (1) noted that firms create market growth through innovation in the midst of market uncertainties, but the entrance of these firms is strongly influenced by different motivations and expectations, including political, regulatory, environmental, or economic (Shane et al., 2003). These motivations could be created through incentives or mechanisms or interaction sufficient to direct firms to the market, with the expectations of meeting actors’ specific vision and targets. The culmination of different components within the TIS, which seeks to capture the processes of development, diffusion and utilization of the technology that could influence the direction of growth of the technology (Bergek et al., 2008b).

Function **F4**; **Market Formation:** A new or emerging technology will often have to compete with an established technology for market share, therefore for the technology to grow into a bridging market from its nursing market (Andersson and Jacobsson, 2000), it may require a protected space to allow it to grow (Hekkert et al., 2007b). This will afford the new or emerging technology space to develop knowledge and expectations. This typically happens through two processes namely, by creating a niche market for it to acquire knowledge through learning processes or via favourable regulatory mechanisms such as incentives or policy goals that may influence the bridging market to emerge into a mass market (Bergek et al., 2008b).

Function **F5**; **Resource Mobilization**: Resources are critical inputs to the activities of innovation system. They can be in the form of human capital (training in technological, legal, financial and economic, operational and management skills) or financial (e.g. grants, seed capital, access to finance, funding of R&D or pilot schemes) and assets (machineries, network infrastructures or buildings) (Bergek et al., 2008b)

Function **F6**; **Creation of Legitimacy**: In order for a new or emerging technology to acquire market growth, it must do so within an established system or overthrow it, thereby fanning the embers of creative destruction leading to resistance from incumbents (Hekkert et al., 2007b). Challenging the incumbents heralds advocacy coalitions that grow in power and size to confront the resistance with a view to create legitimacy (Hekkert and Negro, 2009). The effectiveness of these advocacy coalitions depends heavily on resources such as money, knowledge, size and influence with a view to creating legitimacy for the new technological trajectory (Sabatier, 1988). Legitimisation is a deliberate action by various firms or organisations within the innovation system to overcome the "liability of newness" (Bergek et al., 2008b) as incumbents, media or other interested parties may seek to de-legitimise the technology by unit performance, growth potential or cost. (Negro et al., 2012).

Function **F7**: **Development of Positive Externalities:** As individual firms grow within the functions in the TIS, such as legitimacy, market formation, entrepreneurial activities and knowledge development, they may not be fully able to appropriate the whole benefits of investment and growth. Other firms or actors may benefit from them in areas such as knowledge spill over, reduced uncertainty and further legitimisation which may result in the increase of new entrants and technology clusters can be considered as a positive externality (Bergek et al., 2008b)

Adopting the functionality pattern approach of a TIS framework to assess the performance of CHP-DH systems within the UK may offer several benefits to this research due to its "diagnostic" (Kern, 2015) and "explanatory" (Markard et al., 2015) capacities. Firstly, it presents the tool to describe the status of CHP-DH system in the UK with a view to determining the mechanisms that are blocking or inducing innovative activities within the system, thereby offering the opportunity to map these functions to provide a picture of the system performance (Johnson, 2001). Secondly, it would make more feasible the differences in institutional infrastructures when comparing different innovation systems and thirdly it offers the potential to provide clarity of governance mechanisms to achieve set targets (Hekkert et al., 2007b).

In explaining the development of a TIS using the functional approach, there are two distinct phases that defines the technological transformation of a socio-technical system. They are the formative and growth/market expansion phases (Jacobsson and Bergek, 2004). According to Bergek et al. (2008a) and Bergek et al. (2008b), the formative phase is determined by time dimension, often depicting early entry of actors and high uncertainties. While the growth phase is determined by when the market is formed and up to when its self-sustaining. This phase is also known as the market formation phase, which is further divided into three categories, namely: (a) nursing market – when market begins to evolve and with limited size, (b) bridging market – enlargement of actors and increased market size, (c) mass market – when market is fully evolved and self-sustaining. However, Winskel et al. (2012) argue that the framing of innovation systems in terms of functional patterns may not fully capture the influence of socio-technical factors or learning impacts from the various learning processes such as learning-by-doing from other industries.

The formative phase of CHP-DH innovation system shall be discussed below, while what phase of growth it currently holds shall discussed in the concluding chapter 11.

3.7.2 Formative Phase of CHP-DH innovation system in the UK (1910 – 1980)

Bergek et al. (2008b pg:82) defined the formative phase of a TIS to typically be characterised by three features. These are the early entrance of firms and organisations, institutional alignment and formation of networks. This is occasioned by the high uncertainty experienced by the entry of entrepreneurial actors and investors and the role of policy makers regarding the technology, market and regulations. The formative phase of the CHP-DH system in the UK has been captured from the period of early schemes in the early twentieth century to 1980 when the first national assessment of CHP-DH potential was carried out.

Entrepreneurial Activities- F1

Early entrance of actors in to the CHP-DH innovation system can be traced to the 1911 city centre power station at Manchester (Russell, 1993, Kelly and Pollitt, 2010) and later the Boots Company system by River Trent in 1919 (Jarvis, 1986) and a few other isolated systems such as the systems operated by the Bank of England (Rüdig, 1986). However, LAs have been central to the development of DH networks in the UK, due to their role as custodians of the social and economic fabric of their locality, but it wasn't until in the late 50s that the first successful CHP-DH system in the UK was built on the back of residential housing estate in Pimlico by Westminster City (Martin and Thornley, 2013, Roelich et al., 2013, Diamant and McGarry, 1968 pg 172, Jarvis, 1986).

Electricity companies which were hitherto regional and municipally owned were nationalised in 1948 even though few municipal and private companies were endeared to CHP-DH systems before nationalisation (Russell, 2010). Nonetheless, private industries who generate electricity and heat for local consumption were also involved in the CHP-DH industry. However, the state and LAs started a couple of CHP-DH systems but due to technical and economic difficulties, many systems were either discontinued or never left the feasibility stage (Russell, 1993). Key government departments involved were the Ministry of fuel and power – responsible for gas, coal, electricity and heating, Ministry of Town and Country Planning – responsible for new towns, Ministry of Housing – responsible for development of houses. Other are the gas council and 12 area gas boards that were formed after the nationalisation which were responsible for the regions (Arapostathis et al., 2013).

However, it was not until the 1977 Marshal report resulting from the concerns of the global energy shock, which recommended amongst others a national heat board and a strong government intervention to open the CHP-DH space for growth.

Market Formation – F4

The UK has a long history with deep cultural place of open heating by coal as opposed to centralised heating resulting in lack of interest by municipal electricity utilities in CHP-DH systems (Rüdig, 1986), which often resulted in resistance of DH networks by both the gas and electricity industries (Russell, 1993). The heating culture has been dominated by production and supply of gas through three key phases of transformation due to economic and environmental pressures. These includes; coal carbonization – production of town gas from coal, oil gasification – using refineries of produce gas from oil and lastly from natural gas (Arapostathis et al., 2013). For instance, since 1812 when London gas-light and coke company was established as the first UK gas company (Falkus, 1967), pipelines has been used to supply gas to buildings in the UK for over 200 years (Dodds and McDowall, 2013, KPMG, 2016) which provides fuel for residential heating. Due to the availability of cheap coal to produce town gas and extensive gas networks for heating houses, DH networks in cities has been unpopular in the UK, but more popular in the industrial sector where there was demand for steam or heat plus power (Sievers et al., 2005). Therefore, the availability of cheap town gas from coal through pipelines to houses for heating did not incentivised the deployment of DH networks for residential houses, thereby essentially locking out heating from CHP-DH systems and stifling the formation of market for CH-DH systems. Nonetheless, in a brief period in the sixties, coal and oil companies offered heat service packages due to competition in the domestic heat market (Russell, 2010). However, the dominance of gas through gas network in the provision of heating in the UK was further reinforced by the discovery of natural gas from the North Sea in the late 1950s (Arapostathis et al., 2013). The discovery of natural gas was followed with widespread upgrading of gas networks to high transmission gas networks known as the NTS (National Transmission System) between regions and low distribution gas network replacement programme known as the IMRP (Iron Main Replacement Programme) to replace all iron pipes that were within 30m of any building with polyethylene pipes (Dodds and McDowall, 2013). The upgrade of the gas infrastructures also includes the conversion of gas burners to be natural gas complaint from 1966 leading to the conversion of more than 40 million appliances by 1977 (HoP, 2017).

Furthermore, the operation of many CHP-DH systems by the LAs were truncated by the poor economic and technical characteristics of the system, leading many LAs to sought Government's intervention to guarantee losses, but the LAs were not successful in securing such guarantees from the central government (Russell, 1993). This suggest that the failure of many early CHP-DH systems may have contributed to the stifling of the formation of DH market. However, electricity from CHP had little resistance compared to heat from DH as many CHPs were developed by electric utilities and industries to generate electricity before and after the nationalization of the electricity industry. This culminated in CHPs contributing about 8% of electricity to UK's gross electricity production by 1953, which is still considered the highest contribution from CHP according to available records till recent times (DECC, 2013b).

Therefore, the complexities of combining the provision of the dual product of electricity and heat was disadvantageous to the formation of a CHP-DH market. In part because of lack of heating governance infrastructures, economic assessment of CHP-DH systems and minimal recognition of CHP-DH systems in mainstream energy provision.

Resource Mobilization – F5

While the few industries developed CHP-DH systems privately to cater for local demand, the lack of powers limited LAs to develop CHP-DH systems. They often had to sponsor local bills at the parliament and by 1955 some thirty councils had obtained powers to develop DH and generate electricity (Russell, 1993). However, part of the compromise with the state for the LAs to obtain such powers was the acceptance of strict separate accounting to forestall any form subsidy from the state and the refusal by the state to underwrite any CHP-DH scheme (Russell, 1993). Suggesting that as there was scarcity of successful CHP-DH systems, with some struggling economically and lack of support from the state, the LAs lacked sources to mobilize resources and therefore were rightly cautious to develop citywide CHP-DH systems.

Creation of Legitimacy – F6

The failure of several early schemes impacted on the legitimacy of CHP-DH systems in the UK. The reasons for the failure are attributed to several causes. Such as in Gorton and Blackley in Manchester built in 1919, the system was unsuccessful due to pipeline corrosion (Diamant and McGarry, 1968 pg:171). Flixton near Manchester also suffered pipeline corrosion, while the Duddeston and Nechells in Birmingham suffered from poor costing (Diamant and McGarry, 1968 pg:171-172). Similarly in Dundee, the CHP-DH system could not survive the day due to bad economic position of the system (Russell, 1993). These failures were further reinforced by poor management, ineffective maintenance and low quality labour force (Jarvis, 1986). Consequently, many CHP-DH systems attracted criticisms for decades and therefore LAs lacked successful systems to draw experience from, resulting in low social acceptance of CHP-DH system into the social fabric in UK.

3.7.3 Governance on TIS-Functional Pattern

Infrastructures are socio-technical systems because of their complexities arising from the interaction of technical, economic, political and social actors to ensure their diffusion and utilization. The functional pattern of the TIS framework which is the adopted diagnostic and explanatory tool used in this research in analysing the performance of CHP-DH system as socio-technical system draws from the activities of the dynamic interaction of these actors. This suggests that the modes of governance of the interactions of these actors are vital for the technology to meet set targets and goals (Carlsson et al., 2002, Hillman et al., 2011). Additionally, from a socio-technical perspective, one of the key requirement for the performance of an infrastructure is the adoption of a coordination mechanism to forestall failure (Jonsson, 2005, Finger et al., 2005). However, one of the criticisms of TIS is that they do not capture the influence of external factors that may impact on the development and diffusion of the technology such as social, financial or environmental sufficiently (Markard and Truffer, 2008b). Kern (2015) also argues that TIS should look beyond market entry and knowledge generation to capture the political agency of varying actors in activities such as coalition building, writing narrative, lobbying e.t.c and how they can shape the selection environment of technology adoption. Thus, he suggests that TIS does not underpin the strong impacts of socio-political processes on the performance of socio-technical systems. In response to this criticism, TIS scholars opine that the functionality pattern of TIS captures both exogenous and endogenous factors that influences the dynamics of the system, but however, agree that more work is required in the analysis of the context (Markard et al., 2015).

Furthermore, firms in a TIS usually find it difficult to drive technological discontinuity – adopting new technologies to change market position: due to uncertainties and risk, which translate to higher transaction cost and leads to barrier to new entrants, and therefore may require governance support to diffuse the technology to a self-sustaining state (Bergek et al., 2008b). Effective governance however can enable coordination mechanisms (regulatory, market and public/private partnerships) to shape the functions of TIS (knowledge development and influence the direction of search, entrepreneurial experiment, market formation, legitimation and development of positive externalities) and the understanding of the inducing and blocking mechanisms by TIS actors (Hillman et al., 2011).

Therefore, to further enhance the quality of coordination of the TIS framework, considering the complex horizontal and vertical coordination requirement for the embedded processes of both electricity and heat sectors and their actors that are crucial to the performance of CHP-DH systems in the UK. A complimentary layer of governance will be required to compensate for the weakness of inherent governance processes within the TIS (Brousseau and Raynaud, 2006, Cohendet and Uerena, 2005 pg:238). Hence, governance concept will be integrated with the TIS functional pattern to further capture and coordinate activities of actors that can influence the diffusion of CHP-DH system in the UK. Governance concept was adopted for this research, because of its reliance on social initiatives for sustainable development and diffusion of technology and contribution to social goals rather than conventional policy instruments which tends to be more top-down without much consideration to social initiatives (Hillman et al., 2011). Governance concept also reinforces the role of the state concentrating on steering powers (e.g. making ground rules) while leaving rowing (e.g. services provision) to other segments of the system or actor such as LAs and governance concentrates on a particular area, particular sector or locality rather than global (Jessop, 2001).

Therefore, policy intervention that seek to reduce the effect of the blocking mechanisms on the diffusion and utilization of CHP-DH in the UK shall be termed as governance mechanisms, which is a typical measure used to entrench governance. Theoretical and empirical evidence suggests that governance mechanisms can influence the rate and direction of technological diffusion (Jaffe et al., 2005, Hillman et al., 2011, Nilsson et al., 2012). These mechanisms should be characterised by transparency, consistency and getting it right from the start, but also importantly to be predictable for the long term if the goal is to see new entrants or investors (Connor et al., 2015). These mechanisms should also exhibit seamless and strong interaction between the components of the structure to bring about the desired push through a systematic coordination and directionality (Geels, 2004a pg:8). However, there is no consensus on how these governance mechanisms should be measured with a view to determine its effectiveness (Torfing, 2012 pg:109), but many available indicators such as the quality of coordination, are based on subjectivity and surveys (Norris, 2011 pg:188). Nevertheless, governance shall provide the bridge between the heterogenous actors and disciplines within the TIS, such as political, social groups, developers, operators, consultants, accountants, financiers, users, umpires, suppliers, regulators and so on (Kersbergen and Waarden, 2004).

3.7.4 LAs role in the TIS

Infrastructures exhibit stability and lock-in features, due to huge sunk cost, increasing returns and network externalities (Unruh, 2000, Unruh, 2002) and are known to be large scale capital goods producer with multiusers that often requires public intervention. Such as CHP-DH systems that produce electricity and heat. Suggesting that they are indices of socio-economic performance of the society which has high political relevance, that may partially or directly involve the hierarchies (State or LAs) of governance. Therefore, the array of actors that interact to determine the performance of an infrastructure span through the social, technological, economic and political spheres of the society. However, due to the complexity of interaction, governing the processes and elements that constitute the structure of the sociotechnical system is often a challenge (Finger et al., 2005). One of the key elements of TIS is the aggregation of actors through networks under similar institutional structures (Markard et al., 2015) to adopt and utilize a specific technology for economic growth. However, the concept of TIS mainly focuses on the meso-level of the system with little attention on the micro-level and therefore not able to capture all the activities at the micro level (Markard et al., 2015, Bergek et al., 2008b, Kukk et al., 2015). Furthermore, weak socio-political processes between the levels of government had been identified as one of the deficiencies of the TIS concept. Therefore, considering a recent report by UNEP (2015) which suggests that LAs are in the best position to be global champions to facilitate the diffusion of DH systems, a key feature of the governance layer is the role of the LAs in influencing the performance of the TIS functions. In part because of their frontline role to promote social, economic and environmental wellbeing of their community and as part of the hierarchies of governance.

Van De Ven (1996) argues that a system cannot innovate without a champion. In a similar vein, early work on TIS had suggested that for a system to reach stability and mass market, it requires an entrepreneur/actor who has the capacity to formulate visions that will capture the economic potentials of the system and create the required density of relationship amongst actors that would lead the system to mass market (Carlsson and Jacobsson, 1994). Such entrepreneurs are actor/actors with powerful attributes – such as political resources, to initiate and drive the diffusion of the TIS, are captured as “prime movers” (Jacobsson and Johnson, 2000). Other literatures have identified this role of a dominant actor as “system builders” (Joerges, 1988, Hughes, 1987) or “change agents” (Rogers, 2010 pg:37, Musiolik et al., 2012) and several work on system builders in TIS has also been embarked upon by scholars (Musiolik et al., 2012, Kukk et al., 2015, Hellsmark and Jacobsson, 2009, Hellsmark, 2010). These prime movers are known to have the capacity to instigate innovation than the market (Boschma and Frenken, 2010 pg:488), and lead the transformation process of socio-technical systems and drive interaction (van Mierlo et al., 2010, Rao and Kishore, 2010). Empirical evidence from Devine-Wright et al. (2001) suggests that the prime movers can connect the bridges of innovation systems from the local networks to regional to national and to international networks. This is with a view to increase learning process. Therefore, Jacobsson and Johnson (2000) notes that prime movers are often located within the capital goods industry.

Drawing on the narrative on the role and attributes of the prime movers including political strength, LAs as an actor within the TIS structure can draw on their political, structural and relational resources (Farla et al., 2012), such as social capital -trust, norms and networks (Pollitt, 2002), geographical proximity to CHP-DH actors (Boschma and Frenken, 2010 pp:123) and part of hierarchies of governance in the UK to influence the functions of TIS. Hence, LAs shall be assigned the role of the prime mover in the TIS considering their dominant attributes and strategic position.

3.8 Conclusion

According to Finger et al. (2005), infrastructures exhibit key features, which includes: (a) networked based that contribute to goods and services, (b) increasing returns and network effects that requires governance. (c) Social goods producer. These features suggest that infrastructures would require huge investment and precipitate sunk cost, that would constitute barriers for structural change. Therefore, infrastructures are impossible for sudden transition, but rather they have tendencies for incremental change (Frantzeskaki and Loorbach, 2008) and path dependencies (Bolton and Foxon, 2015) which has political, economic, societal and environmental elements to its transformative capacity. Thus, suggesting the necessity of a partial or direct involvement of the hierarchies of governance (state and LAs) in the operation or management with a view to determine the desired the social or economic objectives.

The heterogenous elements that influence infrastructures, rightly qualifies them as socio-technical systems. Three common concepts that are used to study socio-technical systems were discussed. These include: Large Technical Systems (LTS), Multi-Level Perspective (MLP) and Technological Innovation Perspective (TIS). All three have the capability to investigate infrastructures as socio-technical systems and capture the linkages of the heterogenous (technical and non-technical) elements within the system to effect technological changes. However, considering the purpose of the research to investigate CHP-DH in the UK with a view to address the system failure and the diagnostic and explanatory potentials of TIS, this research adopted the TIS concept to use as the analytical framework going forward. A broad and generalised discussion of the TIS theoretical frameworks was undertaken to gain a better understanding of how the various activities within the CHP-DH TIS impacts on the diffusion of CHP-DH in UK. In driving the innovation within the TIS, LAs were designated as the prime mover within the TIS structure due to their unique political, structural and relational resources (Farla et al., 2012), such as social capital -trust, norms and networks (Pollitt, 2002), and part of hierarchies of governance in the UK to influence the functions of TIS. Furthermore, the concept of Governance was discussed and how it can complement the TIS concept with a view to compensate for its weaknesses and create opportunities to reduce the effect of the blocking mechanisms to the diffusion of CH-DH system in the UK.

Summarily, the integration of both TIS and governance concepts will offer the opportunities to advance governance measures to influence the transformation of CHP-DH in the UK. In operationalizing this framework, the functional pattern of the TIS shall be integrated with a governance layer to stimulate more bottom-up governance measures.

4.0 Overview of best practice of governance of CHP-DH systems in Europe

Several countries have adopted CHP-DH systems to meet different challenges, from energy security, climate mitigation or socio-economic reasons. In Europe many countries have shown interest in the deployment of CHP-DH systems, but the research shall focus on two countries (Netherlands and Norway) with similar energy paradigm in terms of natural gas production and appetite for competition in the energy market through liberalisation. These countries become a ready choice to consider for further comparison with the UK, because they both possess similar energy resource in the form of natural gas that dictated the pattern of the political economy - interaction of political and markets forces, in the UK energy space. Furthermore, they both sought to follow the UK in energy liberalisation in a bid to entrench competition, through governance instruments. CHPs in Netherlands contributed about 35% to national electricity generated in 2013, while DH contributed about 4% to national heat demand. While in Norway, CHPs contribute about 0.28% to national electricity production in 2015, with DH contributing about 3% to national heat consumption.

The narrative below seeks to capture an overview of the various governance structures and market regimes in Netherland's and Norway's CHP-DH industry which may provide further insight on the pathway and diffusion of CHP-DH systems.

4.1 Netherlands

The Dutch energy system has been driven by gas since its discovery in 1959, leading to a wide spread development of gas infrastructures and exploration, though in 1969 the first nuclear plant was built and a second one by 1973 which suggested that nuclear was also going to play a critical role in its energy policy (Pruiksma, 2013). However, the countries gas reserve which currently stands as the largest within the European Union and second largest gas producer after Norway in the European continent (Deloitte, 2015) indicates that role of gas may continue to be critical to the Dutch energy system. Since the 60s the abundance of gas may have instigated an energy policy that is focused on least cost energy to meet a guaranteed demand and security of supply with no long-term energy strategy in place before the global oil crisis of the early 70s (Pruiksma, 2013). Since oil prices are intricately linked to gas prices, the oil crisis resulted in high energy prices globally. The oil crisis and the emergence of environmental groups had caused the Dutch government to have a rethink on energy policy that considers gas reserves are infinite, but rather natural gas should be considered as a strategic fuel to be restricted to high grade applications (Raven and Verbong, 2007).

In response to the 1973 oil crisis, the Dutch government introduced its first comprehensive energy report in 1974 which seeks to emphasis on measures to incentivise energy efficiency, reduction on energy consumption and further natural gas restrictions, then subsequently, the 1975 White paper on energy, which many considered as the turning point for the Dutch energy policy (Steen et al., 2008 p.183, Jong, 2004). It was a turning point because it was the first time CHP was mentioned in a government energy report but with little or no significant role (Jong, 2004).

However, despite the various measures seeking to promote energy efficiency, such as investment grants for home efficiency, it was not until 1978 that the government accepted that industrial gas turbine CHP could be considered as a vital energy saving option based on the advice from Dutch Energy Council (Blok, 1993).

The first gas turbine was installed in 1968 at Dow Chemicals (Jong, 2004) with CHP contributing about 12% to electricity production in 1968 (Raven and Verbong, 2007). However, consequent upon the acceptance of CHP role by the government, the Dutch Energy council in 1978, proposed several key governance measures to stimulate the diffusion of CHP in the Netherlands. These include: the formation of an advisory body with members drawn from the government, utilities and industry to come up with modalities to stimulate the diffusion of CHP and to establish a body to function as an ombudsman to handle disputes (Blok, 1993).

Subsequently in 1979, a commission on cogeneration for the industry was established on the advice of the Dutch Energy Council, with members drawn from Gasunie (Dutch gas company), industry, power producers, Ministry in the field of energy and the Ministry of Economic Affairs (Hekkert et al., 2007). In its first report, the commission concluded that additional 2000MW of CHP could be installed by year 2000 to add to the 1100MW already installed by 1980 (Hekkert et al., 2007). It also recommended that more natural gas should be provided to CHPs to facilitate the expansion of gas turbines, CHP to be included in the electricity grid planning and expansion, investment grants should be given to CHP developers to reduce payback time, utilities should pay the CHPs the fuel cost saved by their electricity supplied to the grid (Blok, 1993, Steen et al., 2008 p. 184). The investment grant scheme was assimilated into the Investment Act which provides about 12-13% of capital investment (Blok, 1993). Further recommendations were made in 1982 due to the disappointing level of penetration of CHPs. In part, because of the poor economic growth and the CHP growth trajectory was mainly anticipated from industries who were already struggling with high cost of oil and gas. The recommendations include: feasibility studies on CHP deployment by companies to benefit from subsidies – Government eventually subsidised about 50% of the cost of the studies (Blok, 1993), the removal of gas restriction for CHP development, free grid connections for industrial CHP plants and feed-in tariffs (FiT) for power supplied (Raven and Verbong, 2007). Also in 1982 the National Investment Bank was established, to militate against high interest rate and limited capital by offering finance at favourable rates without security or any risk assessment to projects like CHP (Blok, 1993, Hekkert et al., 2007).

These governance instruments in early 80s were instrumental to the growth trajectory of CHPs in the Netherlands, though mainly from industrial plants – due to more experience in gas turbines than other sectors of the society. Key growth driver was the profitability of CHP plants due to the FiT scheme leading many new CHP plants to change operational strategy from meeting local electrical demand to heating demand since excess electricity can be sold profitably (Verbong and Geels, 2007). However, in terms of policy there was tension between the electricity from gas fired CHPs, coal gasification to militate against depleting gas reserve and nuclear plants. No sooner did it become clear to the government that coal gasification was more in the longer term with its antecedent environmental challenges and the loss of legitimacy by nuclear power due to the accidents at Three Mile Island (1979) and later at Tsjernobyl (1986) resulting in CHPs taking frontline position in government energy policy (Jong, 2004). This further strengthens the interdependencies of natural gas and CHP in the Netherlands. Also, vital to the penetration of CHPs in the 80s was the partnership between utilities and industries to develop CHP systems, such as the partnership between AKZO and the EGD a regional utility in 1983. This form of joint venture became attractive to banks to offer financing (Hekkert et al., 2007). The result was the share of industrial CHP from decentralised power increased to 95% in 1988 from industries contributing 10.6% in 1968 to the total generated electricity, mainly through the installation of about 85 new industrial CHP units between 1968 and 1988 (Verbong and Geels, 2007).

However, this growth phase of CHP systems in the Netherlands experienced a significant change in institutional arrangements in the late 80s. Prior to this time, there was no competition in the electricity market with the electricity supply divided into regional boundaries (Raven and Verbong, 2007). In 1989, the Electricity Act and Gas Act were introduced with a view to create competition in the energy sector. Key driver was the electricity act 1989, which mandated several governance arrangements. These include, the separation of ownership of the production of electricity from distribution, the distribution companies were now allowed to buy electricity from the cheapest sources or produce electricity themselves but to a maximum 25MW (Hekkert et al., 2007). Others include: Obligation on distribution companies to purchase power supplied to the grid from CHPs and pay a minimum tariff. Also, just about the same time with the Electricity Act, a market broker was established as part of the Cogeneration Incentive Programme, to play the role of an information hub for the CHP industry and link CHP industry actors (Steen et al., 2008 p. 185).

As a result of the electricity act, four power production companies emerged that own the Dutch Electricity Generating Board, with the responsibility of planning, high voltage transportation and national pooling, while the distribution companies were now responsible for electricity and gas distribution (Blok and Farla, 1996). From the gas perspective, Gasunie (Dutch gas producer) and gas distributors (electricity distribution companies) agreed on a specially reduced tariff for CHPs in 1990 and they (CHPs assets) were exempted from ecotax if the electricity was consumed locally and produced with natural gas (Jong, 2004). Ecotax was a tax on energy introduced in 1996 for energy consumers.

However, in a bid to minimise the dependence on power producers by distribution companies, the distribution companies circumvented the process by forming joint venture with industries to develop CHP plants and sell excess power to the grid. Furthermore, due to the emergence of climate change awareness, the government and the electricity sector actors came to an agreement to reduce CO_2 emission through an environmental action plan. The distribution companies identified this as also an opportunity to form joint venture agreements with industries to develop CHP projects with a view to meet their emission targets.

Due to the impact of several governance mechanisms, including the Electricity Act, the contribution of CHP to total electricity production increased from 19% in 1988 to 23% in 1993 (Blok and Farla, 1996). This also resulted to excess capacity from CHPs to the electricity grid leading to planning and monitoring crisis arising from frequency instability and voltage regulation which posed a daunting task to the electricity grid operation (Hekkert et al., 2007, Verbong and Geels, 2007). However, the growth was not stifled, but in an attempt to stem its growth, an eight months moratorium was agreed in 1994 between the power producers and distribution companies to postpone all CHP development above 2MW (Hekkert et al., 2007).

Another vital governance instrument that impacted on the electricity market and by extension the CHP systems was the liberalisation of the electricity market mandated by the Electricity Act of 1998 in accordance to the European Union directive. This electricity act ended the special treatment meted out to CHPs such as special transmission tariff for CHPs and the eradication of FiT for CHP as they were now to negotiate in the competitive market (Hekkert et al., 2007). However, the Dutch government obtained a relieve from the European Commission on noticing that CHPs struggled to cover their marginal cost by introducing some measures. Such as, introducing a feed-in subsidy for CHP electricity supplied to the grid and from 2003, CHPs were granted certificates based on plant efficiency or CO_2 performance under the Netherlands emission trading system, which can be traded. This 1998 Act opened the doors for large European energy companies to purchase power assets from former national and distribution companies such as Noun and Essent, currently owned by Vattenfall and RWE respectively (Deloitte, 2015). The Dutch power production market is slightly dominated by four major players which control about 55% of installed capacity in 2013 – Noun/Vattenfall, Essent/RWE, E.ON, and Electrabel/GDF SUEZ. The transmission network is wholly owned by the government through TenneT, while the distribution network is operated by eight companies with four companies – Enexis, Delta, Liander and Stedin, managing about 90% of the network and the supply/retail arm is 100% liberalised with consumers allowed to choose their supplier (Deloitte, 2015). It is noteworthy that Enexis and Liander are owned by providential and local authorities. Also, consequent upon the new electricity act of 1998, the Dutch Electricity Generating Board was dismantled. The key regulator for the energy sector is Authority for Consumers and Markets (ACM), which are the regulators for gas, electricity and heat.

On CHP, the effect of the liberalisation of the electricity market through the 1998 Act induced a gradual stagnation on the growth of CHPs in the Netherlands with its effect more pronounced around the year 2000. Key causes were the reduced fixed compensation for electricity exported to the grid, fall of market price for electricity leading to many CHPs shutting down during off-peak periods and no incentive for retired CHP plants to be replaced (GasTerra, 2010). In addition, they faced competition from large European energy suppliers (Verbong and Geels, 2007). However, by 2005, it started to show signs of growth again due to the increase in uptake from agriculture and waste incineration sectors with an 84% growth by 2006 from 2005 (Daniëls et al., 2007). Key sector uptake from the agricultural sector were the horticultural companies that adopted CHPs due to the existence of heat buffers and consume some of the electricity produced locally with opportunity to sell the excess to the electricity at peak times. Thus, making it economical for its uptake. This made the agricultural sector as the second most important sector to uptake of CHP after the industries (Daniëls et al., 2007) and becoming a net exporter of electricity from CHP by 2007 (ECN, 2015).

In the Netherlands, CHPs more than 5MW must be registered with TenneT and report the capacity availability on an hourly basis (GasTerra, 2010). Furthermore, no licence is required to generate or supply electricity under the Electricity Act of 1998 apart from off-shore wind. However, if its intended for supply to small scale users of maximum 3X80A, you are then subject to licence requirement by the ACM (Vlam and Oosterhuis, 2016). While, Transmission and distribution of electricity and gas are subject to regulation.

Key actors in the Netherlands CHP-DH sector apart from the ACM are Cogen Nederland, which is Dutch Association for the promotion of CHP, VEMW, the association for energy, environment and water, which has amongst others a strong interest in CHP-DH systems. Others are CertiQ, which is the issuing body for CHP Guarantees of Origin (GoO) that is also linked to feed-in schemes, and the Ministry of Economic Affairs, which is the ministry responsible for CHP policies (IEA, 2008b). Another key actors are EnergieNed – This is the trade association for electricity, heat and gas producers, traders and suppliers and the other is Stichting Warmtenetwerk - The Dutch association for DH and Cooling (DHC) with members drawn from universities, municipalities, utilities, research organisations, consultants, suppliers, and contractors.

The trajectory of diffusion of CHP in the Netherlands does not seem to follow the same path as District Heating, though they both seem to intersect in 1989 after the electricity Act and other governance mechanisms. Historically, the first DH system in the Netherlands was in Utrecht in 1923 and a second one in 1949 at Rotterdam before the next one was built in 1983 (Raven and Verbong, 2007). Prior to the oil crisis in the 70s, heat sector was predominantly supplied by gas due to its abundance and there was little interest from the government to supply heat from the electricity sector (Jong, 2004). However, like in the electricity sector, when government responded to the oil crisis by establishing a CHP committee, a special committee on DH (BAS) was also established in 1974 with members drawn from the utilities, Gasunie and the scientific community. The key focus of the special committee on DH is to investigate the potentials of DH systems and provide support to the local and regional authorities in decision making. This led to the development of 16 DH systems after embarking on about 50 feasibility studies (Raven and Verbong, 2007). This led to the growth of heat supply from DH systems. However, by mid-eighties, DH systems began to lose legitimacy. In part, because of lack of individual metering, sale of heat were below expectation and the fall of energy prices in 1985 (Blok and Farla, 1996). Other factors include the increase in interest rate to as high as 13% that inflated the cost of capital and technical difficulties in the operation of the network (Jong, 2004). Therefore, the operations of DH systems became uneconomical, which impeded the further growth of DH systems in the Netherlands.

Key features of the Dutch energy landscape pre-1989 electricity act was that most DH systems were supplied from large centralised plants (IEA, 2008b) and many of the large electricity plants were owned by the provinces (regional) while the local authorities (municipalities) own the gas distribution companies. Suggesting why local gas companies opposed the development of DH systems, because of path dependencies in the supply of local heat demand (Jong, 2004). Therefore, most DH systems were developed by electricity companies and were struggling to survive during this period. Recent data shows that there was about 400 DH schemes in the Netherlands by 2015 (Euroheat and Power, 2017b).

However, it was the intervention of several key governance measures in the late eighties that changed the DH growth trajectory in the Netherlands. First was the campaign embarked by the district heating association in 1989 for the urgent intervention of government to revive the ailing DH sector (Jong, 2004). The government responded by offering many DH companies financial aids to escape bankruptcy (Raven and Verbong, 2007). Secondly, because of the effect of emission on climate, the government signed environmental agreement to reduce CO_2 with the electricity sector. Consequently, the power producers introduced heat plans focusing on mainly using CHP-DH systems to meets its environmental targets by adding additional 1250MW capacity of CHP, because they consider CHP-DH system as a cost-effective solution to save energy (Jong, 2004). While, thirdly, as part of meeting environmental goals the electricity producers and distribution companies reached an agreement on sharing financial risk in deploying energy saving measures such as CHP-DH systems and lastly the impact of unbundling of the electricity sector through the Electricity Act 1989.The act allowed for horizontal integration of the gas distribution and electricity distribution companies but electricity production had to be separated from distribution (Blok and Farla, 1996).

The introduction of competition in electricity market by the 1989 Electricity Act, also triggered many CHP systems to consider heat demand in their operational strategy. Thus many electricity distribution companies developed CHP-DH systems in cooperation with final heat users, making heat market strategic to CHP-DH developers/operators (Jong, 2004). These measures were considered as stage setting for the revival of DH systems in the Netherlands into the nineties.

The regulation of heat in the Netherlands has been self-regulatory with heat tariff from large energy companies being capped based on Not-More-Than-Otherwise (NMDA) principle – which makes gas as the reference price - as being recommended by the energy association – EnergieNed, this is with a view to protect captive consumers from the DH companies' monopoly position (Oei, 2016, Scheppers, 2009). While heat tariff from smaller suppliers, such as housing corporations are typically based on the actual cost of heat supply being computed by heat cost allocation agencies and most heat suppliers adopt a portfolio strategy by using profits from viable heat grids to compensate for loss-making grids (Scheppers, 2009). The heat sector is vertically integrated even after the electricity act had unbundled the electricity sector.

However, since the liberalisation of the energy sector, The Netherlands had tried to introduce a heat act since 2003 that would efficiently capture the aspirations of heat consumers by replacing the existing self-regulation regime of the heat industry. After several years of deliberation, it was expected to have come into effect by 2011 but it didn't due to some perceived challenges by the DH association. Such as the ownership of meters, which the heat act had allowed heat customers to procure and install their own meter, but the association had protested that customers don't have the requisite expertise to maintain heat meters (Van der Zee, 2011). Consequently, it went for further review until January 2014 before the Netherlands had its first Heat Act came into effect. Key features were obligation for licence requirement to embark on heat supply and tariff regulation. However, it was still criticized by the regulators

(ACM), heat users and suppliers, because it was not seen to have sufficiently captured the role of owner associations in representing/protecting their members (heat end users). Secondly, the lessors of homes were excluded from the heat Act, when most often heat was part of the tenancy agreement with lessees, which may lead to conflict in interpretation of the tenancy laws, consumer protection under the civil code and the Heat Act. (CMS, 2017).

However, after further reviews, a revised Heat Act that may have accommodated these observations and it's expected to come into force by 1 January 2018. This revised bill is also expected to mandate a negotiated access to DH grids as oppose to regulated third party access and provide clarity and protection with regards tenancy roles in a heat supply contract. It's also expected to include a mandatory tariff cap for small end users based on the NMDA principle with opportunities for heat users to terminate supply contract as long as the agreement was entered into after the amendment of the Act (CMS, 2017).

The development of CHP systems in the Netherlands has been described as a success through the deployment of various governance mechanisms that targeted electricity production but the same cannot be said of District Heating (DH) systems. In part, due to early path dependencies of gas distribution companies in the supply of gas for heating (Raven and Verbong, 2007, Hekkert et al., 2007), lack of sufficient legitimacy for DH systems (Jong, 2004) and less priority given to heat in energy policy dialogue until lately (PROVOOST et al., 2015) despite heat demand making up about 55% of final energy consumption in the end-user sector (ECN, 2015a). This suggest why CHP provides almost 35% of total electricity production in 2013 (DG ENER, 2016), while DH supplies about 4% of total heat supply in 2013, in spite of natural gas providing 93% of the total heat supply in 2013 (Euroheat & Power, 2017). Indicating that the growth trajectory of CHP and DH systems in the Netherlands are not coupled, rather, heating is predominantly provided through house hold gas use, while 90% of DH were sourced from recycled heat and direct renewable sources (Euroheat & Power, 2017).

Nonetheless, The National Energy Agreement initiated by the Social and Economic Council (SER) (an advisory board of Dutch government and parliament) was signed in 2013 between various energy actors and government with a view to meet national target as mandated under EU 2020 directive. Part of the Outcome of these agreement with government was that there will be incentives for decentralised generation such as CHP to generate electricity and heat that is locally consumed (PROVOOST et al., 2015). Such as exemption from VAT, system tariffs and energy tax, which may provide a net advantage to a CHP provider of local energy of about 0.23/kwh (Vlam and Oosterhuis, 2016). Also of important note is the significance of CHP in the Netherlands 2020 emission target, which CHP has been estimated to contribute about 16% to the national reduction objective (GasTerra, 2010). Suggesting that the National Energy Agreement is the first join-up governance instrument that attempts to capture electricity and heat production, but it's not clear if DH was sufficiently captured.

4.2 Norway

Norway is the largest gas producer in Europe (Deloitte, 2015) and is one of the few countries in the world with enormous renewable energy potential such that in 2015, 98% of its electricity generation was from renewable energy, which includes:- 96% of hydro and 2% of wind energy (ENOVA, 2017). Drawing upon the history of CHP-DH system in Norway that dates to first half of the twentieth century, the first thermal power plant was installed in 1936 but it was not until in 1950 that the Prestegata district heating centre supplied heat to the city hall in Oslo (nfv, 2017).

Norway is known to historically be endowed with hydro potential, though during the 60s to the very early 70s fossil fuel contribution to household energy consumption was as much as 40% (Boeng and Holstad, 2013), but in response to the global oil crisis in 70s which led to increase in energy prices, the government considered to explore more hydro potential in a view to stem the effect rising oil prices. Consequently, there was rise in river development and construction of dams, leading to wide spread condemnation from environmentalist that resulted in the developmental plan to identify rivers to be preserved and or not by the parliament in 1973 (Eikeland, 1998). This has contributed to the national position to currently develop 60% of its hydro potential, preserve 20% and reserve 20% for small scale development (Hagos et al., 2014). However, the oil crisis herald the beginning of the largest hydropower development in Norway with an increased capacity of 10,715MW hydro capacity from 1974 – 1989 (Boeng and Holstad, 2013).

Hydropower development has been burdened by various governance instruments instigated by environmentalist. Such as the 1979 White paper, which emphasised on the rational management of natural resources, then subsequently, the 1985 White paper that highlighted the need to consider the impact of electricity production on the environment in future energy policy (Eikeland, 1998). This was closely followed by the 1988 White paper which suggested that electricity industry could contribute positively to the environment, if energy saving measures were deployed. However, none of these instruments disrupted the electricity industry as much as when request for liberalisation and competition through a market based trading system joined the energy policy debate. In part, because non-government actors, for example - academic economist, accused the government of taking advantage of the publicly owned vertically integrated electricity sector to set energy prices and leading to development of excess capacity (Eikeland, 1998).

In response to the call for liberalisation and competition in the electricity sector, which had already begun to sweep through Europe, for instance the electricity liberalisation in UK, the 1990 Energy Act was introduced that instigated reforms to the electricity and heat sectors in Norway. The reform essentially came into force by the 1st of January 1990 and its key objective was efficient production of energy as an effective way to increase efficiency in the electricity sector through market based mechanisms. This led to the altering of the governance structure and introduction of competition in the electricity sector. A new high-tension transmission grid operator/manager – Statnett- was established, while the power production and distribution arms of the electricity sector were still mostly owned by municipalities with some privately owned utilities (Newbery, 2001a pg: 177). This is with a view that all utilities (public and private) will be competing in the same electricity pool managed by Statnett, with the municipalities still retaining their franchises for area of operation. The energy act also stipulates that prospective actors require a licence to participate in electricity areas depending on the size of electrical output. For instance, less than 1MW output, a licence will be provided by municipalities, less than 10MW output, it would require a licence from Norwegian Water and Energy Directorate (NVE), while over 10MW would require a licence from the king's council (NMPE, 2015). Currently, the state, county authorities and municipalities own about 90% of power production capacity, with limited ownership from foreign investors and the ten largest producers account for about 72% of national power production (NMPE, 2015).

Sequel upon the introduction of the Energy Act, a moratorium was applied to the development of hydro dams and abolition of area franchises for municipalities with a view to curtail excess hydro production and further entrench competition (Eikeland, 1998). By 1996, an integrated power system between Norway and Sweden had begun, with joint power exchange pool known as the Nordpool with the options to electricity consumers to choose their suppliers. However, due to the long dry season of 1995 and 1996, resulting in much of Norway's hydro capacity being tapped, this instigated the government to begin to contemplate an alternative source of power generation from natural gas plant considering Norway's huge gas reserves, in addition with further exploration of hydro resources. Consequently, two natural plants were approved by the parliament to be developed, but change of government, obligations under the Kyoto protocol and stiff opposition from environmentalist did not allow these projects to be executed (Eikeland, 1998). Furthermore, increased taxes on fossil fuels and Gothernburg Protocol which emphasises on air pollution, may all have impacted on the poor legitimacy of fossil fuel based plants (Boeng and Holstad, 2013). In part because it was argued that these natural gas plants would add to Norway's carbon footprint.

Therefore, historically, due to the huge hydropower capacity which often provides low energy prices, electricity heating and other regulatory mechanisms on fossil fuel based generation, the contribution of CHP has been insignificant to Norway's energy profile. However, available data suggest that CHP contribution has increased from 0.08% to Norway's gross electricity production in 2006 to about 0.28% in 2015 (Eurostat, 2017). This increment could partly be attributed to a few governance instruments that may have impacted on CHPs. Such as investment supports for renewable CHPs from Enova – A government agency supporting new technology advancements and supports from the Research Council of Norway that offer supports for research and development to CHPs to improve industrial development (Kempegowda et al., 2012). Despite the little increment seen in the growth of CHPs in Norway, she has being the largest gas producers in Europe (Deloitte, 2015), CHP technology was still seemly not considered as vital in the energy policy debate as even the recent green certificate market between Norway and Swedish electricity market started in 2012, renewable based CHPs in Norway were absent with only hydro and wind being considered. Therefore, no capacity from CHPs was expected or entitled to electricity certificate from Norway, while Sweden had captured CHP in the same scheme (NVE, 2017, NVE, 2014). Suggesting that the role of CHPs in Norway's energy profile may continue to be insignificant.

However, the technology trajectory of DH systems in Norway seems to be better favoured by various governance interventions, even though it still represents a small proportion of 3% of the total energy consumption in Norway (NMPE, 2015). This low penetration of DH systems is still attributed to the huge hydro resources which provides low electricity prices and electric heating. Nevertheless, the recent rising prices of electricity and commitment to meet several climate change goals, such as carbon neutrality by 2030 (Patronen et al., 2017) has greatly influenced the governance led penetration of DH systems. Key governance instrument was the 1991 Energy Act, which introduced several measures that impacted on the selection environment of DH systems in Norway. The energy act, provided the framework for construction and operation of DH networks, as well as requiring DH developers to apply for a concession to develop one in an area that has been earmarked for DH by the municipalities. Furthermore, the act allows for DH companies with an output of over 10MW to obtain a licence from NVE (NMPE, 2015) and it also stipulates the pricing structure for heat from DH systems, which emphasis that the price of heat should not be higher than alternative heating source, which is usually referenced to the price of electric heating in the case of Norway. Sequel upon the approval and development of DH systems in a concession area, the municipality would then issue directives for any building built within the DH marked areas to mandatorily connect to the DH network. However, buildings that are mandated to connect to the DH systems are not obliged to use the heat supply from the DH network, but are also free to enter into heat contracts with other heat suppliers. Though, other heat suppliers are not allowed to develop new heat networks as there can only be one DH network in a concession area (Patronen et al., 2017, Aanensen and Fedoryshyn, 2014). The DH suppliers consider these mandatory connections as critical to their economics.

The mandatory connections to DH is being regulated by the Planning and Building Act (P&B). This act (P&B) also places a limit on buildings on heat generated from electricity and fossil fuels. For instance, all buildings of over 500m^2 should have a minimum of 60% renewable heating, while buildings below 500m^2, should have a minimum of 40% renewable heating. The P&B act also stipulates a ban on fossil fuel generated heat on all new and renovated buildings (NMPE, 2015, Juhler, 2013). Thus, stimulating the use of DH systems to provide heat for buildings. The combination of these governance mechanisms (Energy Act and P&B Act) and the ban on waste landfill in 2009, which stimulated the development of waste incineration plants to provide heat to DH networks, may well contribute to the significant uptake of waste fuel for input to DH, as about 50% of DH inputs came from waste incineration in 2016, with waste wood providing 21% (SN, 2017a). Considering that many DH operators see waste fuel as competitive to the electricity prices for heating, which may impact on the selection environment of heating sources by consumers.

Other governance measures that seeks to influence the penetration of DH systems are some fiscal and regulatory measures adopted by the government. Such as the Energy fund established in 2012 and being administered by Enova SF, a state company owned by the Ministry of Petroleum and Energy (MPE). The source of the energy fund is from budgetary allocation from the state, levy on grid tariff and returns on the capital invested in projects (NMPE, 2015). One of the key objectives of the energy fund is to increase the use of energy carriers like DH for heating other than the use of electricity, oil or natural gas and its modus operandi is to provide funding support for projects like DH heating from renewable energy sources. In 2016, 22 DH projects benefitted from the energy fund with many application are for the expansion of already existing schemes and the scheme is expected to run till 2020 (ENOVA, 2017). Other fiscal measures include: the electricity tax for electricity used for energy production and DH production, which has been reduced in 2017 from 16.32øre/kWh to 0.48øre/kWh (Patronen et al., 2017).

The DH sector in Norway has been growing steadily since the introduction of the energy act in1991 with an average growth of consumption of DH of about 9% since 2000 (Patronen et al., 2017). However, the last 10 -15 years had witnessed the most significant growth (Aanensen and Fedoryshyn, 2014) with the net DH production increasing over 95% from 3066GWh in 2007 to 5910GWh in 2016 (SN, 2017c). DH companies also increased by over 167% from 40 in 2007 to 107 in 2016 (SN, 2017b). This growth can largely be attributed to various governance instruments, rising price of electricity and environmental goals through renewable generation of heat. The largest consumers of DH are the service (60%) and residential (25%) sectors in 2016 (SN, 2017a). These two sectors accounts for an average of 87% of total DH consumption from 2000 – 2015 (Patronen et al., 2017). Recent data shows that there were about 261 DH schemes in Norway by 2015 (Euroheat and Power, 2017b).

DH schemes in Norway are mainly owned by the municipalities with Oslo having the largest DH scheme (Juhler, 2013) and about 90% of the major cities have DH systems (ENOVA, 2017). The key actors in the CHP-DH sector are (a) the Ministry of Petroleum and Energy responsible for overseeing the overall energy policy, (b) Norwegian Water and Energy Directorate (NVE) – the energy sector regulator for electricity and heat. Others are (c) ENOVA – responsible for promoting environmental friendly technologies (d) Norsk Fjernvarme (Norwegian District Heating Association) – responsible for advocacy for DH systems, (e) Ministry of Local Government and Modernisation – responsible for the regulation of mandatory DH connections (Patronen et al., 2017).

In Norway, CHP and DH growth are not coupled as DH appears to have more focus from government than CHP. In part, because of the historical dependence on hydro resources for generation of electricity and heat, despite its huge gas reserves and secondly, CHP is considered to be mostly fuelled by natural gas, which is not attractive to environmentalist considering its carbon footprint. Thus, systematically locking out CHP from key energy governance mechanisms. However, the energy debate appears to lay emphasis on using renewable sources to provide alternative heating for Norway, resulting in increasing use of renewable fuel such as waste for DH and other governance mechanisms to influence the penetration of DH systems. This suggest that the pillars of Norway's energy policy are energy efficiency and environment commitments.

4.3 Brief Comparisons

The two countries (Netherlands and Norway) both appears to have been stimulated by the oil crisis to change its overall energy policy direction, though each taking a different path. For instance, Netherland choose to establish different commissions in response to the oil crisis for heat and CHP diffusion, while Norway decided to ramp up development of hydro power stations. However, it was not until the wave of liberalisation and competition in the energy sector started in Europe, which was led by the UK, that both introduced key governance instruments that disrupted the electricity and heat sectors. Netherlands introduced separate governance pathways for electricity and heat, though heat was in the back foot as a result of path dependency of gas heating. While Norway, had an integrated approach through an energy act, which attempts to capture electricity and heat sectors, but with minimal recognition of CHP contribution to electricity due to the dominant electricity production from hydro.

A key distinction between the two countries was also the role of municipalities in planning of DH zones within their localities. There was little information on the roles of governance instruments in planning of DH zones by municipalities in the Netherlands and there were no mandatory connections to DH systems. However, in Norway, using the Planning and Building Act, municipalities could map out concessions areas for DH systems and mandate connection of new buildings to DH systems. Another distinction was that the Norway CHP-DH sector was driven by the public, as the state and municipalities own a large proportion of energy companies, while in the Netherlands, the private industries and horticulturist played a significant role in the uptake of CHP-DH systems as well as the municipalities.

FACT SHEET

#	Characteristics	Netherlands	Norway
1	Electricity Act/Energy Policy	Electricity Act	Energy Act
2	Heat Law/Planning and Building Act	Heat Act 2014	Planning and Building Act
3	Energy system drivers	Gas	Hydro
4	Regulatory mechanism for renewable CHPs	FiT	Nil
5	Dominant fuel used for Electricity production	Gas	Hydro
6	Dominant source of heating	Gas	Electricity
7	Dominant fuel used for CHP	Gas	Renewables
8	Dominant fuel used for DH	Renewables	Renewables
9	CHP to electricity production	35%	0.28%
10	DH contribution to heat production	4%	3%
11	Ownership of CHP and DH systems	Private/Public	Municipalities
12	Dominant DH uptake sectors	Industries and Agriculture	Service and Residential
13	No of DH schemes by 2015	400	261
14	Heat pricing	Referenced to gas	Referenced to Electricity

A similarity between the two countries was that the dominant fuel for DH was renewables, despite both countries large gas reserves. In Netherlands, this was due to strategic position of gas in delivering heating to household through mature gas infrastructure. While in Norway, environmental consideration such as its carbon neutral ambition, was critical to the insignificant role of gas in its heating sector. Furthermore, both countries have similar heat pricing methodology, as they both have a policy that the heat price should not be more than the alternative source of heating. DH output was referenced to gas price in Norway, while it was referenced to electricity price in Norway.

Furthermore, both countries energy policy was driven by liberalisation and competition, but the environmentalist in Norway exerted much more pressure on the government to chase energy liberalisation and competition with much focus on environmental goals. Which persistently seem to be locking out the local role for gas in national energy debate. However, the Netherlands had more consideration on energy efficiency alongside environmental goals, while promoting liberalisation and competition in the energy sector. Therefore, the role of gas in providing efficient energy through CHP-DH systems was captured in the long term environmental goals in the Netherlands.

Summarily, the Netherland's CHP-DH diffusion pathway appears a better choice to draw lessons from because of the potential applications or adoption of lessons that may impact the socio-economic fabric of the UK. For instance, the UK has a similar mature gas infrastructure like the Netherlands, which is the primary source of heating and therefore impacts on the selection environment of CHP-DH system as an alternative heating source. While in Norway, electricity from hydro power stations is the incumbent source of heating. Secondly, it's not likely that the mandatory connection to DH systems as stipulated by the planning and building act in Norway in concession areas shall be applicable in the UK.

5.0 European Union & UK Governance Mechanisms on CHP- DH system and LA Engagement

5.1 European Union Policy Drivers of CHP-DH systems

The modern European Union's energy policy crux can be said to be founded on the desire of the commission to have a single integrated energy market flow from the Single European Act (SEA) that was signed in 1986 and came into effect in 1987 (EU, 1986). However, the SEA at its inception did not include electricity, gas and heat but rather focussed on energy resources, reinforcing the European Coal and Steel Community and the European Atomic Energy Community with its focus on nuclear energy. Partly due to the un-interconnected nature of the grids within large part of the EU and vertical ownership structure of these assets by national champions like EDF in France, in the 12 member states including Denmark as the only Scandinavian country as at 1986. Nonetheless after several working papers and directives, the Maastricht treaty of 1992 eventually led to the emergence of electricity and gas directives of 1996 and 1998 to promote internal energy market (Langsdorf, 2011) and the 2007 Trans-European Networks (TEN) initiative to create synergies of energy grids (electricity supplies, oil, and gas pipelines) of member states (Davies, 2013).

Furthermore, the Kyoto protocol adopted EU-wide in 1997 also influenced other policy levers like the 2001 Renewable Energy Directive (2001/77/EC) and the 2003 Emission Trading Directive (2003/87/EC) with a view to reduce emissions. This stirred the convergence of energy and environment in the EU energy policy spectrum until in 2007 when the first energy action plan was introduced to improve security of energy supply, sustainability, and competitiveness across the continent through a set of strategies known as Energy 2020 strategy; which some consider as the foundation of modern EU energy policy (Langsdorf, 2011).

This Energy 2020 strategy entails 20% reduction of Green House Gases (GHG) below 1990 baseline by 2020, increase energy consumption from renewable energy sources by 20% and a 20% increase in energy efficiency by 2020, which has been adopted by member states (Fabrizio, 2013) . Each Member State has a national target, with the UK bound to achieve a target of 15% of its energy from RE by 2020. The UK Government has stated it will aim to achieve this with three sub-targets, 30% of electricity demand, 12% of heat demand and 10% of transport demand from RE (DECC, 2009).

Another key deliverable from the energy action plan was the EU's Third Energy Package (TEP) introduced in 2009 which heralded several governance mechanisms focused on the electricity and gas industries such as the formation of European Network of Transmission System Operators – Electricity (ENTSO-E) currently representing 42 transmission network operators from 35 countries. The key features of the TEP are a competitive and integrated energy market amongst member states. TEP covered five broad areas, which includes unbundling of energy (electricity and gas) suppliers from network operators; improve cooperation amongst grid network operators, establishment of ACER

(Agency for the Cooperation of Energy Regulators), increasing the independency of regulators and transparency in retail markets (Dutton, 2015). However, climate change activists criticised the TEP for not doing enough to unbundle the energy industry in EU (Langsdorf, 2011).

Nonetheless, there are several other governance mechanisms which may impact on the penetration of CHP-DH systems as shown in Table 2 below. These include:

	Directives	Objectives
1	Cogeneration - Combined Heat and Power (CHP) Directive 2004/8/EC	It seeks to promote high-efficiency CHPs based on 'useful heat' demand which is defined as the heat generated from CHPs that meets a specific heat demand (EU, 2004)
2	Renewable Energy Directive (2009/28/EC)	It mandates member states and LAs to evolve mechanisms or administrative ways such as planning to promote electricity and heat production and adoption of DH and cooling from renewable sources to meet the 20% renewable energy sources (EU, 2009a)
3	Energy Efficiency Directive 2012/27/EU	It seeks member states to undertake a detailed assessment of CHP, DH and cooling potential with a view to deploying governance structures including heat maps to cost effectively deploy them and encourage developers of power plants above 20MW capacity to consider CHPs (EU, 2012).
4	EU Emission Trading Directive (2003/87/EC)	This directive introduced an EU Emission Trading Scheme (ETS) aimed at reducing GHG emission through promoting the use of more energy efficient technologies including CHPs. It is a cap and trade mechanism that targets energy intensive industry with more than 20MW thermal input. Facilities receive tradeable emission allowances (EUA) provided by the

		member states and can trade excess permits to those with a shortfall.
5	Energy End-use Efficiency and Energy Services (Energy Services Directive) Directive 2006/32/EC	This directive sought to promote the use of ESCO "Energy Service Company" to implementing energy services (EU, 2006c), which the CHP-DH industry hugely benefits from as one of the key governance structures to develop and manage CHP-DH projects (Werner and DHCAN, 2004).
6	European Energy Performance of Buildings Directive2010/31/EU	This directive seeks member states to promote the use of alternative energy systems such as DH systems that would reduce the energy needs of new buildings for heating and cooling to a cost optimal level and also increase the number of nearly zero-energy buildings (EU, 2010a).

Table 2: EU governance mechanisms that may impact on CH-DH systems

Additionally vital policy frameworks that may impact on CHP-DH system are the 2008 adoption of the "green paper towards a secure sustainable and competitive European energy market" to define the scope of the TEN - Energy to encompass the full energy transportation network (Davies, 2013). Which includes, gas, LNG terminals, underground storage, electricity transmission network and oil pipeline. However, heat network was not captured in the TEN-E initiative. Additionally in 2009 a revised version of the energy action plan was introduced in the energy roadmap 2050 with a view to reducing emissions by 80% by 2050 compared to a 1990 baseline through promotion of renewable energy sources for electricity, heating and cooling by synthesizing various scenarios and competition (EU, 2010c). However, none of these scenarios involved the large-scale implementation of district heating, but instead focused on the electrification of the heating sector (primarily using heat pumps) and/or the large-scale implementation of electricity and heat savings (Connolly et al., 2014). Suggesting that the EU may not have evolved a joined-up policy framework for CHP-DH systems.

5.2 Governance of CHP-DH in the UK

Governance is entrenched through governance mechanisms or instruments (Levi-Faur, 2012 pg:13) that stimulates motivation for interaction that is sufficient to direct firms to the market, with the expectations of meeting actors' specific vision and targets. These mechanisms are expected to lead to the development, diffusion and utilization of the technology and influence the direction of growth of the technology (Bergek et al., 2008b). Governance mechanisms should have certain characteristics or outcomes which are intended to meet the desired goals of the policy formulator and stakeholders. These include amongst others, incentives to potential developers through guaranteed income, elimination of barriers to grid connection and market at reduced administrative cost, and it's publicly accepted (Mendonça, 2007 pg:xvii). These mechanisms could be regulatory, market or public/private partnership driven (Hillman et al., 2011, Nilsson et al., 2012)

Governance mechanisms that may impact on the development and penetration of CHP-DH systems in the UK can be broadly divided into five components namely, fiscal mechanisms (tax exemptions and rebates), financial/investment incentives (loans and grants), obligatory schemes (obligation on suppliers), price support (FiT, tendering/auction) and quantity obligation (renewable obligation certificates). Johnstone et al. (2010) had argued that investment incentives which also includes third party financing and investment guarantee may be more efficient in inducing innovation for high fixed cost RES technologies such as CHP-DH systems. However, with increasing use of combinations of mechanisms for example the average use of mechanisms per country in the EU is about 3, this has shown more efficacy in inducing innovation of RES (Kitzing et al., 2012). In part because technologies respond differently to mechanisms in relation to their technological and commercial maturity and policy expectations as suggested by Johnstone et al. (2010). Hence a further narrative on the various governance mechanisms in both the electricity and heat sectors deployed in the UK that may impact on CHP-DH systems and the impact of local governance structure on its penetration.

5.3 Electricity Governance Mechanisms

The UK has deployed several governance mechanisms in the electricity sector to meet its renewable energy milestones that encapsulate energy security, sustainability and affordability over stipulated periods of time. As highlighted earlier these mechanisms with respect to the electricity sector has taken different shapes and the narrative below shall attempt to discuss them with a view to highlight the interaction with CHP-DH systems in the UK.

5.3.1 Renewables Obligation (RO)

The RO is a quantity obligation mechanism that required energy suppliers to present evidence that they had procured a certain volume of renewable electricity for every MWh to be determined by Secretary of State of Energy, through submission of Renewable Obligation Certificates (ROCs) to the regulator, Ofgem.

The RO has been modified several times. Its initial conception was to be a technology neutral scheme because Government didn't want to be seen as 'picking winners' (DTI, 2001), therefore allowing suppliers to choose from any technology, but this was rapidly failing as less established technologies, at least some of which were essential to meeting UK RES-E targets were systematically priced out from the mechanism (Wood and Dow, 2011). Additionally other systemic failures were observed in the scheme, such as volume risk imposed by the annual limits and sale of future power, excessive price uncertainty induced by competition, NETA/BETTA arrangement that aggravated the balancing risk due to RE plant intermittency, and market risk due to price volatility over the life of the scheme (Mitchell and Connor, 2004, Lipp, 2007). Further reviews of the RO were made to include banding of technologies and mitigate other risk such as introduction of guaranteed head room of about 8% gap between expected renewable output and the obligation level (Woodman and Mitchell, 2011).

In 2012 the banding was further reviewed to include other technologies like the biomass conversion with CHP and enhanced co-firing of biomass with CHP. There were reductions in the number of ROCs for some other technologies like co-firing of biomass with CHP (standard) and Co-firing of energy crops with CHP (standard) (Table 3). A key point to note in the 2012 banding regime is that after April 2015, new CHP entrants won't be able to be part of the RO, though this holds for all RES-E as the RO is being superseded by Contracts for Difference (CfD) mechanism.

CHP Types	**ROCs/MWh**		**Comments**
	Year of modification 2009	**Year of modification 2012**	
	2010-2014	**2013-2017**	
Waste with CHP	1	1	
Co-firing of biomass with CHP (standard)	1	1.5	Unit by unit approach and close band by April, 2015
Co-firing of biomass with CHP (enhanced)	NA	1.5	Unit by unit approach and close band by April, 2015
Co-firing of energy crops with CHP (Standard)	1.5	2	Band to be closed subject to consultation and close to new entrants by April, 2015
Dedicated energy crops with CHP	2	2	This would regress to 1.9 in 2015/16 and 1.8 in 2016/17
Dedicated biomass with CHP	2	2	Close to new entrants by April, 2015
Biomass conversion with CHP	NA	1.5	Close to new entrants by April, 2015

Table 3: CHP Technologies to benefit from renewable obligation

Source:(DECC, 2012f)

However, these modifications of the RO scheme did not seem to mitigate the inherent failures associated with the scheme. Firstly, the balancing risk that arises from the current complex BETTA arrangement places high cost of membership and penalties on intermittent generators and reinforces the lock-in of the large plants. This balancing risk drives small generators to sign contracts with consolidators or suppliers at a premium of either shearing embedded benefits or reduced market rate. Secondly, the impact due to delay in planning approvals and lack of grid access can greatly impact on renewable CHPs leveraging on the RO as there is no guaranteed connection to the grid (Wood and Dow, 2011). Thirdly, in modelling the RO banding, the input parameters were capital cost, operational cost, cost of capital, capacity limits and capital grants (OXERA, 2007). While the outputs were levy exemption certificate (LEC), electricity prices and ROC as revenues, but they didn't recognise additional revenues that could accrue to a CHP developer such as heat. In part, because heat has been considered as a by-product, indicating the impact of revenue from heat was not fully captured. The non-evaluation of the revenue risk completely could have also led to CHPs not appropriately allocated the desired ROC value and some cases reduced ROC from 2010 banding value such as co-firing biomass CHP. The uncomplete allocation risk is compounded by the fact the trading arrangement does not still internalise the externalities of electricity exports such as carbon reduction from CHP-DH systems. Thus the revenue flows of CHP generators still don't reflect the environmental benefits of reduced CO_2 emission. This is partly due to the usual practice of policy makers not to fully converge the cost risk with the revenue risk, which is typically presented as a business case to an investor (Gross et al., 2010).

Lastly the constant review and changes of the RO mechanism would suggests policy uncertainty, with the RO scheme suffering an almost annual changes since inception (Woodman and Mitchell, 2011). Policy uncertainty is perceived as a risk especially for new entrants under the RO scheme (Wood and Dow, 2011), which would leave CHP developers struggling to put up a financial forecast for the economic life of the system, hence may attract a premium from financers or equity holders.

However, the Feed-in-Tariff (FiT) mechanism was introduced to help mitigate some of these risks for small capacities while the Contract for Difference (CfD) will be introduced to replace the reformed RO for large renewable capacities on a longer term, but the narration below would highlight how far these risks have been militated against or reduced.

5.3.2 Feed-In Tariff (FiT)

The Feed-in-Tariff (FiT) mechanism is a price support mechanism that guarantees a fixed price for each unit of electricity produced by eligible RES-E. The UK FiT is available only to specific RES-E technologies below 5MW, namely: microCHP, anaerobic digestion (AD), hydro, solar photovoltaic (PV), and wind. FiT mechanisms typically grant priority grid access to RES-E generators to feed in their power at a fixed price with a view to accelerate technological penetration to a point of commercial maturity (Mendonça, 2011). The thrust of the UK FiT is to provide price and market certainty to generators with a cap of 5MW for eligible installation with an estimated rate of return of 5-8% over the life of the project (DECC, 2009b).

The scheme was the only support for <50kW generators while those above 50KW to 5MW had the option to choose between the RO or FiT scheme. The scheme provided about 1.2% (3.8TWh) of renewable electricity to the total electricity production in the UK (299.2TWh) during 2014-15 (Ofgem, 2016b). However the technologies covered under the FiT scheme suggest that the scheme may not have a significant impact on CHP-DH systems. In part because microCHPs are more akin to providing energy to individual buildings (Hawkes and Leach, 2008b) than a multi building, which could be considered the remit of larger CHPs. Secondly, the policy thrust of the FiT mechanism is also to drive energy efficiency in energy use by rewarding self-generation rather than seeing it as any other investment (DECC, 2009b). Hence the UK FiT scheme may have little significance on CHP-DH systems.

5.3.3 Electricity Market Reform

In 2012 the UK introduced the Electricity Market Reform (EMR) policy with its objective of attracting investment into low carbon technologies to meet climate change targets, while securing the supply of electricity at a minimal cost to tax payers as the UK seeks to meet the overall energy target moving forward to 2050. EMR is a mixed policy bag of regulatory and economic incentives. It's encapsulated into four policy mechanisms, namely: Contract for Difference (CfD), Capacity Market (CM), Carbon Floor Price (CPF) and Emissions Performance Standard (EPS).

5.3.3.1 Contract for Difference (CfD)

CfD is a price support mechanism delivered through auctioning introduced by the UK Government with the objective of militating against volatile wholesale electricity prices by reducing investment risk to renewable energy generators through a top-up on the electricity market price to a pre-agreed amount known as the 'strike price'. This means generators would receive revenue for selling their electricity into the market plus an additional payment when the market price is below the strike price as shown in Figure 8. Conversely if the market price is above the strike price, the generators pay back the difference.

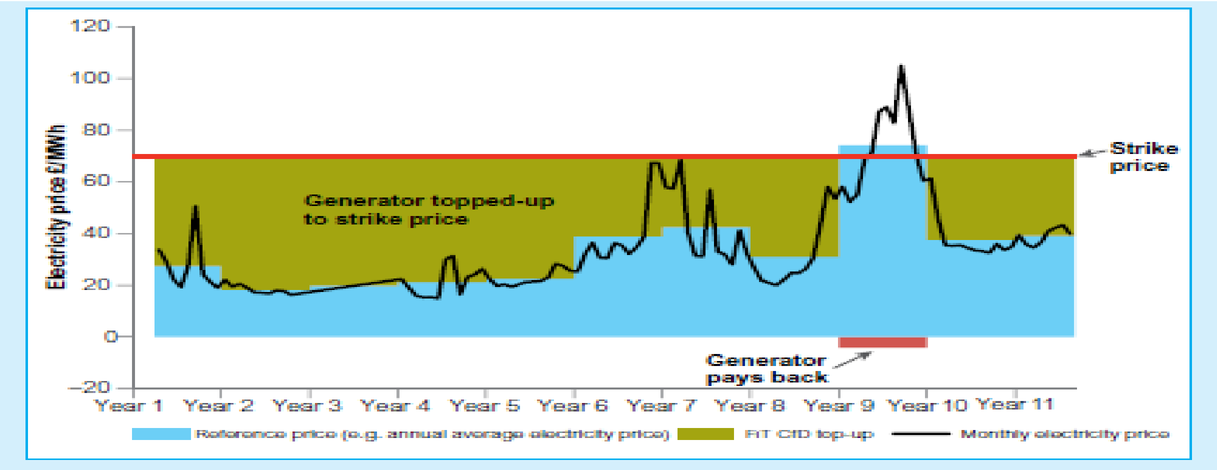

Figure 8: Operation graph of the CfD

Source:(DECC, 2012d)

Key features of the CfD scheme is that, it's a multi-unit, sealed bids and uniform price auction (Fitch-Roy and Woodman, 2016). Indicating that bidders through multiple bids can adjust their strike price depending on capacity or delivery year in a sealed manner with the last accepted offer below the maxima capacity or administrative strike price becoming the uniform price for all successful bidders in a given delivery year commonly referred to as pay-as-cleared (OXERA, 2014). The CfD is banded into three groups: established technologies, less established technologies and biomass conversion as shown in Table 4 with Government recently revising delivery period from 2020 to 2026 (DBEIS, 2016b).

Table 4 below shows the various technologies that shall benefit from the CfD scheme and bands of strike prices

Pot 1 (Established Technologies)	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**
Energy from Waste (with CHP)	80	80	80	80	80
Hydro	100	100	100	100	100
Landfill Gas	55	55	55	55	55
Solar PV>5MW	120	120	115	110	100
Onshore Wind	95	95	95	90	90
Sewage gas	75	75	75	75	75
Pot 2 (Less Established Technologies)	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**
Advanced Conversion Technologies (With or without CHP)	155	155	150	140	140
Anaerobic Digestion (with or without CHP)	150	150	150	140	140
Dedicated Biomass (with CHP)	125	125	125	125	125
Geothermal (with or without CHP)	145	145	145	140	140
Offshore Wind	155	155	150	140	140
Remote islands Onshore Wind				115	115
Tidal Stream	305	305	305	305	305
Wave	305	305	305	305	305
Pot 3 (Biomass Conversion)	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**
Biomass Conversion	105	105	105	105	105

Table 4: Strike prices for renewable technologies (£/MWh)

Source: (Grant Thornton and Pöyry, 2015b)

The scheme is to be funded by consumers through suppliers but a budgetary framework of determining the yearly allocation is done by the Secretary of State under the Levy Control Framework (LCF). National Grid shall administer the scheme, with the Electricity Settlement Company (ESC) to process payments but a separate company, the Low Carbon Contracts Company Limited (LCCC), as its implementation coordinator. The basic qualification requirements to participate in the auction are planning consent, a grid connection offer, incorporation detail, to be non-beneficiaries of RO, FiT and capacity mechanism schemes. Plants above

300MW must show evidence of a supply chain (Grant Thornton and Pöyry, 2015b). Which is an evidence that applicants with over 300MW low carbon electricity generation, has documentation showing plans of contributing to development of skills, innovation and competition in the low carbon electricity market (DECC, 2015n).

The CfD is an attempt to reduce or eliminate some of the perceived risk exhibited in the RO, such as price uncertainty, carrying of ROCs and discounts applied to only the wholesale electricity price and not the entire revenue stream (DECC, 2013i). However, other forms of risk may emerge, such as the linkage of the funding of the scheme to the treasury which is dependent on the fiscal policies from the treasury. Qualification risk may also emerge, it has been suggested CfD may favour large incumbent developers with the financial muscle to get faster grid connection offers and planning consents with construction/delivery risk of new projects on strict time lines (Grant Thornton and Pöyry, 2015b). However, investors are able to choose between CfD and RO during the transition years 2014/15 – 2016/17.

The first round of CfD auction awarded in February, 2015 was for a total of 2.1GW capacity across 27 projects with about 4% (94.75MW) from energy from waste with CHPs (DECC, 2015r). The next round of auction is slated to be in November, 2016. However the scheme was burdened with delays and uncertain schedules, partly as a result of Governments underestimation of the complexity of the scheme and an initial non-engagement with stakeholders (Grant Thornton and Pöyry, 2015b).

A more elaborate discussion on the impact of the CfD auction process on CHP-DH system was undertaken in chapter 9 of this research work in responds to a research question.

5.3.3.2 Capacity Market Mechanism (CM)

Capacity mechanism is one of the corner stones of the government electricity market reform regime. It seeks to provide security of supply of electricity to the grid and ensure system stability as the grid may experience a potential closure of about 14GW of existing plants by 2020 (HoC, 2015). In part because of increasing low profit for gas plants due to market uncertainty, ageing of nuclear plants and regulatory pressure on coal plants by the EU's Large Combustion Plant Directive (LCPD) forcing closure of older coal plants (Ofgem, 2013c).

The main objective of this mechanism is to incentivise sufficient investment in the reliable capacity required to meet demand (DECC, 2013i). The CM auctions contracts every four years ahead of year delivery of capacity (this is known as T-4). A second, annual auction is held one year ahead (known as T-1) with Demand-Side Response (DSR) from 2016. The scheme after an initial delay held its first auction in December 2014 and another in 2015.

The scheme is to provide capacity through the following routes, which includes new plants, existing plants, electric storage, new and existing DSR and interconnection, which were all segregated into three distinct groups for contracting as shown in Table 5. While the cost is to be passed on to consumers through electricity suppliers, but its budgetary framework is still under the LCF.

However the Government plans to set a separate budget for the Capacity Market when there is greater certainty on the size of the costs involved (HoC, 2015). Similar to CfD, the scheme is to be administered by System Operator, NG, with Electricity Settlement Company (ESC) providing settlement of invoices to both suppliers and Capacity Market Units (CMUs) similar to the function of Elexon in the electricity market. While Ofgem will provide dispute resolution between NG and the CMUs, and own and manage the CM rules after the first auction (DECC, 2014k).

Contract Duration	Type of Plant	Price Cap
1 Year	Existing	£75/KW/Year
3 Years	Refurbished	£125/KW/Year
15 Years	New Build	£250/KW/Year

Table 5: Fee Bands of CM commitment to electricity consumers

Source: (NG, 2016a)

Two separate auctions were conducted by NG in 2014 and 2015. Table 6 breaks down the clearing prices and capacity procured is both auctions. Following a consultation of these two auctions, the Government will introduce some changes to the CM, bringing forward another auction to January 2017.This is partly due to the impact of construction/delivery risk to the scheme as there is beginning to be signs of some plants backing out of the capacity agreement and opting to pay the penalty instead (DECC, 2016c). Consequently the termination fees and credit cover for the scheme has been increased and plants that fail to deliver from two years of award will be now be disqualified from future capacity auctions (DECC, 2016c).

This suggests that the scheme could already be showing signs of "missing money" syndrome (Joskow, 2013), whereby price caps have disincentivised bidders as the prices may be suppressed to attract awards.

	Clearing Price (£)	Awarded Capacity (GW)	Total Auction Entry (GW)	CHP & Autogeneration awarded (%)	CHP & Autogeneration that exited (%)
2014 T-4	19.40	49.3	64.96	8.6	3.45
2015 T-4	18.00	46.35	57.72	9.07	0.56

Table 6: Performance of CHP at the two CM auctions

Source: (NG, 2015a, NG, 2015d)

CHPs between 2- 50MW are eligible to participate in the CM auction scheme, recognising CHPs ability to provide dedicated generation for a specified period of time. Further, smaller CHPs units can aggregate and present a joint output to collectively provide 2MW of capacity as a CMU. CHPs can also participate in the demand side response (DSR). However they are inhibited from participating if they are already beneficiaries of RHI, FiT, CfD, RO, long term STOR (Short Term Operating Reserves) or any other low carbon support governance instrument.

Nonetheless, they can participate if they have short term STOR or balancing services contract (DECC, 2014i).

A further discussion on the interaction of the CM scheme and the CHP-DH systems has been undertaken chapter 9 as a response to a research question

5.3.3.3 Carbon Price Floor (CPF)

CPF was introduced to stabilise the price of carbon and thus incentivise low carbon development. This is as a result of the uncertain price of carbon or not high enough to encourage sufficient investment in low carbon electricity generation in the UK (DECC, 2011c), partly due to low price of carbon at the EU Emission Trading Scheme (EU ETS). Hence a scheme to help balance the price of carbon in a collaborative manner with the EU ETS to spur the desired investment in low carbon technologies.

The carbon floor price is a combination of regulatory and taxation mechanism that obliges UK based carbon emitters to pay for the right to pollute as a top up if the market price for carbon falls below the reference price. The targeted sectors are the energy intensive industries such as the steel, chemicals, cement industries and power generators. Vital to this mechanism is the price of carbon at the EU level, which is directly related to the volume of carbon allowance in the market. The UK CPF seeks to distinguish between the existing climate change levy which was a downstream tax with CPF as an upstream tax, requiring generators now be charged at the relevant carbon support rate depending on the fuel type being used.

The government launched the scheme in 2013 at a fixed support price of £4.94/tCO_2 for carbon which represents the difference between the government target carbon price and the market price of carbon in the EU ETS. The Government estimated that the total price of carbon (support plus EU ETS) would rise to £15.7/tCO_2 and would rise along a straight line to reach £30/tCO_2 in 2020, then continue to rise to £70/tCO_2 by 2030 as seen in Figure 9.

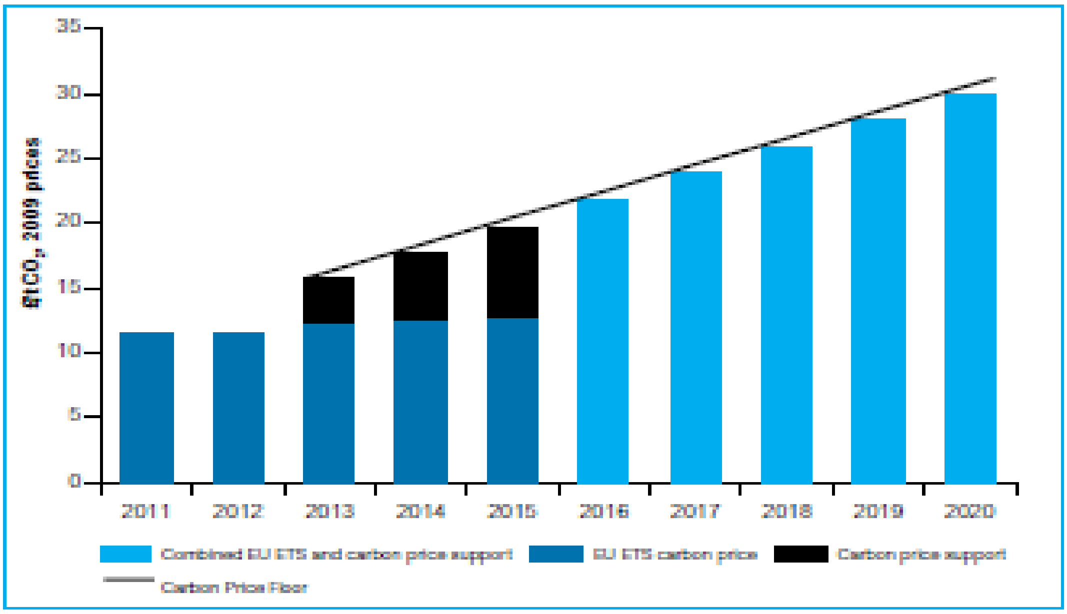

Figure 9: Carbon price floor to 2020

Source: (DECC, 2012d)

However, the Government's projection for carbon price continentally has been below expectation as the carbon price at the time of announcement in March 2011 it was around £15/tCO_2 but by January, 2013 it had fallen to £4/tCO_2 (Ares, 2013) and was hovering around £5t/CO_2 in the first quarter of 2016 (Garside, 2016). This is inconsistent with the Government's expectation of about £20t/CO_2 by 2016 (see Figure 9). Resulting in Government's review of the CPF policy by pegging the CPS to £18t/CO_2 from 2016 to 2020 (HMRC, 2014). In part due to the excessive supply of permits at the continental level, the increased levy on the UK industries without a corresponding levy on their counterparts in Europe and the risk of carbon leakage (the relocation of production to less taxed areas). Suggesting that there is no clarity on the long term view of the CPF scheme for CHP developers to develop business models on its back.

Furthermore, the UK manufacturing association is agitating for the scheme to be scrapped against a claimed projected increase on electricity bills for medium-sized manufacturers (Stace, 2013) as British firms in the EU ETS, including the struggling steel industry, pay an additional £18t/CO_2 more than their European counterparts (Carbonnel, 2016). A further discussion on the interaction with CHP-DH systems in the UK is captured in section 9.2.1.3 as a response to a research question.

5.3.3.4 Emission Performance Standards (EPS)

EPS is a performance regulatory mechanism to curb carbon emissions from new plants by setting standards above which an emission control technology is to be adopted or face closure. The EMR has set 450gCO_2/kWh as the EPS for any new entrants into the electricity production sector with exceptions for new coal and gas power plants fitted with carbon capture and storage demonstration plant until 2045 (DECC, 2011). The impact on CHP is almost negligible as most CHPs have certification from CHPQA which exempts them from EPS as good quality CHPs.

5.4 Heat Governance Mechanisms

The UK committed to a 15% legally binding national target for consumption from renewables as part of the 2009 EU Renewable Energy Directive (2009/28/EC). A cornerstone of the UK's target is to generate 10-12% of heat demand from Renewable Energy Source – Heating (RES-H) (DECC, 2009). The UK spends about £32billion annually on the provision of heat energy and heat accounts for a third of Greenhouse Gas (GHG) and nearly half (44%) of energy consumption(DECC, 2013a).

Several governance instruments have been developed to RES-H through traditional instruments such as grants (e.g. Community Energy Programme - that offered grants to develop CHP-DH projects as in Aberdeen and Birmingham but closed in 2007) (Webb, 2016a pg:139) or loans (Green Deal). More recently the UK introduced the world's first tariff mechanism specifically designed to stimulate the growth of RES-H with the Renewable Heat Incentive (RHI), which has some potential to support CHP-DH.

5.4.1. Renewable Heat Incentive (RHI)

This is a tariff mechanism introduced to encourage the deployment of renewable heating technologies. It is administered by Ofgem though DECC sets the tariffs based on forecast budget and technology diffusion. The scheme is to encourage the generation of heat from renewable technologies for space heating, water heating and process heating. Applications are classified into two distinct groups' non-domestic buildings, which covers heating in commercial, public, industrial sector and district heating while the second group covers domestic buildings. The domestic group covers single domestic properties, owner-occupiers, private landlords, registered providers of social housing, self-builders and third party owners of a heating system, though new builds are not eligible to benefit from the scheme (DECC, 2013l). However, in relation to this research that has its focus on CHP-DH system. The domestic RHI known as Phase II of the RHI scheme would have little relevance because it does not support district heating, hence only discussion on the non-domestic RHI (Phase I) would be taken forward.

The non-domestic RHI tariff seeks to provide 12% rate of return to the reference installation which is linked to the Retail Price Index (RPI) to reduce the impact of inflation while also regularly degression for new entrants. Triggering degression allows the Government to limit spending on the scheme by bringing down deployment in line with affordable budget. The principle behind the tariff design is to compensate for the additional cost for generating heat from renewables rather than compensating for the full cost of equipment or fuel used (Connor et al., 2015). The scheme provides twenty years of payment of the tariff and is currently expected to be open to new entrants until 2021.

The RHI's introduction was subject to substantial delays arising from a number of factors such as change of political leadership; support routes, fiscal economy and low learning experience on RES-H (Connor et al., 2015). For example the leadership change came with the coalition Government's emergence at the 2010 general election, and a desire to switch the funding source from consumer energy bill to the general budget (DECC, 2011f).

RHI phase I performance from the start of the scheme till date (2nd Quarter, 2016) according to the latest report by Ofgem (2016a) shows solid biomass boiler as greatest beneficiary with 93.53% of accredited installations, followed by GSHP 3.1%, solar thermal with 1.5%, ASHP (0.92%), Biomethane (0.31%), Biogas (0.3%) and (WSHP (0.25%). Below is the overview of key characteristics of the non-domestic RHI in Table 7.

	Phase I
Sector	Non-Domestic
Commencement	2011
Rate of Return	12%
Metering	Metered
Payment	20 Years
Most technology Uptake	Solid Biomass Boiler (93.53%) – by 2nd Quarter 2016

Table 7: Overview of key characteristics of Non-domestic scheme of the RHI

Source: Ofgem (2016a), Ofgem (2016d) and (Connor et al., 2015)

The tariff structure going forward to the next phase has been reviewed to reflect new cost data, heat loads and capacity factors. These new concerns have been reflected in the new tariff bearing in mind the level of deployment of each technology and the need not to incentivise over-production of heat or waste renewable heat. The resultant effect was the introduction of tiered and increased tariff for GSHP, 100% increase for large biomass, while small and medium biomass remained unchanged (see Table 8).

Table 8: Non-domestic RHI distribution for Phases I and II

Tariff	Eligible Technology	Eligible sizes	Tariff (p/kWh) ending 2013	Tariff (p/kWh) 2014/15	Duration	Measuring /Payment methodology	Comments/ Amendments
Small commercial biomass	Solid biomass including solid biomass contained in municipal solid waste (including CHP)	Less than 200KW	Tier1: 8.6	Tier1: 8.6	20 Years	Metering or Heat Loss calculation: Tiered tariff to provide for capital cost in tier 1 then operational cost from tier 2. This is calculated on a 15% load factor basis by 1314hrs of Opes * capacity size	2014 Tariffs are subject to existing budget management mechanism; Required to now submit a RHI emission certificate or a valid environmental permit
			Tier2: 2.2	Tier2: 2.2			
Medium commercial biomass		200kW ≤1000kW	Tier1: 5.3	Tier1: 5.3			
			Tier2: 2.2	Tier2: 2.2			
Large commercial biomass		1000kW and above	1	2		Metering or Heat Loss calculation	Required to now submit a RHI emission certificate or a valid environmental permit
Small commercial heat pump	Ground sources heat	Less than 100KW	4.8	7.2 - 8.2		Metering or Heat Loss calculation	Value for money cap

Large commercial heat pumps	pumps; water source heat pumps; deep geothermal	100kW and above	3.5				introduced for both tiers
All solar collectors	Solar collector	Less than 200KW	9.2	10.0 - 11.3			Value for money cap introduced for only tier 1
Biomethane and biogas combustion	Biomethane injection and biogas combustion,	Biomethane - all scales; Biogas combustion except combustion, except from landfill gas - less than 200kW	7.3				

Source: (DECC, 2013m)

A detailed discussion on the impact of RHI on CHP-DH systems is undertaken in chapter 9.

5.5 Fiscal/Financial and Obligatory Mechanisms

Fiscal and financial mechanisms are policy instruments from the state that defines the spending and taxation regimes on a technology, which can be used to stimulate innovation of the technology to compete in the market (Brown and Chandler, 2008). While the obligatory mechanisms places targets on energy suppliers/generators to deploy energy efficient measures in the domestic sector. The predominant tools used in the fiscal/financial mechanism are tax incentives, loans, grants or subsidies. Below is a brief narration of various fiscal/financial and obligatory mechanisms which has been operational in the last five years that may have impact on the penetration of CHP-DH systems in the UK.

- Climate Change Levy (CCL) is the tax on consumption of gas, electricity or other fuel by business and industrial entities but it excludes consumption of renewables. More detailed narrative on its impact on CHP-DH system is undertaken in section 9.2.1.3.

- Enhanced Capital Allowance (ECA) scheme allows businesses in the UK to write off 100% of investment of CHP parts against taxable profits in the year of purchase as long as the equipment is listed in the Energy Technology Product List (ETPL) (Carbon Trust, 2015)

- Tax exemptions from business rates on CHP plant parts and machinery but not for heat recovery plant and boilers (DECC, 2015c)

- The UK had and still deploys several grant/loans mechanisms that may impact on the growth of CHP-DH system. Such as the HNDU schemes to Local Authority's to facilitate the development of DH schemes.

- Low Carbon Infrastructure Fund (LCIL): This was a one-off funding scheme launched in 2009 to support the delivery of DH infrastructures as part of the development of new homes or refurbishment of existing homes in England. It was a £26m fund, administered by Homes and Communities Agency (HCA) in partnership with Department of Communities and Local Government (DCLG) and Department of Energy and Climate Change (DECC) (HCA, 2011). The scheme benefited about 13 LAs, connected 24,167 new and existing homes using five different technologies (HCA, 2011).

- Community Energy Savings Programme (CESP). This is an obligatory mechanism that requires major energy suppliers/generators to fund energy efficient projects to the tune of about £350m targeted at low income areas in partnership with local authorities and housing associations (CAG et al., 2011). Though smaller energy suppliers with less than 250,000 customers were not obligated to join, the cost of the scheme was passed on to the consumers through their energy bills (HoC, 2013). The scheme operated from 2009 to 2012 but supported CHP-DH systems in the area of upgrade, connecting and metering of DH networks, and DH benefited about 8% of the uptake by the end of the scheme (Ofgem, 2013h). A further discussion on its interaction with CHP-DH systems is undertaken in chapter 9.

- Energy Companies Obligation (ECO) **– (**successor to formerly Carbon Emissions Reduction Target (CERT) and the Community Energy Savings Programme (CESP)): This is an obligation on energy suppliers to install energy saving measures in UK homes with green deal as the scheme partner from where suppliers will seek the required fund for the scheme (DECC, 2013c), which will be repaid by consumers through energy bills. Energy suppliers shall receive targets from Ofgem based on their share of gas and electricity in the market set by DBEIS (Ofgem, 2015f), with the scheme being implemented in two phases namely: ECO1 (Jan 2013-

March 2015) and ECO2 (April, 2015 – March 2017)(Ofgem, 2016f). Connections of DH networks can benefit from the scheme and is the only measure in the scheme that does not require a green deal report or a chartered surveyor's report (Ofgem, 2015f). Further discussion is undertaken in Chapter 9 on its relevance on CHP-DH penetration.

5.6 Impact of local governance structure on UK CHP-DH penetration

5.6.1 The context of LAs engagement in the governance of CHP-DH systems in the UK

Cities under the jurisdictions of Local Authority's (LA) account for approximately two-thirds of the world's primary energy consumption, enabling vital economic and social activities but also creating significant environmental impacts at both local and urban areas (Keirstead and Schulz, 2010). LAs hold a strategic position in developmental projects by virtue of being the custodians of the planning powers and the duty to promote the social, economic and environmental well-being of their community. More importantly, many have suggested that the long-term static position of local authorities places a responsibility on them to play a significant role in achieving the national goal of developing a low-carbon economy and meeting local energy obligations (Keirstead and Schulz, 2010, Kelly and Pollitt, 2011, Bulkeley et al., 2011, Carbon Trust, 2012b). This desire by LAs to play a role in achieving national environmental targets is reflected in the memorandum of understanding signed between DECC and representatives of LAs, known as the Nottingham Declaration of 2011. This allowed LAs represented by the Local Government Group (LGG) to pledge to support the state on their commitment to national energy targets by jointly designing a mechanism to combat GHG emission and monitor energy reductions (DECC, 2011a).

In contrast, out of the 434 LAs in the UK, there are only a few examples of local authority-led CHP-DH systems in the UK (e.g. Kirklees, Peterborough, Leicester, Birmingham, Woking, Southampton, Nottingham, Islington, Devon County, Shetland, Sheffield, Newcastle, Coventry, Tower Hamlets, Highland Council, Leeds, South Gloucestershire DC, London Borough of Hackney and Aberdeen (LEP, 2007, Gearty, 2008, Kelly and Pollitt, 2011, HCA, 2011, SWM, 2014, Hawkey and Webb, 2016 pg:126-131)). This meagre LA participation in CHP-DH system can be attributed to a number of exogenous and endogenous factors which may have influenced their participation in developing CHP-DH systems. Key amongst the exogenous factors is that the state exerts the power to evolve energy policies in the UK (Bale et al., 2012). LAs in the UK have a long history of being under the apron of the state, such that any significant regulatory and financial activity that is not statutory or endorsed by the state may be considered *ultra vires* (meaning outside the authority, therefore it becomes null and void) (HoC, 2014a, Tingey et al., 2016 pg:158). This command and control stature of the state may have contributed to the erosion of the institutional self-esteem of the generality of LAs to be able to evolve innovative energy policies such that some have considered energy security as not their business but a mandate of the state and can only manage fuel poverty (Keirstead and Schulz, 2010).

However, several successive governments have made attempts to devolve powers to the LAs to empower them in the governance of electricity and heat arena in the UK partly due to national concern to meet environmental and energy targets. The devolution of powers seeks to stimulate the LAs to evolve innovative energy policies to jointly combat the national challenge. For instance in 2010 Government lifted the ban on LAs selling excess power generated from renewable energy to the National Grid thus allowing LAs to enter into partnership with the private sector or local communities to invest in renewable projects and enabling them to benefit from various Government incentives. Such as FiT, RO and RHI, with a view for LAs to jointly participate in meeting environmental targets (DECC, 2010a).

Consequently, Kelly and Pollitt (2011) suggested that UK LAs are beginning to take responsibility for local energy concerns as they realise the concerns for residents being exposed to fuel poverty amidst increased tension between environmental effects locally and economic survival of residents. However, they suggest that many LAs are focussed on delivery of energy-related services rather than strategic coordination, with most UK local authorities taking little or no strategic role in energy provision.

These energy strategies will have to be encapsulated in energy policies by LAs which will enable them to translate policy outputs "*the political decisions taken, the laws passed and the money spent*" to the desired policy outcomes *"the results or consequences of the outputs*" (Newton and Van Deth, 2010 pg:324). Interestingly, as the state showed signs of devolution of powers to the LAs, it was not clear if the remit of evolution of energy policy was also devolved. For instance the London Borough of Merton introduced a novel energy policy in 2003 requiring all new non-residential developments above $1000m^2$ to incorporate an allowance for at least 10% of its energy requirements from a renewable energy source (TCPA, 2006). The state initially considered it an affront to its mandate in energy policy formulation but later conceded that other LAs could adopt a similar policy route to actualise their energy targets (Keirstead and Schulz, 2010). Consequently, this innovative approach is commonly known as the "Merton rule" and has been adopted by many other LAs, for instance it can be considered an enabler in the Southampton district heating scheme (Gearty, 2008). Hence the strategic role of LAs in the energy arena may still have the scar of the command and control stature of the state.

Other impact of the state is that the LAs are not financially self-regulated because of limited taxation freedom, unlike some of their northern European counterparts with higher financial autonomy (Keirstead and Schulz, 2010). The LAs rely on the state for about two thirds of their annual budget (Tingey et al., 2016 pg:158) and for every £1 derived from taxation the state controls and allocates 91 pence (Crewe, 2016). Therefore vying into capital intensive investments like CHP-DH systems by LAs is strongly tied to the support from the state. Evidently that's why the LAs have to depend on the financial gesture of the state to provide the inertia for CHP-DH schemes through grants and loans since the early publicly known

CHP-DH scheme in Pimlico to lately the HNDU supports to LA (Diamant and McGarry, 1968 pg:172, DECC, 2015b, Webb, 2016a pg:139).

Another exogenous factor is the centralisation of energy systems in the UK with communities owning about 0.08% of the total installed electricity capacity and 0.3% of renewable electricity capacity (Julian, 2014). Suggesting that LAs may have limited participation in the electricity arena in the UK which could be attributed to several electricity market failures earlier discussed in chapter 2. However, key to note is that since nationalisation of the energy industries in the 1940s, electricity and gas were taken out of the hands of local authorities in the UK and subsequent privatization of these industries in the 1980s & 1990s which allowed the expertise to reside within the private sector. Hence LAs have been hindered by limited expertise and capacity in energy development and management (Webb, 2016a pg:137, Bale et al., 2012).

The planning system is another area which the state overtly controls. The UK had been practicing a more centralised planning system but there has been a gradual shift of devolution of planning powers to LAs since the liberalisation of the energy sector (Lehtonen and Nye, 2009). A more detailed discussion on planning was undertaken in section 2.2.8.

A key endogenous factor that impacts CHP-DH governance in the LAs is the political will of LA leadership. The successes of local energy strategies depend strongly on buy-in by both political leadership and employees of the LAs (Kelly and Pollitt, 2011, Bale et al., 2012). It is difficult to get an LA mandated CHP-DH project through an LA partly because of the huge financial implication without the political capital from the leadership. For instance in the Aberdeen DH system, a member of the board went against the advice of the council's legal team that the project should be abandoned due to high risk of tenant non-payment. A commitment of the deputy leader of Birmingham Council was also key to the success of the Birmingham DH scheme against fears on financial cost (Webb, 2016a pg:142-144)

Summarily, a combination of both exogenous and endogenous factors on the LAs has seemly impacted their participation in the development of CHP-DH in the UK with the motivation to meet environmental and economic goals as key drivers. However, these goals have been hampered largely by the tension between hierarchical governance structures and local innovation even in the recent drive of devolution of power to the LAs. A more detailed discussion was undertaken in chapter 8 on the roles LAs can take to overcome these tensions in response to a research question.

5.6.2 Ownership/Governance of Energy Service Companies (ESCOs) by LAs

Development of energy projects, including CHP-DH systems, is associated with risk and expertise; just as crucial is the requirement of breadth of skills to engage in a CHP-DH development. The local authorities often don't have the requisite expertise to develop such energy systems, partly due to the provisions on self-regulation status of LAs in the UK and the budget cuts from 2011 to 2015 which has further reduced its potential (LGA, 2013b). Therefore, like any project developer, minimisation of multiple risks is usually high on the priority list.

Given that risk should be assigned to the parties that would best manage it, a model of risk allocation is usually applied to define the owners of various risk and the control. These considerations help LAs to facilitate the decision process on how best to manage technical, economic and financial drivers in a project like CHP-DH system, while still focused on their primary duty of local governance. Hence the development of a business model that would re-balance these priorities in favour of public goods and environment which are their primary concerns. Generally, these models are frequently referred to as “Energy Service Companies” ESCOs. LAs have found the use of ESCOs as a credible vehicle in developing CHP-DH systems with a view to operating them at arm’s length from a parent company (Kelly and Pollitt, 2010) thereby insulating themselves from unbearable risk such as project or financial risk.

The EU had given a direction to understanding the fundamentals of the concept of ESCOs via the Energy End-use Efficiency and Energy Services (Energy Services Directive) Directive (2006/32/EC) (EU, 2006c). In it, the EU acknowledges the crucial role of establishing the terminology “ESCO” and advanced a definition of the term “energy service company” (ESCO) as “*a natural or legal person that delivers energy services and/or other energy efficiency improvement measures in a user's facility or premises, and accepts some degree of financial risk in so doing”* (EU, 2006c). It goes further in defining the agreement that binds the beneficiary and an ESCO (the provider of the energy efficiency improvement measure) as ‘energy performance contracting’ where investments are paid for based on a contractually agreed level of energy efficiency improvement.

ESCOs can be confused with Energy Service Providers (ESPs) which are companies that provide energy services to energy users for a fixed fee depending on the agreed energy savings or the ESP runs the risk of paying the LA/client the value of unrealised energy savings that was agreed upon (LEP, 2007). While the ESCOs are possible vehicles for sharing or taking over LA/client financial or project risk for the energy system, in this case CHP-DH systems. In the UK, energy efficiency projects/CHP-DH systems are predominantly developed through creating an ESCO via a competitive tender process in accordance with EU procurement legislation (LEP, 2007). Therefore the procurement of ESCOs depends significantly on site-specific conditions, largely determined by how risk averse the LA is and the motivation behind the scheme. It also depends on the energy policy direction of the government and the position it allocates to CHP-DH in its overall energy policy portfolio. It effectively leaves each LA to dictate its choice of governance structure to adopt, within the constraints already laid out.

On deciding on the motive or strategy of the scheme and risk allocation pattern by the LA’s, the choice of ESCO governance model to finance the project becomes vital. The ESCO governance model that is often adopted depends on the form financial mechanism to fund the project which largely depends on the risk allocation. ESCO governance models for projects are either guaranteed savings or shared savings arrangement (Okay and Akman, 2010). In a guaranteed savings scheme, the ESCO will cover the technical risk by guaranteeing the energy savings and shields the LA from any performance risk but leaves the LA with the credit risk to repay the loan from the lenders (Marino et al., 2011). While in shared savings scheme, the ESCO could cover the technical and credit risk but the LA receives a share of the energy savings in accordance with the pre-agreed percentage in the energy performance contract (EPC). However, in both arrangements the enumerations of the ESCO is directly tied to the energy savings achieved (Bertoldi et al., 2006, Marino et al., 2011) which also creates additional revenue for the LAs. Below in Figure 10 is the schematic diagram of financing mechanisms generally applicable in ESCO arrangements.

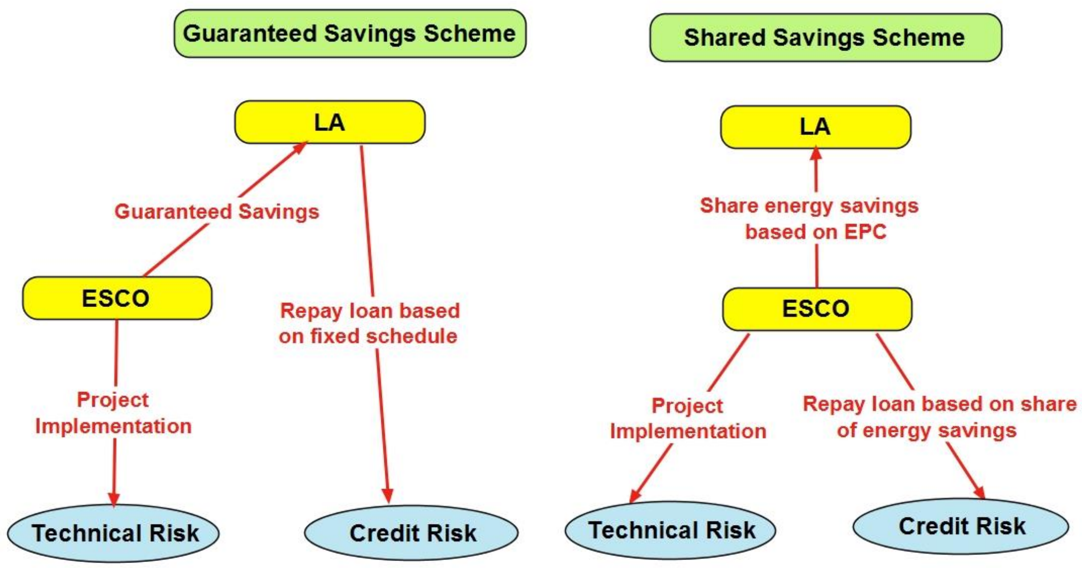

Figure 10: ESCO Financing Mechanism

Source: Adapted from (Bertoldi et al., 2006, Morgado, 2014)

In furtherance of the governance model of financing that the CHP-DH system could take, an agreed ownership structure will have to emerge to reflect the motive or strategy of the scheme. In the UK there are three common ownership variants of ESCOs being practiced by LAs (Hawkey and Webb, 2016 pg:125-129). Firstly, a private sector led ESCO where the ESCO is wholly owned by the private sector. In this category, the LA has little or no influence on ESCO operations and reduced risk exposure; it is therefore often driven by commercial rather social motives. The LA can partake in profit sharing partly because of their role in the ESCO facilitation and secured demand provision. For instance in the Southampton Geothermal Heating Company Limited, a limited company by shares with Utilicom as the sole owner but shares profit with the council as when declared (LEP, 2007). Another example is the Barkantine Heat and Power Company (BHPC) a wholly owned subsidiary of the London Electricity Group with a 40% excess profit sharing agreement every two years with Tower Hamlets (LEP, 2007).

The second model sees the ESCO partially owned by the LA, typically with an interest <20% with the remainder being held by one or more private entities, again indicating more commercially driven rather than social perspective. This may take the shape of joint venture agreements between the ESCO and the LA to specify the functions and objectives of the ESCO with their respective roles. The risk is shared amongst both parties, with the LA having a little more risk than in the first model and with a measure of influence on the ESCOs strategic direction. A typical example is the Woking Council partnership with a Danish company in the Thameswey Energy Limited ESCO, where the LA initially had 19% stake in the joint venture before taking a 90% stake after changes in Danish tax law and UK accounting rules governing LAs (Hawkey and Webb, 2016 pg:128-129)

The third ESCO model is when the LAs seeks to own a greater percentage (>20%) of the ESCO or its entirety, thus having a high degree of influence. This also means that the LA will bear a greater burden or all of the risk. The key driver for this governance option is the ability to steer the strategy towards social, environmental and economic directions. This option is also being adopted if private partners don't see the scheme as viable enough to warrant their take up but may rather participate on contractual terms. For instance the Aberdeen CHP-DH ESCO, where the LA created an ESCO limited by guarantee, suggesting it's not a profit-oriented company (APBenson, 2011).

There is no format or institutionalised procedure for ESCO formation, or support other than that an ESCO can claim capital tax allowances on the investment it makes (Bertoldi et al., 2006). However, the adoption of ESCO models by LAs in developing CHP-DH schemes could result in several positive outcomes benefiting both parties. For instance, the LAs would receive local energy developments plans including new energy planning strategies to installing DH networks and heat maps for the long-term development of CHP-DH scheme. For example the Aberdeen ESCO arrangement brought forward plans which would have normally taken more than 10 years to implement (APBenson, 2011). While the LAs in turn provide things like long term guarantees to take heat and/or power from the system, facilitate and guarantee planning right, right of way and locations for installation of CHP equipment and DH pipes (Kelly and Pollitt, 2010).

Conversely, the operationalisation of an ESCO may encounter several challenges. For instance, Vine (2005) suggested that an ESCO may compete for scarce capital with small plants coupled with the lack of verification and monitoring mechanism for performance, it is considered more risky than supply side only (electricity or heat production only) projects to attract finance. Others are non-availability of governance framework to reflect the workings of an energy efficiency project.

Further discussion on the potentials of ESCOs models by LAs on the penetration of CHP-DH systems in the UK has been undertaken in chapter 7 in response to a research question.

5. 7 Gas grids in the UK heat sector

Gas network is a key infrastructure to the penetration and performance of CHP-DH system in the UK, in part because two thirds of fuel used by CHPs is supplied by gas network in the form natural gas. For instance, in 2014, natural gas makes up about 67% of fuel used by CHPs (DECC, 2015g). The role of gas in the heating and electricity sector has a long history of being embedded in the UK's energy consumption culture. Pipelines has been used to supply gas to buildings in the UK for over 200 years (Dodds and McDowall, 2013, KPMG, 2016), since 1812 when London gas-light and coke company was established as the first UK gas company (Falkus, 1967). Suggesting the significance of gas network on the social, environmental and economic life of the society and the diffusion of CHP-DH systems in the UK. DECC reports gas as the dominant fuel for CHPs in the UK at 67% in 2014 and estimates that this will continue until 2035 (DECC, 2015g) (see Figure 11).

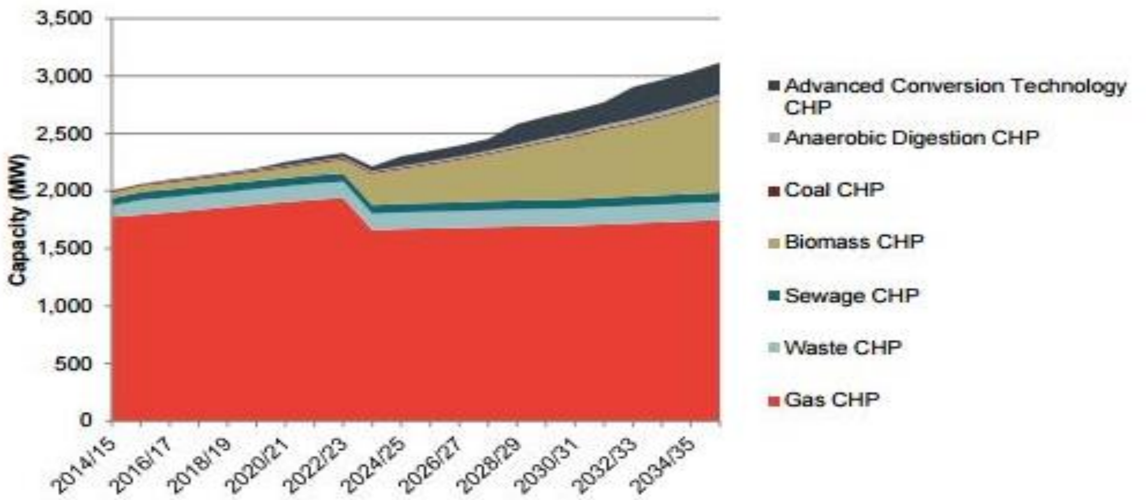

Figure 11: CHP forecast with dominant fuel

Source: (FE, 2015a)

Gas production and supply in the UK is known to have undergone three key phases of transformation as alternative to coal as the primary source for electricity and heat production due to economic and environmental pressures. These includes; coal carbonization, oil gasification and natural gas eras (Arapostathis et al., 2013). According to Arapostathis et al. (2013), the 19th century witnessed coal as the primary source of manufacturing gas through carbon carbonisation from low grade coal, which was initially used for lighting by commercial and middle-class consumers and later for cooking but not for heating for a number of reasons. Such as the high cost of gas compared to coal and incomplete combustion of town gas leading to accumulation of soot and odours in buildings (Dodds and McDowall, 2013). The manufacturing of gas from coal "town gas" herald the development of gas pipelines locally by municipals and private companies. However, after widespread development of town gas network to buildings, advertisement and legitimization though installation of prepaid meters, gas share for lighting, cooking and heating began to widen until cost of production was beginning to be a concern to the government, as the government had nationalised and amalgamated the gas industries by the 1948 Act (Arapostathis et al., 2013). The 1948 Act created the establishment of the Gas Council and 12 Area Gas boards responsible for the regions, which then sought for alternative ways to reduce the cost of gas production by manufacturing gas from oil through refineries in the middle of the twentieth century, shortly after the second world war. However, by 1960, coal carbonisations was still the dominant gas production method in the UK until the emergence of natural gas, which was initially imported as liquified natural gas from America and Venezuela and later the discovery of the UK's North Sea gas in the late 1950s (Arapostathis et al., 2013).

Subsequently, the discovery of the North Sea gas, which was seen to have a higher caloric value and quality than the town gas but with similar fast burning properties will meet the desire and aspirations of the Gas Council to provide a cheaper, more environmental and sustainable fuel for both electrification and heating (Arapostathis et al., 2013). However, to meet the growth in demand and capacity that would follow the adoption of natural gas, the existing town gas network had little interconnectivity between regions, with little storage capacity and existing gas burners also lacked the capability to be used with natural gas (Arapostathis et al., 2014). Therefore, two major issues stood on the way to the widespread use of natural gas, which were the upgrade of local gas network to high (transmission) and low (distribution) -pressure gas networks between regions, though many town gas networks to buildings were left and the conversion of gas burners to be suitable for natural gas. This led to a national conversion programme by the Gas council of appliances to be natural gas complaint from 1966, leading to the conversion of more than 40 million appliances by 1977 (HoP, 2017). While a development of high pressure national gas transmission network known as the NTS (National Transmission System) was started and by 1977, the low pressure gas network replacement programme known as the Iron Main Replacement Programme (IMRP) was also started to replace all iron pipes that were within 30m of any building with polyethylene pipes (Dodds and McDowall, 2013). The focus of the IMRP is to reduce leakages on the low pressure networks with a view to improve safety concerns and it's slated to be finished by 2032 (HoP, 2017).

These expansion in gas infrastructure alongside rising demand for gas and other governance activities such as the privatization of the gas industry in 1986, which triggered the "dash for gas" in 1990s that resulted in about 20GW capacity of gas plants at an average growth of 2.1GW/year between 1991 and 2001 (McGlade et al., 2016), which all contributed to the significant displacement of coal by natural gas as the major primary energy source in the UK. Culminating in the share of coal as primary energy supply of 40% in 1970 being halved to 20% in 2012 and the share of gas rising from 5% in1970 to 35% by 2012 and a 20% reduction carbon emission (McGlade et al., 2016).

Since the 1986 privatization of the gas industry and the subsequent Utility Act 2000, a regulator was established for the industry known as Office of Gas Supply (Ofgas), which was later amalgamated in 1999 with the Office of Electricity Regulation (Offer) to be later known as Office of Gas and Electricity Market (Ofgem). The establishment of a regulator has seen more robust regulation given the participation of variety of actors, stability and lock-in attributes of gas grid as an infrastructure. A key aspect of the regulation of gas infrastructure (also with electricity infrastructure) was the methodology to incentivise investment and control price. The gas industry has witnessed two major regulatory frameworks which are the Retail Price Index-X (RPI-X) and RIIO (Revenue = Incentive + Innovation + Output) frameworks since privatisation. The first regulatory approach was the RPI-X, which is a price cap regulation that is based on incentives to control prices, where the expected revenues are fixed for a period of five years but offers opportunities for reviews during the period for adjustments, such as inflation or increase in customer base (Ofgem, 2009b). The RPI suggest that the price increases only with the rate of inflation, while encouraging efficiency by a factor known as X (Simmonds, 2000). The X reflects the potential cost savings by the company due to increase in efficiency or technological progress (King, 1998) and the value of X started with an efficiency factor of 2% (Simmonds, 2000). The price control framework under RPI-X, was focused on two types of incentive measures namely: efficiency incentives - innovation in reducing cost and Interruption incentive – improvement of quality of service (Ofgem, 2009b).

However, in spite of the advantages of the price cap regulation under the RPI-X frame such as improvement of quality of service, reduced prices and incentivising investment of more than £35bn since privatisation, the RPI seemed to be challenged by the role of new dynamics in energy arena like climate change in infrastructure governance (Ofgem, 2010b). Thus, the evolution of the RPI-X framework to RIIO to capture the necessity of network companies to provide services that is value for money in a sustainable way that reflects its impact on the environment. The RIIO is also indexed to the RPI as against Consumer Price Index (CPI) that is being used in Australia (King, 1998). In part because corporate and Government bonds in the UK are tied to RPI and not CPI, which would allow network companies to seek finance to deliver their plans at a reasonable cost (Ofgem, 2010c). The key elements of the RIIO frameworks are namely: a) An ex-ante (upfront) control of revenues by network companies to deliver outputs efficiently, b) time limit of eight years for each control period and c) Returns to network companies shall be based on Regulated Asset Value (RAV) – capitalising all network cost at a fixed percentage, while also considering the depreciation (Ofgem, 2010c). The model presents comfort to equity and debt investors in a view to make the industry attractive for financing. The RIIO framework demands a business plan from each network company before the commencement of the regulatory period, explaining how they would achieve several outputs outlined in the frameworks. The expected outputs to be reported on are namely: customer satisfaction – improve customer response, conditions for connections – improve connection processes, reliability and availability - security of supply, safety – reduce accidents, environmental impact – reduced carbon foot print and social obligations - reduce fuel poverty (Ofgem, 2010c). The first regulatory period of RIIO framework for gas infrastructure (including electricity) started in 1st April 2013 and ends on 31st March, 2021, though with a four year review period within the eight years (Ofgem, 2015g). Therefore, the RIIO seeks to incentivise gas network owners to invest in the development of the grid in a sustainable manner by guaranteeing investments. Furthermore, the RIIO framework uses an uncertainty mechanisms to reduce the exposure of investors to risk outside their control, such as allowing the increase/decrease of revenue depending on volume/new customers (Ofgem, 2010c).

In addition to these regulatory incentives for the development of gas grids, natural gas supplies to non-commercial and domestic premises benefit from a reduced VAT rate and exclusion from Climate Change Levy (CCL). This is known as qualifying use. Gas supplies to low usage in the threshold of 5 therms or 145kWhr per day or 150 therms or 4,397kWhr per month shall also attract a reduced VAT rate (HMRC, 2016). However, the use of natural gas by businesses and non-domestic customers shall attract a standard VAT rate and CCL (plus VAT on CCL) (EDF, 2018). Therefore, drawing on the incentive to develop gas networks by guaranteeing investment through the RIIO framework and the fiscal incentives to gas consumers from gas network in the way of reduced VAT rate may have reinforced the lock-in of gas network in the heating sector. Especially considering the absence of a regulator for the heating sector, which makes the regulation of DH sector through laissez-faire - little or no interference from the state/LA, with no price regulation and the discovery of the North Sea gas which has a higher combustion property than town gas may all have culminated in the dominance of gas grid in the provision of heating. The resultant is natural gas is providing about 70% of heat energy consumption in the UK with about 90% of households in the UK being supplied natural gas from the gas network and gas network supplying more than twice the energy delivered by electricity network (HoP, 2017).

6.0 Research Objectives and Methodology

6.1 Introduction

This research seeks to provide a conceptual and empirical insight into the performance of CHP-DH technology in the UK by particularly interfacing Technological Innovation System (TIS) functional approach and governance concept with a view to investigate on how governance mechanisms can be improved to stimulate its diffusion and address system failure. The research addresses three broad research questions that includes: Firstly, what governance structures that permeate the CHP-DH landscape in the UK and the dominant risk profile. Secondly what innovative roles Local Authorities as part of governance hierarchy and a prime mover in the TIS structure can play in the stimulation of investment and growth of CHP-DH system. Thirdly, what is the impact of existing policy & governance mechanisms on CHP-DH systems in the UK?

In pursuit of these objectives, an in-depth conceptual understanding of governance and technological innovation systems perspective was sought and discussed in chapter 3 with the aim of using the TIS functional approach to reveal the blocking or inducing mechanisms to the diffusion of CHP-DH system in the UK (Jacobsson and Bergek, 2004). The performance of the system functions shall reveal areas that may require governance intervention.

This chapter shall also outline the analytical procedure and methodological pathway adopted to address the research questions, highlight the rationales for chosen methodologies and challenges for future research.

6.2 Research Objectives

CHP-DH systems are infrastructures and thus socio-technical systems that possesses technical, economic, political, social and environmental characteristics. For instance, it has been shown to contribute to efficient use of energy, reduction of GHG and reduction of fuel poverty. These kinds of benefits has been desirable by the European Union (EU) as it seeks through its Energy 2020 strategy to achieve 20% reduction of Green House Gases (GHG) below 1990 baseline by 2020, increase energy consumption from renewable energy sources by 20% and a 20% increase in energy efficiency by 2020 through various instruments (Fabrizio, 2013) as part of the EU responds to the UNFCCC climate change agreement.

The UK initially responded in 2000 to the UNFCCC climate change agreement by introducing the framework to achieve its Kyoto targets of 12.5% below 1990 levels over the period 2008 – 2012 through the Climate Change programme. Part of this target was to double the capacity (electrical) of Combined Heat and Power (CHP) by 2010 (DETR, 2000) with a view to simultaneously generate the two critical energy vectors (electricity and heat) at reduced emission levels compared to separate generation of electricity and heat. However, the target was missed with CHP-DH contribution to energy demand still at less than 10% of the electricity demand, and about 2% of heat demand. Furthermore, CHP-DH systems as networked-based infrastructures are capital goods producer/service delivery that may require public intervention (Finger et al., 2005). This indicates that there may be a problem that may warrant Government intervention through governance mechanism since market and firms fail to meet set objectives in a market economy like the UK (Edquist, 1999).

The low penetration of CHP-DH systems in the UK is not due to technological maturity since various literature suggest that CHP-DH system built in the 50s in London by Pimlico is considered as one of the first successful large schemes in the UK amongst others to showcase the technology on the back of supplying heat to housing estates (Martin and Thornley, 2013, Diamant and McGarry, 1968 pg 172, Roelich et al., 2013). Hence the focus of the research is to investigate the underlying barriers that are militating against the growth of the technology and offer insights to alternative governance routes to its growth by considering the role of the LAs as the TIS prime movers. The summary of the research questions are as follows:

1. What are the features and drivers of the governance approaches that permeates the CHP-DH landscape in the UK and the inherent risk profile of the industry
2. What are the significant barriers to CHP diffusion in the UK and the possible governance interventions to influence CHP-DH diffusion by the LAs as TIS prime mover
3. What are the prevailing governance mechanisms on CHPs and District Heating in the UK and their impacts

Firstly, in understanding the underlying barriers that the CHP-DH is experiencing, it was pertinent to understand what the landscape holds in various perspective such as operational and what are the factors that dis-incentivised developers the most in taking opportunities that the CHP-DH industry tends to offer. Therefore, this leads to the question of what governance approaches permeates the CHP-DH landscape in the UK and the inherent risk profile of the industry, which includes:

- What are the underlying technical and operational characteristics of the CHP-DH landscape?
- What are the dominant economic and management models that reside in the governance structure?
- What are the strengths and weaknesses of the dominant economic and management models?
- Dominant risk profile of the CHP-DH industry.

Secondly, the understanding of both the governance approaches in the landscape and the dominant risk profile would further provide insight to the discussion on the significant barriers that are militating against the CHP-DH system in the UK and the role LAs could play as prime movers and part of hierarchies of governance to create opportunities for a bottom-up approach to facilitate the diffusion of CHP-DH in the UK. This herald the next research question, what are the underlying significant barriers that feed these risk profile and possible roles of the LAs in facilitating the diffusion of CHP-DH systems in the UK, which includes**:**

- What are the significant barriers and possible alternative pathways to ameliorate their effect in the penetration of CHP-DH systems in the UK.
- What possible roles Local Authorities as part of governance hierarchy and as prime movers of CHP-DH TIS can play in the stimulation of investment and growth of CHP-DH systems

Thirdly, since many empirical evidences abound that governance mechanisms can influence the rate and direction of technological change and the UK is known to have deployed several mechanisms in the electricity and heat sectors. It may be necessary to investigate existing inclined mechanisms as determined by the CHP-DH actors and with a view to highlight their impact on the diffusion of CHP-DHs in the UK and possible Government's interventions to address the deficiencies of these mechanisms towards CHP-DH systems. Hence, the fourth and last research question is, what are the prevailing governance mechanisms on CHPs and District Heating in the UK and their impacts. This includes:

- What is the dominant current governance mechanisms for (i) CHP and (ii) DH Networks in the UK and how do they influence the diffusion of CHP-DH systems
- The strength and weakness of the EMR governance mechanism on CHP-DH system
- How can these mechanisms be improved upon to increase its influence on CHP-DH systems?

6.3 Research Strategy and Design

Research strategy is defined as the broad orientation taken in addressing research questions (Robson, 2002 pg:78). The research strategy adopted in this methodology is a flexible path research approach. This is largely because the methodology was more focused on the investigation of the forms of interactions amongst the various elements of the CHP-DH technology system in the UK, which depicts complex and dynamic outcomes and possible governance intervention to address the system failure. Furthermore, there is no consensus on how governance mechanisms should be investigated with a view to determine its effectiveness (Torfing, 2012 pg:109), but many available indicators, such as the quality of coordination, are based on subjectivity and surveys (Norris, 2011 pg:188).

Therefore, in analysing the interactions between the various governance arrangements (actors and institutions), qualitative and quantitative insights were required to develop a meaningful contribution to persuade policy makers. This choice of flexible pattern offers the opportunity to extract the thoughts and impression of all identified stakeholders in the CHP-DH arena on the processes and impacts of governance mechanisms. This is with a view to developing a narrative of each process and update previous narratives in an iterative manner as opposed to developing a fixed narrative at the end of an experiment. The strategy will involve assembling qualitative and quantitative data for narration extracted through interviews and questionnaires from UK actors (Kidder and Fine, 1987).

6.4 Research Framework

The research framework seeks to couple the purpose of this research with the research questions and the underlining theory adopted. The framework would also unveil a two phase methodological pathway (Functional pattern and Mapping of functions) in determining the alternative governance measures that may be required to address the CHP-DH system failures and the method of analysis of data from the agents which will provide the pathway upon which the research can draw a narrative in relation to the research questions briefly enumerated earlier on (Robson, 2002 pg:80-81).

Carlsson et al. (2002) had proposed three criteria's that would lead to an analytical framework of a TIS. They include firstly, what is the level of system analysis. Secondly, how is the system boundary determined - which is how the system will be delineated and the important actors be identified. Thirdly, how can the performance of the system be measured. In response to the first criteria, The research is focused on CHP-DH technology within the UK only and since the CHP-DH system is technically matured but commercially immature due to low penetration (Foxon et al., 2005), the focus will be on its rate of diffusion and utilization in the UK. Essentially indicating that the unit system analysis is the CHP-DH system in the UK.

Furthermore, in response to the second criteria, the research shall delineate the system through information from literatures and industry networks to ascertain the actors, networks and institutions that can influence the diffusion of CHP-DH systems in the UK. While the systems innovation functional pattern was adopted to measure the performance of the system in response to the third criteria, which was discussed in-depth in chapter 3. Subsequently, the functional pattern shall be mapped to unveil the blocking and inducing mechanism which permeates the CHP-DH technology. Below are the descriptions of these two TIS methodological pathways.

6.4.1 Analytical Procedure

Innovation systems often depends on the system failure approach (described in chapter 3) as an alternative to the market failure approach often used by government/policy makers to address the failure of infrastructures or socio-technical systems. However, the systems failure approach has been criticised for only capturing the structural elements of the system and not the processes that are characterized by a socio-technical system (Bergek et al., 2008b, Bergek et al., 2010, Hekkert et al., 2007b). The TIS tool set for capturing both the structural and dynamic activities in a socio-technical system is known as system functions approach. The TIS functional analytical approach seeks to explain how the socio-technical system work and performs in relation to the structure rather than how the system is composed (Markard and Truffer, 2008b). Therefore, the TIS functional approach will be adopted to access the performance CHP-DH systems in the UK.

Adopting the functionality pattern approach of a TIS framework to assess the performance of CHP-DH systems within the UK may offer several benefits to this research due to its “diagnostic” (Kern, 2015) and “explanatory” (Markard et al., 2015) capacities. Firstly, it presents the tool to describe the status of CHP-DH system in the UK with a view to determining the mechanisms that are blocking or inducing innovative activities within the system, thereby offering the opportunity to map these functions to provide a picture of the system performance (Johnson, 2001). Secondly, it would provide clarity on where governance measures can be introduced to weaken the effect of the blocking mechanisms on the CHP-DH TIS (Hekkert et al., 2007b).

The TIS functional framework is made up of seven functions as described in chapter 3 are namely: a) entrepreneurial activities, b) knowledge development c) knowledge diffusion through networks, d) guidance of the search, e) market formation, f) resource mobilization, g) creation of legitimacy/counteract resistance to change (Hekkert et al., 2007b, Hekkert and Negro, 2009, Bergek et al., 2008b, Bergek et al., 2008a).These functions of the TIS are capable of influencing the performance of the system either positively or negatively so as to allow for insight of the impact of the various contributors on performance

In explaining the development of a TIS using the functional approach, there are two distinct phases that defines the technological transformation of a socio-technical system. They are the formative and growth/market expansion phases (Jacobsson and Bergek, 2004). The formative phase shall be explained using information obtained during the descriptive phase of the research and the period of analysis shall be from first CHP-DH systems at about the beginning of the twentieth century to the decade of the first governance mechanism was introduced to influence the penetration of CHP-DH systems in the UK. The first governance measure was the 1977 Marshall report, that assessed the national potential of DH schemes in the UK (Russell, 2010, Kelly and Pollitt, 2010), influenced by the oil shock of the early 70s (Babus'Haq and Probert, 1996). This is in view of the fact that governance emerges through four key iterations namely: processes (modes of social coordination of interaction and steering functions), structures (formal and informal Institutions and actors), mechanisms (Instruments of compliance and control) and strategies (design and adaptation of institutions and mechanism) (Börzel and Risse, 2010, Risse, 2012 pg:700, Levi-Faur, 2012 pg:8). Therefore, the Marshall report can be considered as a governance measure since it provided the strategy to increase the penetration of CHP-DH in the UK.

Consequently, the formative phase which is determined by time dimension and early of entry of actors shall be from 1910 to 1980. The next phase of description shall be the market/growth phase. This phase consist of three phases, which includes: (a) nursing market – when market begins to evolve and with limited size, (b) bridging market – enlargement of actors and increased market size, (c) mass market – when market is fully evolved and self-sustaining (Bergek et al., 2008a, Bergek et al., 2008b). This research shall seek to explain this development phase with a view to determine the market development phase that the UK CHP-DH system is in, drawing on the combination of descriptive and exploratory phases of this research.

6.4.2 Mapping of TIS functions

The second pathway is integrating the TIS functions with the governance layer with a view to improve the functions of the system by introducing mechanisms that would seek to weaken the blocking mechanisms in the TIS. The governance layer will provide more potential for proactive governance to collective problems and mitigations as market and state-led governance are considered too rigid and reactive, largely due to the complexity and multi-layered fashion of society (SØRensen and Torfing, 2009). Consequently, governance approach was adopted for this research, because of its reliance on social initiatives for sustainable development and diffusion of technology and contribution to social goals rather than conventional policy instruments which tends to be more top-down without much consideration to social initiatives (Hillman et al., 2011). Furthermore, governance is entrenched through regulatory instruments (Levi-Faur, 2012 pg:13), it also encourages the development of technological innovations via actors internal capabilities, resources (Griffiths and Zammuto, 2005) and legitimacy (Börzel and Risse, 2010). This will further capture the role of the LAs as prime movers in the TIS structure to draw from their political, structural and relational resources (Farla et al., 2012). Such as social capital -trust, norms and networks (Pollitt, 2002), ability to implement socially binding decisions (Offe, 2009) and as part of hierarchies of governance in the UK to influence the functions of TIS by providing a bottom-up response to the various weaknesses of the system functions.

The integration of these approaches (TIS and Governance) shall be represented in mapping of the TIS functions with key governance interventions by mapping the dynamics relative to the causal relation of the actors, institutions and networks within the CHP-DH TIS structure. These functions shall describe the 'positive or negative contributions' (Bergek et al., 2008b) of the performance of CHP-DH TIS. Therefore the research shall sought for promoters and obstacles to the diffusion of CHP-DH technology in the context of governance mechanisms amongst the actors, institutions and networks, by linking the functions or attributes of TIS to prevailing inducement and blocking mechanisms as depicted in Figure 12 (Bergek et al., 2008b).

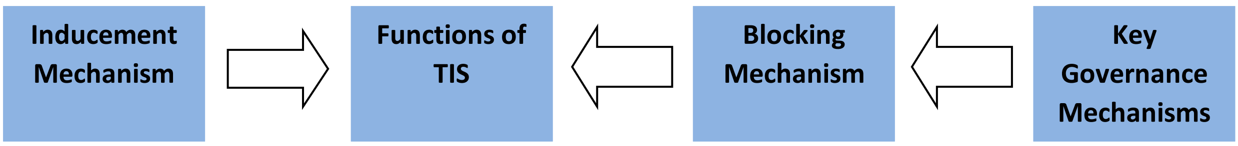

Figure 12: Mapping of TIS functions

In operationalizing the methodological pathways, the various components (actors, institutions and networks) that constitute the structure of CHP-DH system in the UK are identified, which shall feed into the contact list to obtain qualitative and quantitative data.

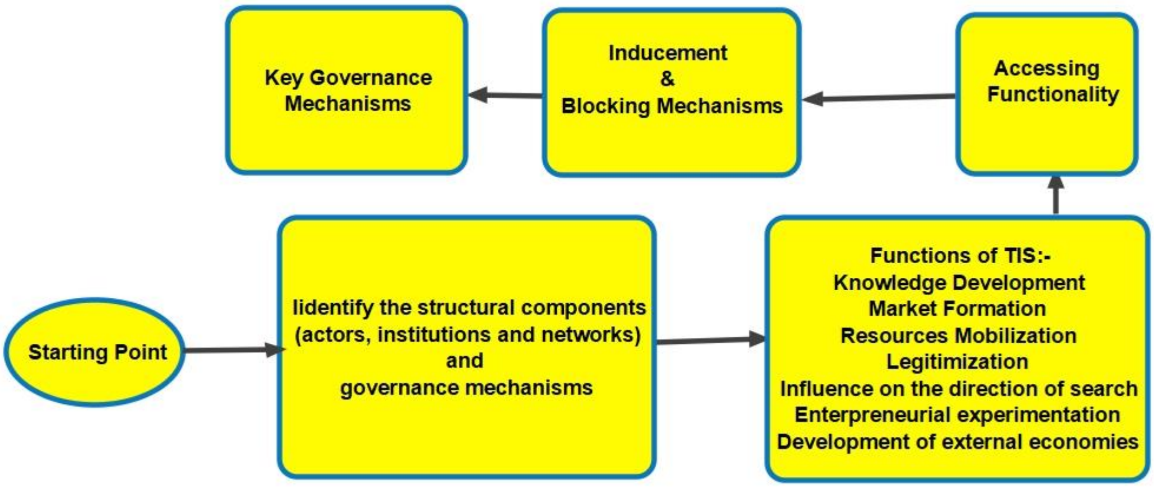

Figure 13: Operationalizing TIS and Governance Concepts

The output of the quantitative and qualitative processes shall provide insight to the functional pattern, which shall seek to diagnose and explain the development phases of the TIS and provide patterns of the system dynamics that has bearing on the technological performance. Consequently, the functionality shall be assessed to unveil the critical inducement and blocking mechanisms that may warrant governance intervention which would seek to reduce system failures or policy erros (Klijn et al., 2012pg:298).

6.5 Research Design

6.5.1 Overview of Research Design

The research design method shall describe the various methods deployed in the research to achieve the set objectives. Its overall approach has been a mixed method of both qualitative and quantitative methods. Drawing from the classification of the paths of enquiry by Robson (2002 pg:59). The research design method could be classified into three groups as below:

Descriptive:

- To portray an accurate profile of persons, networks, institutions, events or situations that have/can influence the diffusion of CHP-DH systems in the UK from literature reviews
- To acquire extensive knowledge of the prevailing governance arrangement that may impact on CHP-DH system in the UK

Exploratory:

- To find out what is happening, particularly in little-understood situations
- To seek new insights
- To ask questions

- To assess phenomena in a new light
- To generate propositions for future research

Explanatory

- Seeks an explanation of a situation or problem, traditionally but not necessarily in the form of casual relationship
- explains patterns relating to the phenomenon being researched
- identifies relationships between aspects of the phenomenon

Answering these questions and drawing on the classification enumerated above requires a better understanding of the two broad strands of literature that forms the platform for quantitative and qualitative analysis. Figure 14 presents a diagrammatic view of the adopted research methods to address the research questions of this research.

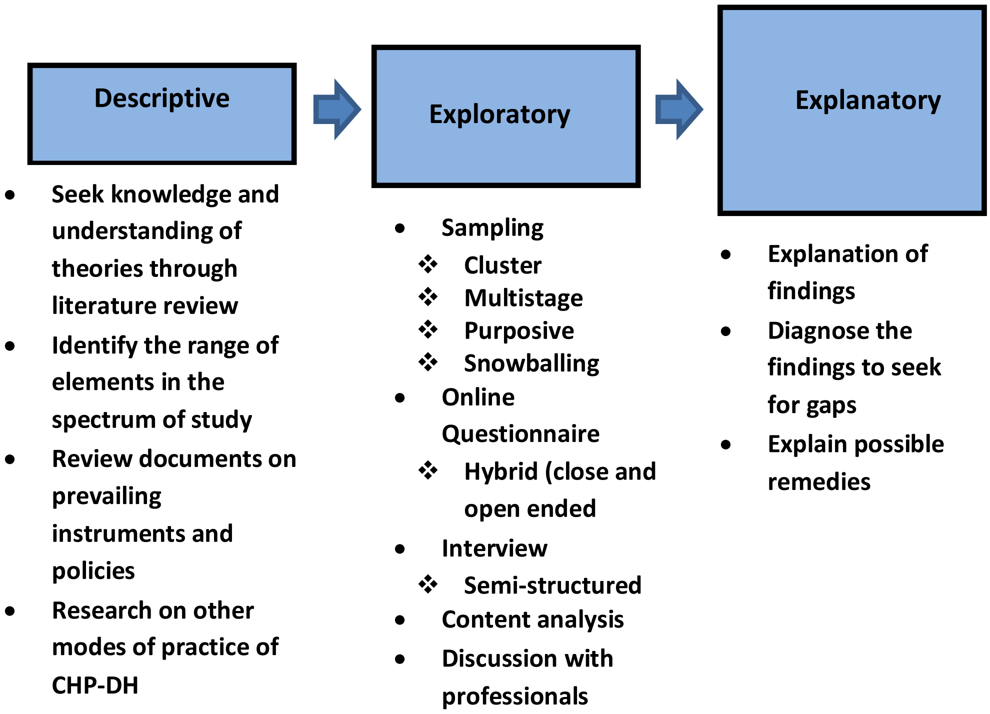

Figure 14: Diagrammatic view of the adopted methodology

The descriptive phase leads to a better understanding of the governance style of best practice of CHP-DH deployment through review of literature from the Netherlands and Norway, status of CHP-DH is in the UK and its actors, which is vital to the researchers objective of capturing the innovation process being investigated (Carlsson et al., 2002). The descriptive stage was followed by the exploratory phase. This entailed consideration of the various ways, such as, collection and sampling of data, surveying, and conducting interviews with the actors identified from the descriptive phase. Lastly the explanatory stage shall entail the data collection, analysis and interpretation from the exploratory phase.

6.5.2 Research Methods – Discussion and Rational for choice of method

There are two key research approaches that has dominated research in social science historically. They are quantitative research or qualitative research methods. These methods are models used to describe or explain the relationships between actions and/or events as we seek to understand the world around us (Black, 2005 pg:7). Quantitative methods describe the investigation of variables of interest and measures them in a prescribed way that seeks to explain the output in a non-judgemental and mechanistic way to form a statistical inference (Robson, 2011 pg:163). Suggesting that the result is in the form of numbers and statistics. It's often recommended to be used during the later phase of the research, as the researcher's vision is clearer as to what he/she is looking for (Miles and Huberman, 1994 pg:40). Furthermore, quantitative data collection is often quick, and analysis consumes less time since its often done with statistical software and more useful for large population. In quantitative research, the research results are relatively independent of the researcher, providing more precise results with high potential credibility with policy makers (Johnson and Onwuegbuzie, 2004). However, it is not without its weaknesses such as the research categories or theories used may not reflect local understandings. Others are generated knowledge may be too abstract for specific local application and the researcher usually is more likely to be too focused on theory or hypothesis testing rather than generation (Johnson and Onwuegbuzie, 2004).

Whilst, qualitative method seeks to use exploratory approaches, with a view to produce textual data instead of numerical data or statistics (Roberts et al., 2006). It is necessary to understand the phenomena in qualitative research because context is important, and the description of the situation is often from the perspective of those involved. Suggesting that the researcher is distanced from the participants with emphasise on subjectivity rather than objectivity (Robson, 2011 pg:19). The scale of persons or situations researched are usually small but resulting data are richer and more time consuming with little room to generalise (Miles and Huberman, 1994, Robson, 2011 pg:19). Qualitative method is also burdened with its weaknesses. Such as difficulties to test theories and hypothesis, greater influence by researcher biases, requires more time compared to quantitative methods to collect and analyse data and its often less credible with policy maker compared to quantitative (Johnson and Onwuegbuzie, 2004).

Mitchell (2008 pg:2) argues that narrow economic quantitative approaches alone without the combination of qualitative social science approaches in framing government policy often leads to an under-valued output. Therefore, the research approach sought to combine the strengths of qualitative and qualitative research methods through a systematic approach and theoretical propositions, which is other-wise known as mix-method approach. The mix-method approach would seek to minimise the weakness of either quantitative or qualitative methods using the strengths of the other, since both methods use empirical observations to answer the same research question (Johnson and Onwuegbuzie, 2004). It would also provide the research triangulation so as to enhance validity and production of a more complete research output (Robson, 2011 pg:167). The mix-method has the potential to address a wider range of questions and has the ability to deal with complex phenomena and situations (Robson, 2011 pg:167). However, the drawback of using a mix-method approach is that it is more expensive and time consuming with more difficulties for a single researcher to carry out both approaches (Johnson and Onwuegbuzie, 2004).

Contextually, the form and nature of governance of electricity and heat markets in relation to CHP-DH is underpinned by complex interactions between the elements in the TIS structure. These interactions of elements in both electricity and heat markets would require effective social coordination and the governing rules to bound all participants (Bevir, 2011). Therefore this research takes a qualitative approach that presents the capacity for gaining insights on the social relations and behaviour of the array of actors, policy impact on the participants and opening the horizon to reconcile the divergent views (Kidder and Fine, 1987, Ritchie and Spencer, 2002 pg:305). Furthermore in interrogating the correlation between the innovation system functions, qualitative approach offered insights to their relationship between the governance mechanism and actors (Hekkert and Negro, 2009).

Consequently, as the research focuses on the investigation of the CHP-DH TIS in the UK with a view to understand the relationship amongst elements of the TIS structure that requires governance intervention and address the system failure by weakening the blocking mechanisms of the system functions. A quantitative method was integrated with the qualitative method so as add credibility to the research for policy makers and politicians across the hierarchies of governance to consider the research contribution to the policy debate on the status of CHP-DH as a scientific proof for government intervention. Secondly, the quantitative method would create the opportunity to repeat and extend the research to capture larger population (Black, 2005 pg:20).

Find below in Table 9 that shows the overview of the features of the adopted mix-method research methodology

	Quantitative	**Qualitative**
Aim	The aim is to gauge the perception of actors in a numerical pattern with a view to explain observation	The aim is to extract detailed, complete description of what is observed
Purpose	Generalization, prediction, causal explanations	Contextualisation, interpretation and understanding perspectives
Objective/Subjective	Objective – Seeks precise measurement and analysis	Subjective – individual actor's interpretation of events is important
Data Collection	Structured questionnaire	Semi-structured interview
Tools	Online survey tool – Survey monkey	Face-to-Face and Voice-to-voice interviews
Output	Data is in the form of numbers and statistics	Data in the form of words

Sample	Large number of actors representing the population that form the sample frame	Small number of samples of actors selected from the sample frame based on their role and categories
Analytical tools	SPSS Software	NVIVO Software
Analysis	Statistical	Interpretive – Thematic and Citation
Researcher role	Researcher aimed to remain objectively separated from the subject matter	Researcher aimed to become subjectively immersed in the subject matter

Table 9: Features of research methodology

Source: Adapted from MacDonald and Headlam (2011)

In drawing on the strengths of one or more of the methodology techniques to compensate for the weakness of another, triangulation technique was also used. Triangulation technique is a multi-method approach that entails using several methods to validate the findings of one or more methods (MacDonald and Headlam, 2011). Data was collected from multiple sources such as quantitative and qualitative sources to enhance the rigour of the process and lend more credence to the validity of the data collected. Another purpose of the triangulation is to complement data already collected (Brannen, 2005) from other sources by reinforcing already informed knowledge and integrate data (Whyte, 1984) that was hitherto not earlier captured. The use of semi-structured face-to-face and voice-to-voice interviews as highlighted was very useful in extracting thought and opinions not solicited from questionnaire respondents due to its flexibility and open ended format but guided by the research boundaries. (Evans and Mathur, 2005, Kajornboon, 2005).

The strength of the quantitative method used here which was a voluntary questionnaire approach via a web-based software had been earlier highlighted but in addition because this was a resource bound academic research bound by time and cost. Online survey is known to have the potential to reduce time and cost, in part, because of its fast response time, no intermediary barriers and ease of data collation (Daley et al., 2003, Trouteaud, 2004, Evans and Mathur, 2005). Scholl et al. (2002) also argues that web-based surveys can significantly improve the representativeness of sample sizes. Therefore, the research leveraged on the spread of internet technology and access across the UK by using web-based survey to improve sample representativeness and response time at a cheaper administration cost comparatively with other modes of survey such as mail/post. The convenience of web-based survey also afforded the opportunity to contact over a thousand actor's multiple times including many others that offered to opt out during the six months period of the quantitative data gathering (April to September 2015).

6.5.2.1 Challenges of methodology approach

Frequently, qualitative method takes much longer time and requires more clarity of objectives during the design stages as against the quantitative method (Berg, 2009 pg:2). Furthermore, the challenge of the qualitative methods is that it has high propensity to throw up similar evidences, which may raise questions on its validity and self-bias level and it can precipitate a massive unreadable document (Yin, 2003pg:10-

12). In remedying these challenges, a clear and systematic approach was adopted in the methodology using multi methods or triangulation within a carefully planned time line until data saturation point was seen to be reached.

However, triangulation is not without its limitations or challenges. Triangulation would ordinarily require more time and cost as supposed to other methods, thereby putting pressure on available budget and time resource. It is also not an easy process to replicate, more so if the method is a qualitative one (Jick, 1979). It may also mean practical difficulties in managing a high degree of conflicting data (Robson, 2002 pg:175). The antidote to this constraint was a carefully crafted clear and focused set of questions and a well thought out research strategy to avoid repetition and budget overrun. Mathison (1988) had stated that an alternative conception of triangulation could emerged in the process of triangulation. This was the emergence of inconsistent and contradictory data in addition to converged data. This is expected as actor's opinions and perceptions of the system functionalities differed in a number of ways. For instance, as most respondents think a regulator is required for the heat industry, a few other respondents think the market doesn't need one because of the low level of penetration of CHP-DH systems. However, the converged data gave a direct link to a dominant proposition. In addition to the differing opinions, a more robust understanding of the directional perception of the actors, dominant landscape and the system dynamics were deduced to ensure "theoretical validity" (Onwuegbuzie and Leech, 2007).

Another challenge was the difficulty in scheduling an interview, largely due to the busy schedule of respondents. This required a flexible approach on the part of the interviewer. On the quantitative front, because the questionnaires were sent voluntarily, and many were sent unsolicited, the response rate was affected negatively due to non-response bias. Furthermore, the online surveying tool also had its own difficulties in gathering data, which is discussed in the session (6.7.1).

6.6 Population and Sampling

6.6.0 Population

Population is the target group which the researcher would seek to engage in a study to deduce a result that can be generalizable. Population can be referred to as all the cases of interest (Robson, 2011 pg:270) or the group that shares a set of common traits (Black, 2005 pg:111) or a group of all the elements of interest (Anderson et al., 1993). Population is not restricted by size or geography (Diehl and Gay, 1992) but rather it depends on a common unit of interest, which is often referred to as parent or study population (Ritchie et al., 2003 pg:86)

In line with Carlsson's (2002) position, the two key questions to ponder on in identifying the structure in the CHP-DH TIS are firstly, how to identify specific actors in a system and secondly whether they belong to that system. While Ritchie et al. (2003 pg:87) also notes that defining your study population involves two stages. The first is specifying the collective unit of interest required and secondly, identify the persons required within them. Therefore, the study population or target group for this research for both the quantitative and qualitative methods have CHP and DH as the common element of interest and those that have the capacity to influence the deployment of CHP-DH in the UK such as LAs or government agency. The population of the CHP-DH TIS to be investigated consist of all NHS hospitals that have or developing CHP-DH systems, Universities with CHP-DH systems, all LAs with or without CHP-DH – because of their role as the TIS prime mover with distinct capacity to influence the adoption of CHP-DH, housing associations, industries with CHP-DH, housing estates with CHP-DH systems. Others include, CHP manufacturers/suppliers, DH pipe manufacturers/suppliers, industry networks, consultants, CHP-DH developers, CHP-DH operators, Government agencies, regulators, NGOs, transmission/distribution network operators and electricity suppliers.

Secondly, industry networks/associations were identified to catalogue actors that participate in the CHP-DH industry. Such as Association for Decentralised Energy (ADE), UK District Energy Association (UKDEA), Energy Network Association (ENA), Renewable Energy Association (REA), Euro Heat and Power. Internet research was used to collate NHS hospitals with CHP-DH from the NHS estates list, universities with CHP-DH systems were gotten online from the Higher Education Statistics Agency (HESA) and online details of all LAs in the UK. CHP-DH actors/networks were also gotten from workshop attendants list and conferences, such as the Vanguard DH conference. The Digest of United Kingdom Energy Statistics from DECC was used to discover industries with large scale CHP-DH systems, while the UK National Statistics Office (NSO) as the source for state institutions and actors, that are relevant to CHP-DH penetration in the UK and the culmination was a database of contact details (email, phone numbers and addresses) created in excel software of all relevant actors, institutions and networks.

The target persons representing these organisations differ in positions and role. For instance, in NHS hospitals - the estate directors/manager were contacted, Universities – Head of Engineering/Energy managers, LAs – Energy Managers and Planners, Operators and Developers – Technical/Operations directors, Government agencies – Policy managers, with many others having policy advisers, technical directors, head engineering as officers knowledgeable to speak about the topic of this research. Subsequently, unsolicited introduction letters were sent to the actors to intimate them of the research and confirm the appropriate channel for further communication and for those without email contacts but with phone numbers, they were reached to seek for further contact details. This was a process with several iterations before a more robust database of actors was developed using excel which is known as my sample frame.

6.6.1 Sampling

A sample is a subset of the population to be studied (Anderson et al., 1993 pg:209) and the process of selecting a sample from the population is known as sampling. Out of the study population a sample frame had been developed from the study population. Therefore, the sample frame would constitute a representative sample for the population study since its not possible to contact all the units in the population (Bryman and Cramer, 2011 pg:5). In enhancing and further populating the sample frame a cluster sampling strategy was used to divide the actors into clusters of similar characteristics, for instance stakeholders operating CHP-DH systems, manufacturers of CHPs, DH pipe installers, developers, consultants, state institutions and LAs. This provided the inputs for purposive sample size for the qualitative data collection. Kothari (2004) notes that the size of the sample may not be too large or too small but importantly it should be optimum, and an optimum sample size is one that fulfils representativeness, requirement of efficiency, reliability and flexibility. In militating against researchers' bias in the sampling process, a snowball sampling approach was adopted. A snowball approach is an approach that will allow the use of key contacts and documents to signpost the research to more contacts and documents until the sampling frame becomes saturated and no new contact will offer additional significant information or data (Bernard, 2006 pg:193). The sample frame size was the sample size for the quantitative research, since a large sample size is required for statistical inference and allows for the study to be generalized (Robson, 2011 pg:271). While a purposive sampling strategy was used to select a smaller size of sample from all each category in the sample frame for the qualitative research. This sampling approach provided the opportunity to the researcher to generate a representative sample of the target population and gain insight of more relevant actors after the initial actors have been identifies.

6.7 Development of Questionnaire and Interview Questions

Structured questionnaires were developed with pre-determined questions that were focused on the research objectives with a view to gather quantitative data, while semi-structured interview questions were also developed to engage actors through face-to-face and voice-to-voice interviews to gather qualitative data. Structured questionnaires are questionnaires with concrete, definite and pre-determined questions, so that all respondents will answer the same sets of questions (Kothari, 2004 pg:101), while semi-structured interviews are interviews with non-standardized questions, considering the vast themes and issues to cover, it would allow for further probing and flexibility as the interview progresses (Kajornboon, 2005).

Insight from the descriptive phase was used firstly to prepare questionnaires for online completion in three distinct groups: (i) LAs, (ii) CHP operators (This group also contained LAs that are CHP-DH operators) and (iii) Consultants (this group also contained networks/associations). Ritchie et al. (2003 pg:91) notes that it is important to avoid complex categorisations, so the questionnaires were developed and used in a hybrid form, with focused questions prepared with the opportunity for participatory questions from the stakeholder to allow for flexibility. Feedbacks from an initial interview session with an industry network actor and pre-test comments during a pilot test on the questionnaires from research colleagues were vital inputs to the development of the questionnaire, because of the necessity to reduce design errors and improve clarity (Daley et al., 2003, Gunn, 2002).

The first set of questionnaires were targeted at CHP-DH operators only. This was targeted at them because it sought answers that are related specifically to their CHP-DH asset sizes, operations and connectivity. The questionnaires to the CHP-DH operators had thirty-seven (37) questions. The second set of questionnaires were targeted at LAs specifically because it had questions relating to their local energy policies and CHP-DH penetration and it has seventeen (17) questions in total. The third set of questionnaires was targeted generally at the other actors and was described as consultants. It had twenty-six (26) questions and the questions were more generic questions. These questionnaires were as a result of a rigorous process of several iterations of discussions and editions with my supervision team, before a final confirmation was given for the questionnaires to be sent for a pilot run through other research colleagues. The inputs and suggestion from these two colleagues were taken into consideration to improve and modify the questionnaires.

In the gathering of the qualitative data, interview questions that focused on the purpose of the research were prepared for each category of actor depending on the sector that the actor belong. For instance, the question set for a DH pipe supplier is different from the question set of an electricity supplier. In total, fourteen (14) separate sets of questions were prepared for the various groups including interview sessions held after the quantitative data collection and the writing phase of the research. Though many question sets had some generic questions in them but with additional questions that pertain to the sector in question. The questions were developed based on data gathered during the descriptive phase of the research and snowballing strategy by developing questions for actors depending on response from previous actors. For instance, some LAs comments on the state of heat maps allowed for modification of the question set for a government agency to capture their concern. The qualitative research questions were semi-structured and as such respondents were allowed to ask questions not mentioned in the question set or the researcher could ask additional questions that were consider necessary in the course of the interview.

6.8 Data Collection

Empirical data collection stage within the exploratory phase entailed using two modes, which consisted of a structured online questionnaire for the quantitative data via a web-based software known as survey monkey. While semi-structured interviews were used to get qualitative data via a face-to-face and voice-to-voice interviews. The mix mode of both online questionnaire and interview is evidenced as helping balancing cost and errors in survey results (Groves et al., 2009 pg:178). This stems from the fact that actors in the CHP-DH environment are scattered all over the UK and the use of online survey is a vital medium to collect data from different parts of the country (Evans and Mathur, 2005). In gathering the quantitative data, personalised emails of respondents were used, as this is known to improve response rates from web based survey (Cook et al., 2000). The response rate from this research are as shown in Table 10, with the LA group indicating the highest response rate of about 45% and the average response rate from all three groups from the survey as 28.9%.

Response Rate (%)**Source: <u>www.surveymonkey.com</u>**

Groups	Total Actors contacted	Total Response	Response Rate
LA	329	148	44.98%
CHP OPS	675	129	19.11%

Consultant/Associations	128	29	22.65%
Overall Research Results	1132	306	28.91%

Table 10: Response rate of survey

Response Rate (RR) is a known indicator of the quality of surveys but there is no consensus range of response rates from the research community as it depends on the methodology being used, type of population and other subjective conditions such as response facilitation approaches (Baruch and Holtom, 2008). To further show the incongruity in the acceptable range of RR, Sheehan and McMillan (1999) also catalogued several published surveys done with response rates from 6% to 75% using emails but Mathur et al. (2013) insist that a 5.75% response rate is "fair" for web based surveys because of variables.

Many literatures notes, the low response rate of web-based survey research compared with traditional mail or telephone surveys (Sills and Song, 2002, Cook et al., 2000, Bech and Kristensen, 2009). Additionally the difficulties of a web-based survey to obtain a sample frame that will not precipitate coverage error, non-response error and measurement error (Cole, 2005). However, other studies such as Pealer et al. (2001) and Mehta and Sivadas (1995) suggest that web based survey may produce as good a response rate as other forms of survey. While, Parker (1992) and Kaplowitz et al. (2004) argue that web based surveys may even produce a more useful response rate than other survey methods. Therefore, several measures were adopted to improve the response rate and result validity by minimising the associated errors such as coverage errors, using internet to generate sample frames from NHS estate contact list, DECC Energy digest with list of large CHP operators. Other measures like, sending of follow up emails after sending the questionnaires and reminder emails after a week. This has had significant effect in improving the response rate (Trouteaud, 2004). The researcher took a further measure of using Freedom of Information Act (FOI) request for energy manager contacts from public institutions and Local Authorities. However, some public institutions insisted they were not obliged to give out contact details of the energy manager, but many responded positively, and this increased the response rate.

Other scholars have stated that response rate though an important indicator of the quality of a survey, is not the only useful indicator and may not be as important as response representativeness (Cook et al., 2000, Schouten et al., 2009, Groves and Peytcheva, 2008, Heerwegh et al., 2007). Schouten et al. (2009) argues that a more impressive indicator is the composition of the response relative to the size of the population to be surveyed. They suggest that larger response rates may not always indicate representativeness, that at best larger response rates would reduce the risk of non-response bias. Rather they empirically showed that mixed methods of data collection, such as telephone call back for a purposive sample size would reflect a high representativeness of the sample size. Bech and Kristensen (2009) also argue that web-based surveys can exhibit a better sample representativeness than other traditional survey methods even with a lower response rate. Therefore, in view of improving the response representativeness, questionnaires were administered voluntarily to a purposive sample of actors and then follow ups of reminder email and telephone calls were made to non-respondents.

As part of the exploratory stage, qualitative data was assembled by interviewing actors from a wide spectrum of the CHP-DH industry. Interview is a common avenue to gauge and draw insights from actor's perception and it also offered the researcher the opportunity to modify or update its enquiry pattern (Robson, 2002 pg:273). The interview approaches used were face-to-face and voice-to-voice approaches. The interviews were semi-structured to allow more flexibility and responsiveness, while having a focused engagement. This is as oppose to the fully structured or unstructured interviews that do not integrate flexibility for the actor or the researcher.

Forty-six interviews were conducted cutting across eleven delineated spheres of the CHP-DH industry in the UK with another four actors choosing to respond via written submission. In arriving at the sample size for the qualitative data, a multi-stage sampling was used, since clustered sampling strategy had been used to divide the samples into groups of similar characteristics such as LAs and Universities with CHP-DH systems were grouped together, and purposive sampling strategy was used to get samples from the groups in the sample frame based on their roles and portfolio. This suggest that the rationale for the selection of sample for the interviews is purely based on my judgement of how influential the actor may be due to its position (Robson, 2011 pg:275).Therefore samples were selected purposively from each category until I was successful to arrange an interview. This iterative process starts with sending letters to selected samples from the sample frame requesting for interviews before scheduling interviews with actors that are happy to. The entire period for qualitative data gathering started before and continued long after the quantitative data gathering. This was because the first interview session conducted few months before the commencement of the questionnaire distribution which was with a policy consultant with one of the industry networks provided useful inputs to the development of the questionnaires. Subsequently, interviews were arranged based on availability by respondents and responses from questionnaires. Suggesting that purposive sampling strategy was further used in selecting samples from the questionnaire responses – some respondents gave additional textual backup to their decision, which in the researcher's judgement needed further interrogation with the respondent.

Furthermore, more interviews were conducted after research findings were being reported, this was with a view to seek feedback from actors on some recommendations of the research. This resulted in the entire qualitative data gathering to span through 24months (February 2015 – February 2017). As with the response rate, there is no established test to ascertain the sample size to attain qualitative data saturation (Guest et al., 2006). Therefore, interview targets were drawn purposively from the sample frame and enhanced purposive sampling from some questionnaire responses until theoretical saturation was achieved.

All interviews were taped, transcribed, codified and analysed. The list of interviewees and the coding format used for the analysis is contained in appendix 1, while the various interview transcriptions are also attached digitally in a memory disk. The third and final phase saw the synthetisation of the collated data from both the quantitative and qualitative methodologies for explanation and recommendation of further pathways that may influence the penetration of CHP-DH system in the UK.

A major challenge to note in the qualitative data gathering was the difficulty to get an interview scheduled as there was strong apathy to give interviews considering that it could be time consuming and it was considered by many as a distraction to their primary job. Furthermore, the transcription process that followed the interview process was a painful, long and difficult one that precipitated huge documentary evidence. While a similar challenge was evident in collecting the quantitative data because many respondents felt that they have been inundated with similar request, surrounding energy efficiency and energy policy. However, it was much easier to get respondents to respond to a questionnaire than arrange an interview, because the questionnaires could be filled at any location, while a more serene environment is needed to grant an interview. Below are particular challenges that ensued using the online software during the quantitative data gathering.

6.8.1 Challenges of Survey Software

The online software (survey monkey) was used and it was generally useful and efficient but not optimal. Partly, this was because some inherent challenges associated with online survey set out by Evans and Mathur (2005) and Sills and Song (2002), emerged. In respect to this research three challenges were experienced with the online software, which are narrated as follows:

- **Perception of mail:** Firstly, most often the sent mail (unsolicited and solicited) would reside in the junk or spam folder of the respondents and initially this caused a bit of uncertainty as to whether mails were reaching its destination. However, after a few replies the researcher was assured of the mails being received by the receipt of some replies, but as a remedy to that challenge, a paragraph was included in the follow up mail to indicate the possibility of the survey mail being in their junk folder. This mitigated this challenge a great deal, but another challenge ensued, which was irredeemable by either the respondents or the researcher and that was the system virus protection deployed in various respondent’s software environment. As a result of virus protection, mails sent to many respondents were blocked by their local IT systems. This was uncovered after several phone calls and follow up emails, which led to directly sending the respondents a web link. However, a secondary problem emerged with this solution as the responses from these respondents couldn’t be identified individually via their address, since the responses came back without addresses. Therefore, respondents from web link couldn’t be used to categorise respondents for further research, such as if the need arises to segregate university CHP-DH operators from hospital operators, but for the purpose of this research all were subsumed in the respondents list/group.

- **Systematic – Software operation:** Another major challenge which ensued was mainly that of the software developers, because in a few instances it took 6-8 hours for respondents to receive the link to the questionnaire due to either system (survey monkey) congestion or malfunction. Several complaints to the software developers led to this being fixed but not before many respondents were left frustrated and discouraged. However, respondents were reassured on resumption of the system, but this impacted on the response rate negatively.

- **Systematic - Data Administration:** Survey monkey software does not provide the opportunity to automatically generate the response rate of a survey, rather it provides only the total number of responses (completed and partial) and expects the researcher to manually download the contacts in the sent list so as to access the total number of contacted respondents in a list. If a survey is conducted with several email lists with reminder contacts, it proves a challenge in arriving at the total contact list. In part because the researcher has to manually go through each sent list and extract the email contacts so that the final contact list does not contain duplicates. Therefore, for research like this with over a hundred sent list and with some mail list containing over a hundred email contacts, it can prove challenging.

6.9 Reliability/Validity Test

Reliability and validity are important in both quantitative and qualitative research in reducing errors and improving the trustworthiness of the research (Roberts et al., 2006). Reliability is define as when a procedure of research such as questionnaire can produce similar results in a different circumstance, while validity is the closeness of what is being measured and what is intended to be measured (Roberts et al., 2006). However, reliability and validity are defined differently in quantitative and qualitative methods. For instance, in quantitative research, reliability means if the result can be replicated and viability means if the means of measuring is accurate and measuring what they are intended to measure. While in qualitative research, reliability and validity concepts are used interchangeably and it reflects the credibility, transferability and trustworthiness of the research (Golafshani, 2003). Nonetheless, both research method strive to demonstrate and show that the results are credible, but credibility in quantitative research is a function of the instruments used, while in a qualitative research, it is a case of the researcher being the instrument (Golafshani, 2003).

In gathering the quantitative data, the three sets of questionnaires as earlier highlighted was the instrument of investigation. An initial pilot run of the questionnaires with two of my research colleagues to ensure the questions were relevant and appropriate and to further improve the validity of quantitative data (Roberts et al., 2006). Secondly, the instrument of gathering quantitative data was an online survey software (Survey monkey) and analysis was done with a statistical analytical software (SPSS) which ensures consistencies of result output. In determining the internal reliability of the quantitative data, a Cronbach's Alpha test was used in the SPSS software. Cronbach's Alpha is the widely used indictor for the internal consistency of an instrument and if its result is 0.7 and above, its considered reliable (Bryman and Cramer, 2011 pg:78, Black, 2005 pg:279). The results of the statistical reliability test for the three groups are CHP-OPS - .879, LAs - .891 and Consultant - .877. Therefore using reliable software's for quantitative data gathering and analysis to generate consistent results contributes to the reliability and validity of the research (Kothari, 2004 pg:74).

The interviewees selected for the qualitative research were carefully selected based on their advisory or decision-making portfolios they held in their organisations, which lend credence to them being experts with contemporary knowledge of the CHP-DH industry and enhances the credibility of the research. In gathering the qualitative data, adequate care was taken to improve the reliability of the qualitative data by ensuring the accuracy of the tape-recording of the interviews, by using a digital voice recorder (Philips voice tracer) and careful transcription of the interview (Roberts et al., 2006). Furthermore, triangulation was used to improve the validity of the qualitative data as several data gathering sources were adopted to confirm the data and acceptance of completeness by cross-checking with already published literatures (Halcomb and Andrew, 2005). Also, of note, was the use of NVIVO software (a computerized a data analysis software) as the analytical tool for the qualitative data. The use of this software provided the opportunity to systematically code the transcripts, detect patterns that are categorized as themes and store the data for easy retrieval, which enhances the reliability of the research. However, there are other ways to reduce researcher bias and increase the research validity that was not used by the researcher, such as feedback to all the respondents on the outcome of the data analysis obtained from them for validation of their impression or perception. This method was not adopted due to resource limitations of this research relating to time and cost.

Qualitative research is described by Onwuegbuzie and Leech (2007) as incapable of being assessed for validity, "rather validity is relative to purpose and circumstance". They argue that instead of an assessment being used to admit or dismiss varying interpretations of data or evaluate or increase legitimation or both, other measures such as audit trail, sample representativeness and triangulation can be used. Therefore, to improve the validity of this research, other measures were taken in addition to data triangulation. This included an audit trail, which required the researcher to keep detailed records of all activities during the research process, from reviewed documents, transcripts of interview and responses to questionnaires. Transcripts and questionnaire responses are attached as appendices to this research.

Generally, carefully research design pathway was taken to capture the heterogenous actors and dynamic interaction between actors that can influence the diffusion of CHP-DH in the UK. Such as the interaction between LA planners and Energy managers within the same council by seeking contribution from both actors. This deliberate approach in designing the research is with a view to improve the reliability of the research (Kothari, 2004 pg:32-33).

6.10 Data Analysis

Quantitative data analysis was done using SPSS (statistical analytical software package). All questions from all three groups will be analysed to draw on descriptive and inferential analysis. While the qualitative data was analysed using NVIVO software and the output from the software was used in two different ways. They were used in generation of thematic inference – meaning a common theme was identified and drawn from the interviews and secondly, citations were directly quoted from the main body of interviews. This enable me to triangulate the qualitative data and derive complimentary and common text units that supports similar pattern with the quantitative data. Using NVIVO helped saved time by tracing common themes from the large body of text quickly. However, the researcher considers NVIVO as not too user friendly, because of how much time and effort is required to study the software to be able to navigate through its functions and this also goes for SPSS, which requires more pre-analysis studies to understand the various analytical methodologies and interpretation techniques before actual analysis.

6.11 Ethical considerations

This research was subject to certain ethical issues. For instance, as part of the qualitative process of interviewing participants for a recorded interview, a consent form was prepared for this thesis by the University of Exeter, which was given to me to send to participants before any interview commences. This was with a view to extract their consent to record the interview before it commences. The form captures the purpose of the interview and informs the interviewee that the interview shall be recorded, and it is part of an academic project which the University can use in a number of ways. Such as research teaching, printed publications, exhibition and so on. The form also seeks to assuage the interviewees that the recorded information and personal details/information provided during the interview shall be used in accordance with the UK data protection act.

Similarly, each questionnaire had a consent page at the beginning of the survey and the survey cannot continue until the participants gives its consent by clicking a next to agree button. The consent page also seeks to assure participants of the confidentiality of their personal data according to the data protection act. It also informed the participants of the various ways the university may use the data but in an anonymous way to conceal their details except the group/category they belong to in the research categorisation list. Secondly, the participants were informed that they have the choice at any time during the survey to withdraw their consent if they wish.

6.12 Concluding Remarks

This chapter seeks to capture the objectives of this research and the methodology that would be adopted to provide answers to the research questions. The research objectives were summarized into four questions and a flexible methodological research approach was adopted. The methodological approach consists of both quantitative and qualitative pathways, which will set the scene for analysis and discussion to address the objectives of this research. The next three chapters shall be discussing the results with a view to use them to answer the research questions as earlier enumerated.

7.0 Results – Statistical Outputs and Governance Map

This chapter captures the statistical results that seeks to provide analytical inputs to the discussion chapter. It also contains the interpretation of the statistical outputs. The sequencing of the statistical results in this chapter shall take the form of three sections, which shall capture responses to quantitative questions considered in each of the discussion chapters. Therefore, this chapter is divided into the three sections, namely, Firstly, Prevailing Landscapes of CHP-DH systems in the UK and risk profile. Secondly, CHP barriers and alternative LA roles, thirdly, Governance mechanisms.

This chapter also captures the CHP-DH industry governance map drawing upon the governance structure and mechanisms that are prevailing in the electricity and heat sectors in the UK, which may impact on the penetration of CHP-DH system in the UK.

7.1 Results - Prevailing Landscapes of CHP-DH systems in the UK and risk profile

Q 1. What is the capacity of your CHP in operation (Percentage) n=97

CHP	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
< 5 MWe	73 (76)	24 (70.6)	11 (68.8)	6 (66.7)	4 (57.1)	4 (80.0)	4(80.0)	3 (75.0)	3 (75.0)	4(80.0)	136 (73.9)
6 – 10 MWe	9 (9.3)	5 (14.7)	2 (12.5)	0	1 (14.3)	0	0	0	0	0	17 (9.2)
11 – 50 MWe	6 (6.25)	1 (2.9)	0	1 (11.1)	0	0	0	0	0	0	8 (4.3)
51 – 100 MWe	1(1)	0	0	0	0	0	0	0	0	0	1 (0.5)
> 100 MWe	7(7.2)	4 (11.8)	3 (18.8)	2 (22.2)	2 (28.6)	1 (20.0)	1(20.0)	1 (25.0)	1 (25.0)	1(20.0)	22 (11.9)
Total	96 (100)	34 (100)	16 (100)	9 (100)	6 (100)	5 (100)	5 (100)	4 (100)	4 (100)	5 (100)	184 (100)

Table 11: Electrical portfolio of CHP systems in the UK

Table 11 above shows that the dominant percentage of CHP electrical capacity sizes for all sites from respondents is less than $5MW_e$. For instance, 73.9% of the electrical capacity of CHP in operation by the respondents are less than $5MW_e$. Therefore

<5MW electrical capacity is the dominant capacity range in the UK CHP-DH landscape.

Q 2. What is the capacity of your heat network operation (Percentage) n=94

CHP	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
< 5 MWth	52 (55.9)	21 (65.6)	10 (66.7)	5 (55.6)	3 (50.0)	3 (60.0)	3 (60.0)	3 (75.0)	3 (75.0)	4 (66.7)	106 (59.6)
6 – 10 MWth	15 (16.1)	4 (12.5)	0	1 (11.1)	2 (33.3)	1 (20.0)	1 (20.0)	0	0	1 (16.7)	25 (14)
11 – 50 MWth	14 (15.1)	3 (9.4)	1 (6.7)	1 (11.1)	0	0	0	0	0	0	19 (10.7)
51 – 100 MWth	7 (7.5)	2 (6.3)	1 (6.7)	0	0	0	0	0	0	0	10 (5.6)
> 100 MWth	5 (5.4)	2 (6.3)	3 (20.0)	2 (22.2)	1 (16.7)	1 (20.0)	1 (20.0)	1 (25.0)	1 (25.0)	1(16.7)	18 10.1)
Total	93 (100)	32 (100)	15 (100)	9 (100)	6 (100)	5 (100)	5 (100)	4 (100)	4 (100)	5 (100)	178 (100)

Table 12: Heat Network Portfolio pattern

Table 12 above shows that the dominant percentage of the size of heat capacity in CHP-DH systems for all sites from respondents is less than $5MW_{th}$. For instance, 59.6% of the heat capacity of CHP-DH systems in operation by the respondents are less than $5MW_{th}$. Therefore $<5MW_{th}$ heat capacity is the dominant capacity range in the UK CHP-DH landscape.

Q 3. What is the mode of operation of your CHP plant (Percentage) n=97

CHP	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
Heat Led	53 (53.5)	15 (44.1)	10 (66.7)	4 (50.0)	4 (80.0)	4 (100)	4 (100)	3 (100)	3 (100)	4 (100)	104 (58.1)
Electricity Led	39 (39.4)	15 (44.1)	3 (20.0)	3 (37.5)	1 (20.0)	0	0	0	0	0	61 (34.1)
Standby	0	0	0	0	0	0	0	0	0	0	0 (0)
No answer	7 (7.1)	4 (11.8)	2 (13.3)	1 (12.5)	0	0	0	0	0	0	14 (7.8)

Table 13: Dominant Mode of Operation of CHP-DH plants

Table 13 above shows that the dominant mode of operation of CHP-DH systems in the UK heat led. For instance, 53.5% and 44.1% of the first and second sites respectively of the respondents are heat led operated. Therefore, the dominant operational pattern in the UK CHP-DH landscape is heat lead operation.

Q 4. What is the length of your heat network? (Percentage) n=98

Length	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
< 1 KM	38 (39.2)	20 (55.6)	11 (68.8)	6 (66.7)	4 (66.7)	3 (60.0)	3 (60.0)	3 (60.0)	3 (75.0)	3 (60.0)	94 (50.2)
2 – 5 KM	34 (35.1)	7 (19.4)	1 (6.3)	0	1 (16.7)	1 (20.0)	1 (20.0)	0 (20.0)	0	0	45 (24.1)
6 – 10 KM	8 (8.2)	2 (5.6)	1 (6.3)	2 (22.2)	0	0	0	0	0	0	13 (7)
11 – 20 KM	3 (3.1)	1 (2.8)	1 (6.3)	0	0	0	0	0	0	0	5 (2.7)
> 20 KM	4 (4.1)	0	0	0	0	0	0	0	0	0	4 (2)
No Answer	10 (10.3)	6 (16.7)	2 (12.5)	1 (11.1)	1 (16.7)	1 (20.0)	1 (20.0)	1 (20.0)	1 (25.0)	2 (40.0)	26 (14)

Table 14: Dominant length of heat network in the UK

Table 14 above shows that the dominant percentage of the length of heat networks in CHP-DH systems for all sites from respondents is less than 1KM. For instance, 39.2% and 55.6% of the heat network length of CHP-DH systems in operation in the first and second sites respectively of the respondents are less than 1KM. Therefore <1KM is the dominant heat network length in the UK CHP-DH landscape.

Q 5- What is your assessment of the level of maturity in the UK district heating supplier chain? CHP Operator and Consultants

			Group		Total
			CHP operator	Consultants	
What is your assessment of the level of maturity in the UK district heating supplier chain?	Mature	Count	6	0	6
		% within Group	4.4%	0.0%	3.7%
	Infancy but growing	Count	42	21	63
		% within Group	30.7%	77.8%	38.4%
	Infancy and stagnant	Count	23	4	27
		% within Group	16.8%	14.8%	16.5%

	Non-existence	Count	8	0	8
		% within Group	5.8%	0.0%	4.9%
	No answer	Count	58	2	60
		% within Group	42.3%	7.4%	36.6%
Total		Count	137	27	164
		% within Group	100.0%	100.0%	100.0%

Table 15: Assessment of CHP-DH industry in the UK

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	23.370[a]	4	.000
Likelihood Ratio	26.316	4	.000
Linear-by-Linear Association	15.046	1	.000
N of Valid Cases	164		

a. 3 cells (30.0%) have expected count less than 5. The minimum expected count is .99.

Table 16: Chi square - Assessment of maturity

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.377	.000
	Cramer's V	.377	.000
N of Valid Cases		164	

Table 17: Measure of association (effect size)

Results from Table 16 above shows that the expected count of the cells is 30% which is more 20% (i.e > 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 26.316 and its corresponding p value was 0.000<0.05 (likelihood ratio =26.316, df = 4, p = .000). Since the p value was less than 0.05, we can conclude that, there is a significant difference in the level of maturity in the UK district heating supplier chain between the CHP operators and consultants. Therefore, we can draw upon the descriptive results from Table 15 above which indicates that about 30.7% of the CHP operators and 77.8% of the consultants expressed that the level of maturity in the UK district heating is at infancy but growing. Hence, there is evidence to conclude that the level of maturity of the CHP-DH industry in the UK is at infancy but growing. Furthermore, drawing from the results of Table 17, the value of Cramer's V is 0.377, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study tends to a medium effect (i.e 0.5) according to Fritz et al. (2012).

Q 6. How do you trade electricity from CHPs? (Percentage) n=98

CHP	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
Consolidator	5 (4.9)	1 (2.9)	1 (6.7)	1 (11.1)	0	0	0	0	0	0	8 (4.2)
Bilateral	3 (2.9)	0	0	1 (11.1)	0	0	0	0	0	0	4 (2.1)
Direct supplier	13 (12.6)	6 (17.1)	3 (20.0)	1 (11.1)	2 (33.3)	2 (33.3)	2 (40.0)	1 (25.0)	1 (25.0)	1 (20.0)	32 (16.7)
Onsite	70 (68.0)	24 (68.6)	9 (60.0)	5 (55.6)	3 (50.0)	3 (50.0)	3 (60.0)	3 (75.0)	3 (75.0)	3 (60.0)	126 (66)
No answer	12 (11.7)	4 (11.4)	2 (13.3)	1 (11.1)	1 (16.7)	1 (16.7)	0	0	0	1 (20.0)	21 (11)

Table 18: Mode of Electricity Trading from CHP

Table 18 above shows that the dominant percentage of how electricity is traded from CHPs in the UK is rather consumed onsite. For instance, 68.0% and 68.6% of the respondents with their first and second sites respectively consume their electricity onsite. Therefore, most respondents of different sites trade electricity from their CHPs Onsite.

Q 7 - What nature of electricity distribution is adopted in distributing electricity from CHP (n – 95)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Only on Private network	51	53.7	53.7	53.7
	Only on Public network	3	3.2	3.2	56.8
	Mostly on Private network	15	15.8	15.8	72.6
	Mostly on Public network	5	5.3	5.3	77.9
	Mostly hybrid of both	4	4.2	4.2	82.1
	No answer	17	17.9	17.9	100.0

Total	95	100.0	100.0	

Table 19: Path of Electricity Distribution

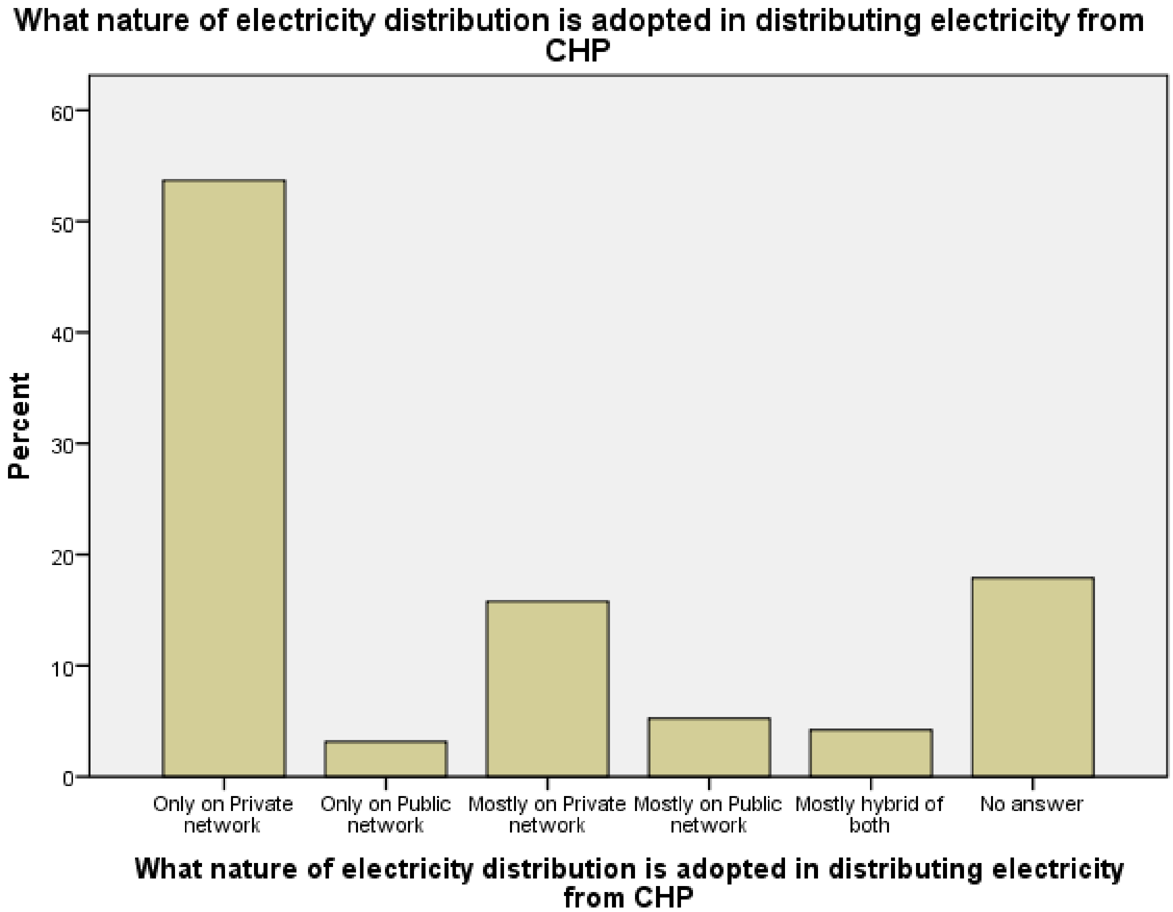

Figure 15: Graph of Electricity distribution adopted

Results from Table 19 and Figure 15 suggest that 53.7% of respondents distribute their electricity only through private networks. This suggests that private network is the dominant path of how CHPs in the UK distribute their electricity.

Q 8 - What economic model is adopted for the CHP – DH project? (Percentage) n = 86

Economic model	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
Fully commercial	23 (26.7)	12 (42.9)	7 (63.6)	5 (83.3)	3 (100)	3 (100)	3 (100)	2 (100)	2 (100)	2 (66.6)	62 (42.2)
Partially commercial with profit caps	5 (5.8)	1 (3.6)	0	0	0	0	0	0	0	0	6 (4.1)
Cooperative / Non Profit	20 (23.3)	4 (14.3)	1 (9.1)	1 (16.7)	0	0	0	0	0	0	26 (17.7)
No answer	38 (61.0)	11 (39.3)	3 (27.3)	0	0	0	0	0	0	1 (33.3)	53 (36)

Table 20: Economic Model of CHP-DH industry

Table 20 above shows that the dominant percentage of the adopted economic model by respondents is fully commercial.

Q 9 - What are your class of heat consumers? (Percentage) n = 84

Class of heat consumers	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
Domestic	13 (14.0)	1 (3.0)	1 (6.3)	0	0	0	0	0	0	0	15 (8.3)
Industry	12 (12.9)	3 (9.1)	2 (12.5)	2 (22.2)	2 (28.6)	1 (20.0)	1 (20.0)	1 (25.0)	1 (25.0)	1 (20.0)	26 (14.4)
Commercial	34 (36.6)	13 (39.4)	9 (56.3)	3 (33.3)	1 (14.3)	2 (40.0)	2 (40.0)	1 (25.0)	1 (25.0)	1 (20.0)	67 (37.2)
Mixed	22 (23.7)	10 (30.3)	3 (18.8)	4 (44.4)	2 (28.6)	2 (40.0)	2 (40.0)	2 (50.0)	2 (50.0)	3 (75.0)	53 (29.4)
No Answer	12 (12.9)	6 (18.2)	1 (6.3)	0	2 (28.6)	0	0	0	0	0	19 (10.6)

Table 21: Heat Customer profile in the UK

Table 21 above indicates that the dominant class of heat customers by respondents are commercial ones with 67% of total sites respondents.

Q 10 - What form of management model is used for the CHP – DH project? (Percentage) n = 82

Management model	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Total
Fully integrated Energy Services Company (ESCO)	23 (28.0)	8 (28.6)	6 (54.5)	3 (50.0)	1 (33.3)	1 (33.3)	1 (33.3)	0	0	1 (33.3)	44 (30.8)
Same production, distribution and supply entities	4 (4.9)	1 (3.6)	0	0	0	0	0	0	0	1 (33.3)	6 (4.2)
Separate production and distribution with different supply entity	3 (3.7)	1 (3.6)	1 (9.1)	1 (16.7)	1 (33.3)	1 (33.3)	1 (33.3)	1 (50.0)	1 (50.0)	0	11 (7.7)
Same production and supply with different distribution entity	1 (1.2)	0	0	0	0	0	0	0	0	0	1 (0.69)
Same distribution and supply with different	1 (1.2)	1 (3.6)	0	1 (16.7)	0	0	0	0	0	0	3 (2.1)

production entity											
No answer	50 (61.0)	17 (60.7)	4 (36.4)	1 (16.7)	1 (33.3)	1 (33.3)	1 (33.3)	1 (50.0)	1 (50.0)	1 (33.3)	78 (54.5)

Table 22: Management used for CHP-DH project

Table 22 above did not offer clear indication of the type of management model adopted by the respondents due to the high value of no answer. However, from the respondents that chose a mode of management, more respondents indicated a fully integrated energy services company (ESCO) model as the management model adopted

Q 11 - Is there any CHP-DH project in the area covered by your Local authority

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	60	43.5	45.8	45.8
	Don't Know	19	13.8	14.5	60.3
	Not at all	52	37.7	39.7	100.0
	Total	131	94.9	100.0	
Missing	System	7	5.1		
Total		138	100.0		

Table 23: CHP-DH Projects in LAs

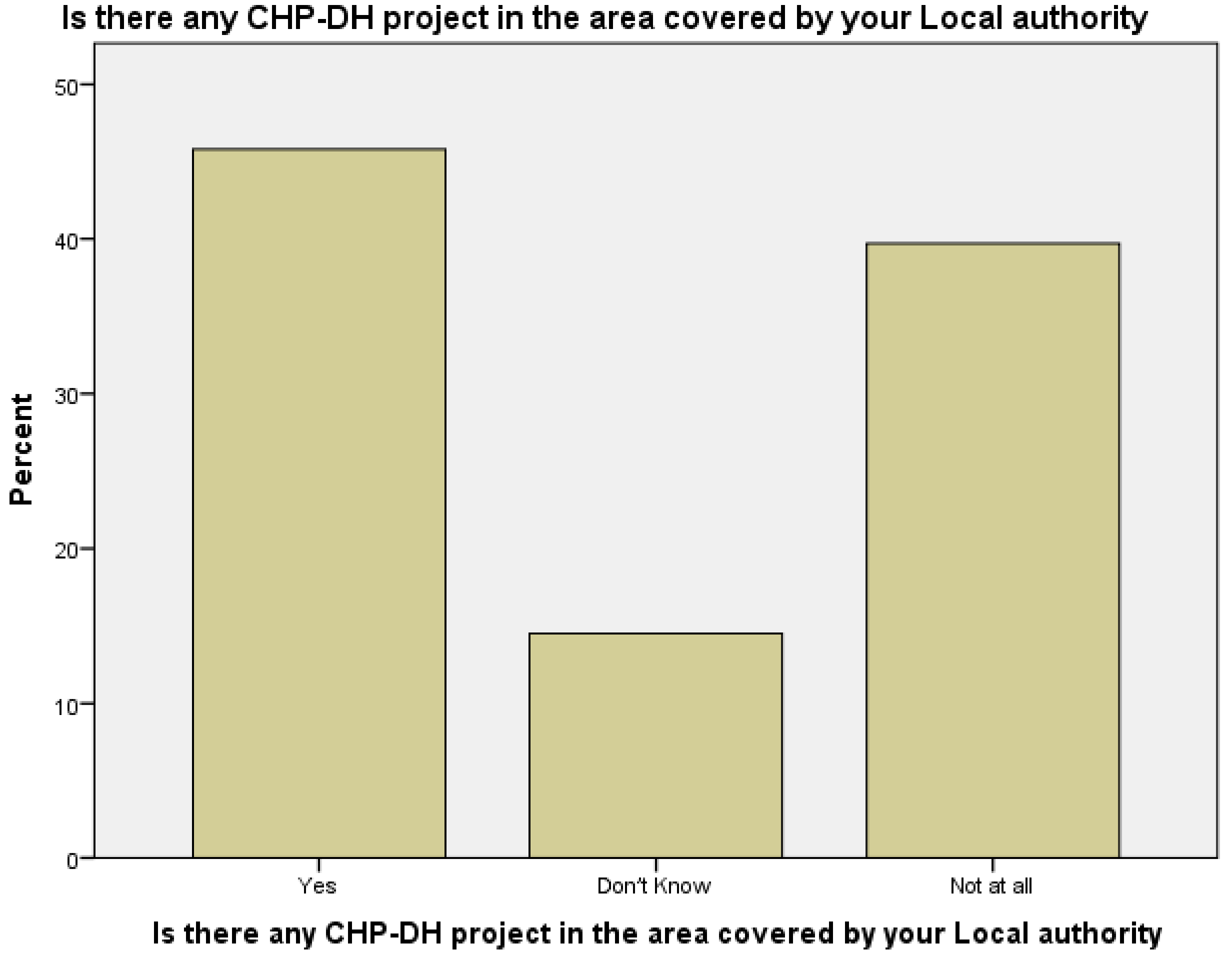

Figure 16: CHP-DH projects in LA

From the Table 23 above and Figure 16, we can observe that, 45.8% of the LAs expressed that, there is CHP – DH project in the area covered by their local authority. While about 14.5% of the respondents don't know and 39.7% of LAs don't have at all. The following bar chart in Figure 16, also shows taller bar corresponding to the same.

Q 12 - Is your local authority directly involved in any CHP-DH project?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Been involved	14	10.1	10.1	10.1
	Ongoing	46	33.3	33.3	43.5
	Considering	35	25.4	25.4	68.8
	Not considering	30	21.7	21.7	90.6
	No answer	13	9.4	9.4	100.0
	Total	138	100.0	100.0	

Table 24: LA involvement in CHP-DH project

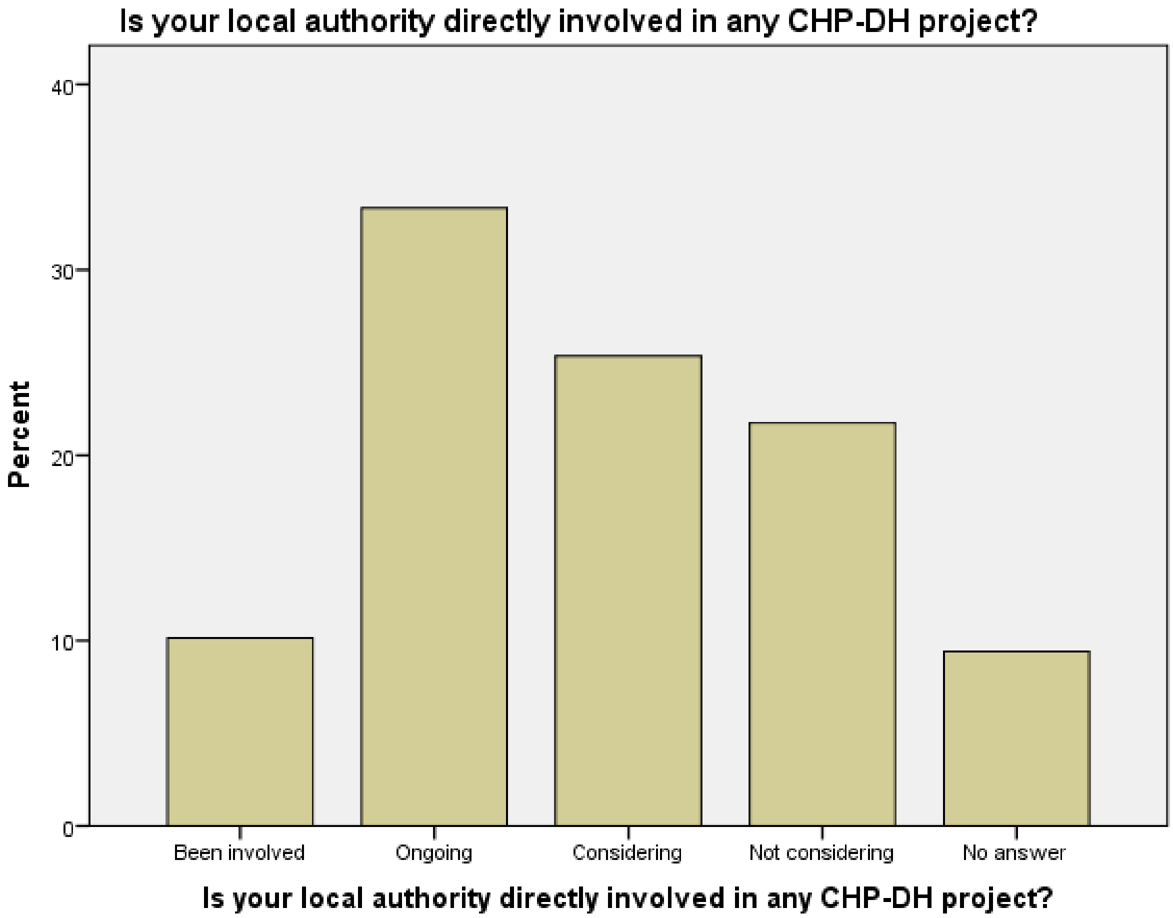

Figure 17: LA involvement in CHP-DH project

From the Table 24 and Figure 17 above we can observe that, 33.3% of the LAs expressed that, their local authority is directly involved in any CHP – DH project. Following the bar chart in Figure 17, it also shows taller bar corresponding to the same.

Q 13 - Risk Analysis Profile of the CHP-DH industry in the UK

Report

Group		Policy uncertainty	Absence of State capital incentive	Lack of local authority incentive	Absence of regulatory regime for heat	Absence of a heat market in the UK	Electricity off-take risk	Heat off-take risk	Developmental/Connection to electricity grid risk	Potential for change in the taxation regime	Tradition of private provision of public goods	Level of public opposition to project
CHP Operators	Mean	3.1053	3.2316	2.8421	2.6316	2.6632	2.4632	2.5474	2.8105	3.1263	1.8842	2.0526
	N	95	95	95	95	95	95	95	95	95	95	95
	Std. Deviation	1.32467	1.28372	1.41659	1.41461	1.56158	1.49332	1.58294	1.51092	1.44577	1.44298	1.25790
Consultants	Mean	3.4074	3.0741	2.6296	3.0370	2.9259	2.1481	3.1481	2.5926	3.0741	1.7037	1.6667
	N	27	27	27	27	27	27	27	27	27	27	27
	Std. Deviation	1.69296	1.46566	1.39085	1.45395	1.43918	1.40613	1.32153	1.18514	1.43918	1.29540	1.14354
LAs	Mean	3.1957	3.4203	3.2101	2.9348	2.9565	2.1377	2.3043	2.9710	2.6739	2.0217	2.0290
	N	138	138	138	138	138	138	138	138	138	138	138
	Std. Deviation	1.41864	1.34984	1.43701	1.41528	1.46427	1.56229	1.67249	1.54231	1.51471	1.53531	1.36131
Total	Mean	3.1846	3.3154	3.0154	2.8346	2.8462	2.2577	2.4808	2.8731	2.8808	1.9385	2.0000
	N	260	260	260	260	260	260	260	260	260	260	260
	Std. Deviation	1.41304	1.33867	1.43581	1.42223	1.49884	1.52424	1.62141	1.49750	1.49297	1.47700	1.30340

Table 25: Risk profile descriptive table

Report

Group		Land acquisition and compensation	Availability of finance	Financial attraction of project to investors	Cost of Finance	Delay in planning permission	Planning permission risk	Unavailability of CHP-DH construction Skills	Construction on time & cost overrun	Operation cost overrun and revenue expectation	Local authority experience in Public Private Partnership/Public Finance Initiative
CHP Operators	Mean	2.0421	3.4105	3.2316	3.2737	2.7895	2.7474	2.5684	2.8000	3.0842	2.4737
	N	95	95	95	95	95	95	95	95	95	95
	Std. Deviation	1.32019	1.44026	1.57408	1.25004	1.51513	1.50155	1.54129	1.37299	1.30191	1.50773
Consultants	Mean	1.5185	2.5556	2.8148	2.3704	2.0370	2.0370	2.8889	2.2222	2.5556	2.6667
	N	27	27	27	27	27	27	27	27	27	27
	Std. Deviation	1.01414	1.67179	1.38778	1.44510	1.05544	1.31505	1.33973	1.39596	1.42325	1.73205
LAs	Mean	2.3913	3.4420	3.3913	3.0000	2.4855	2.4203	2.7609	2.8116	2.9783	3.0435
	N	138	138	138	138	138	138	138	138	138	138
	Std. Deviation	1.44199	1.39351	1.44704	1.63448	1.37886	1.39766	1.43753	1.47757	1.53055	1.37161
Total	Mean	2.1731	3.3385	3.2731	3.0346	2.5500	2.5000	2.7038	2.7462	2.9731	2.7962
	N	260	260	260	260	260	260	260	260	260	260
	Std. Deviation	1.38276	1.46017	1.49337	1.50249	1.41469	1.43992	1.46543	1.43756	1.44234	1.48115

Risk Analysis Profile of the CHP-DH industry in the UK

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Policy uncertainty * Group	Between Groups	(Combined)	1.955	2	.978	.488	.615
	Within Groups		515.183	257	2.005		
	Total		517.138	259			
Absence of State capital incentive * Group	Between Groups	(Combined)	3.758	2	1.879	1.049	.352
	Within Groups		460.380	257	1.791		
	Total		464.138	259			
Lack of local authority incentive * Group	Between Groups	(Combined)	12.105	2	6.052	2.981	.053
	Within Groups		521.834	257	2.030		
	Total		533.938	259			
Absence of regulatory regime for heat * Group	Between Groups	(Combined)	6.407	2	3.204	1.591	.206
	Within Groups		517.481	257	2.014		
	Total		523.888	259			
Absence of a heat market in the UK * Group	Between Groups	(Combined)	5.034	2	2.517	1.121	.327
	Within Groups		576.812	257	2.244		
	Total		581.846	259			
Electricity off-take risk * Group	Between Groups	(Combined)	6.322	2	3.161	1.364	.257
	Within Groups		595.413	257	2.317		
	Total		601.735	259			
Heat off-take risk * Group	Between Groups	(Combined)	16.742	2	8.371	3.239	.041
	Within Groups		664.162	257	2.584		
	Total		680.904	259			
Developmental/Connection to electricity grid risk * Group	Between Groups	(Combined)	3.819	2	1.910	.851	.428
	Within Groups		576.992	257	2.245		
	Total		580.812	259			
Potential for change in the taxation regime * Group	Between Groups	(Combined)	12.642	2	6.321	2.877	.058
	Within Groups		564.662	257	2.197		
	Total		577.304	259			
Tradition of private provision of public goods * Group	Between Groups	(Combined)	2.725	2	1.362	.623	.537
	Within Groups		562.291	257	2.188		
	Total		565.015	259			
Level of public opposition to project * Group	Between Groups	(Combined)	3.379	2	1.690	.994	.371
	Within Groups		436.621	257	1.699		
	Total		440.000	259			
Land acquisition and compensation * Group	Between Groups	(Combined)	19.770	2	9.885	5.343	.005
	Within Groups		475.442	257	1.850		
	Total		495.212	259			
Availability of finance * Group	Between Groups	(Combined)	18.523	2	9.262	4.460	.012
	Within Groups		533.692	257	2.077		
	Total		552.215	259			

Financial attraction of project to investors * Group	Between Groups	(Combined)	7.763	2	3.881	1.750	.176
	Within Groups		569.849	257	2.217		
	Total		577.612	259			
Cost of Finance * Group	Between Groups	(Combined)	17.508	2	8.754	3.967	.020
	Within Groups		567.181	257	2.207		
	Total		584.688	259			
Delay in planning permission * Group	Between Groups	(Combined)	13.127	2	6.563	3.339	.037
	Within Groups		505.223	257	1.966		
	Total		518.350	259			
Planning permission risk * Group	Between Groups	(Combined)	12.477	2	6.239	3.057	.049
	Within Groups		524.523	257	2.041		
	Total		537.000	259			
Unavailability of CHP-DH construction Skills * Group	Between Groups	(Combined)	3.116	2	1.558	.724	.486
	Within Groups		553.081	257	2.152		
	Total		556.196	259			
Construction time & cost overrun * Group	Between Groups	(Combined)	8.278	2	4.139	2.019	.135
	Within Groups		526.968	257	2.050		
	Total		535.246	259			
Operation cost overrun and revenue expectation * Group	Between Groups	(Combined)	5.884	2	2.942	1.419	.244
	Within Groups		532.928	257	2.074		
	Total		538.812	259			
Local authority experience in Public Private Partnership/Public Finance Initiative * Group	Between Groups	(Combined)	18.773	2	9.386	4.391	.013
	Within Groups		549.423	257	2.138		
	Total		568.196	259			

Table 26: Risk profile - ANOVA Table

Measures of Association (Effect Size)

	Eta	Eta Squared
Policy uncertainty * Group	.061	.004
Absence of State capital incentive * Group	.090	.008
Lack of local authority incentive * Group	.151	.023
Absence of regulatory regime for heat * Group	.111	.012
Absence of a heat market in the UK * Group	.093	.009
Electricity off-take risk * Group	.103	.011
Heat off-take risk * Group	.157	.025

Developmental/Connection to electricity grid risk * Group	.081	.007
Potential for change in the taxation regime * Group	.148	.022
Tradition of private provision of public goods * Group	.069	.005
Level of public opposition to project * Group	.088	.008
Land acquisition and compensation * Group	.200	.040
Availability of finance * Group	.183	.034
Financial attraction of project to investors * Group	.116	.013
Cost of Finance * Group	.173	.030
Delay in planning permission * Group	.159	.025
Planning permission risk * Group	.152	.023
Unavailability of CHP-DH construction Skills * Group	.075	.006
Construction time & cost overrun * Group	.124	.015
Operation cost overrun and revenue expectation * Group	.104	.011
Local authority experience in Public Private Partnership/Public Finance Initiative * Group	.182	.033

Table 27: Measurement of Association

Summary of p and effect size values

Risk Factor	P value	Eta Square (n^2)	Associated Cohen's d value (Fritz et al., 2012)	Measure of effect according to Cohen (1992)
Heat off-take	0.041	0.025	>0.3	Towards medium

Land acquisition and compensation	0.005	.04	>0.4	Towards medium
Availability of finance	0.012	0.034	<0.4	Towards medium
Cost of finance	0.02	0.03	>0.3	Towards medium
Planning permission	0.049	0.023	0.3	Towards medium
Delay in planning permission	0.037	0.025	>0.3	Towards medium
LAs experience in PPP	0.013	0.033	>0.3	Towards medium

Table 28: Summary of p and effect size values

Drawing from the ANOVA statistical analysis in Table 26, it shows that, Heat off take risk, land acquisition and compensation, availability of finance, cost of finance, delay in planning permission, planning permission risk and Local authority experience in Public Private Partnership/Public Finance had significant difference between CHP operators, Consultants and LAs. This suggest that these risk profile have more impact on investors decision in the development of CHP-DH systems in the UK.

Furthermore, results from Table 28 suggest that the measure of contribution of an effect (taken from Table 27) of each risk factor to the observed variables, when the eta squared value from the ANOVA analysis is associated with the Cohen's d values is almost a medium effect since they are all greater than or equal to 0.3 (Fritz et al., 2012). Hence, land acquisition and compensation have the largest effect and closely followed by availability of finance.

Q 14 - What is the dominant perceived challenge in the UK before the construction of a CHP-District heating system?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Planning Consent	1	3.7	4.0	4.0
	Electricity market	3	11.1	12.0	16.0
	heat load	11	40.7	44.0	60.0
	Lack of capital	6	22.2	24.0	84.0
	Others (Please comment)	4	14.8	16.0	100.0
	Total	25	92.6	100.0	
Missing	System	2	7.4		
Total		27	100.0		

Table 29: Perceived challenges for CHP-DH Construction by Consultants

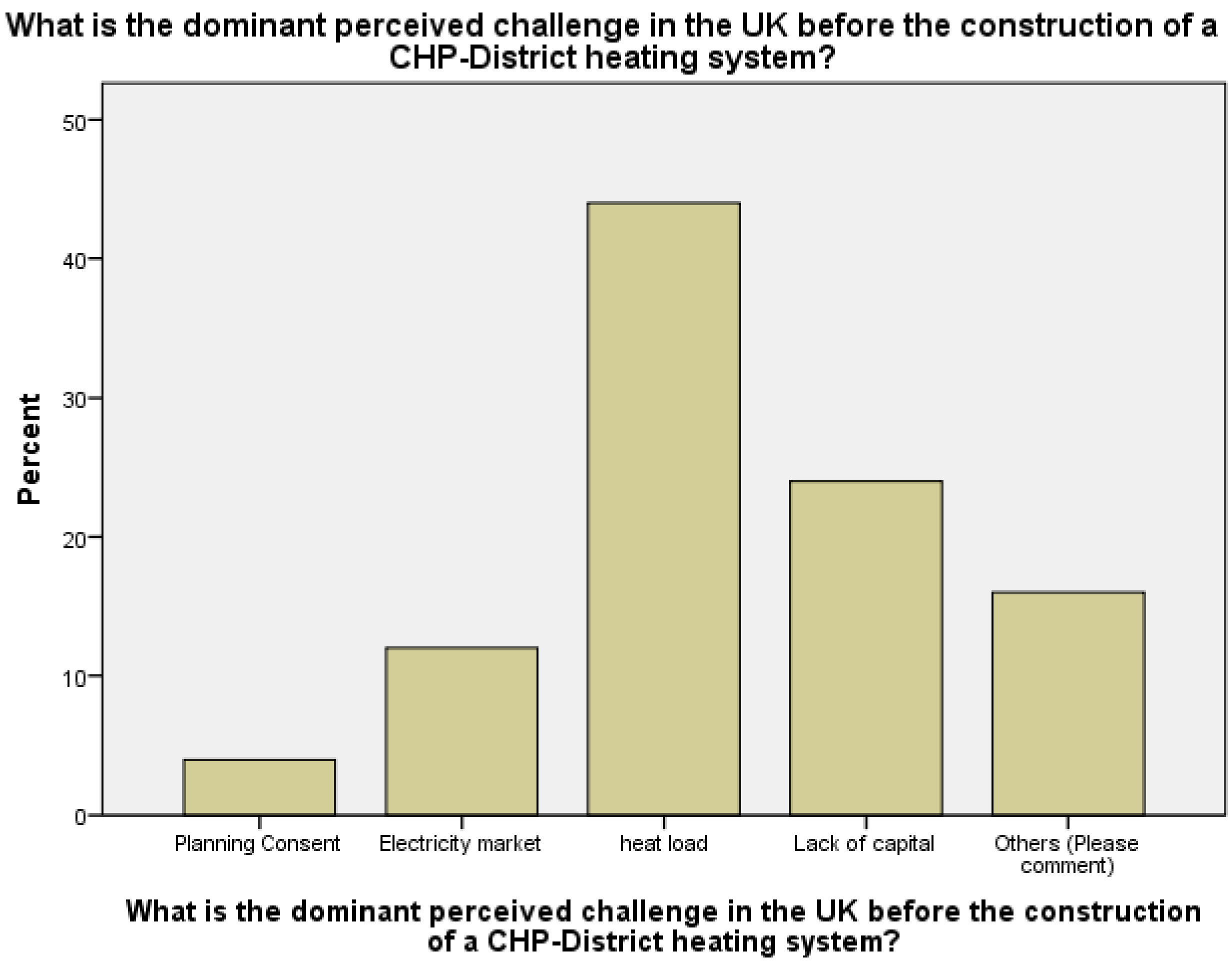

Figure 18: Bar Chart - perceived challenges for CHP-DH construction

Results from Table 29, which are responses from consultants on the dominant challenge they experience before construction. Over 40% of the respondents consider heat load as the most challenging before lack of capital, while another 24% considers lack of capital as the dominant challenge. The bar chart in Figure 18 also shows a similar trend.

Q 15 - What do you think is biggest government induced barrier to your operations?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Planning permits	3	3.2	4.1	4.1
	Taxation	14	14.7	18.9	23.0
	market	17	17.9	23.0	45.9
	Requisite skill	8	8.4	10.8	56.8
	Regulatory	21	22.1	28.4	85.1
	Suggest any	11	11.6	14.9	100.0
	Total	74	77.9	100.0	
Missing	System	21	22.1		
Total		95	100.0		

Table 30: Biggest induced barrier to CHP-DH operations

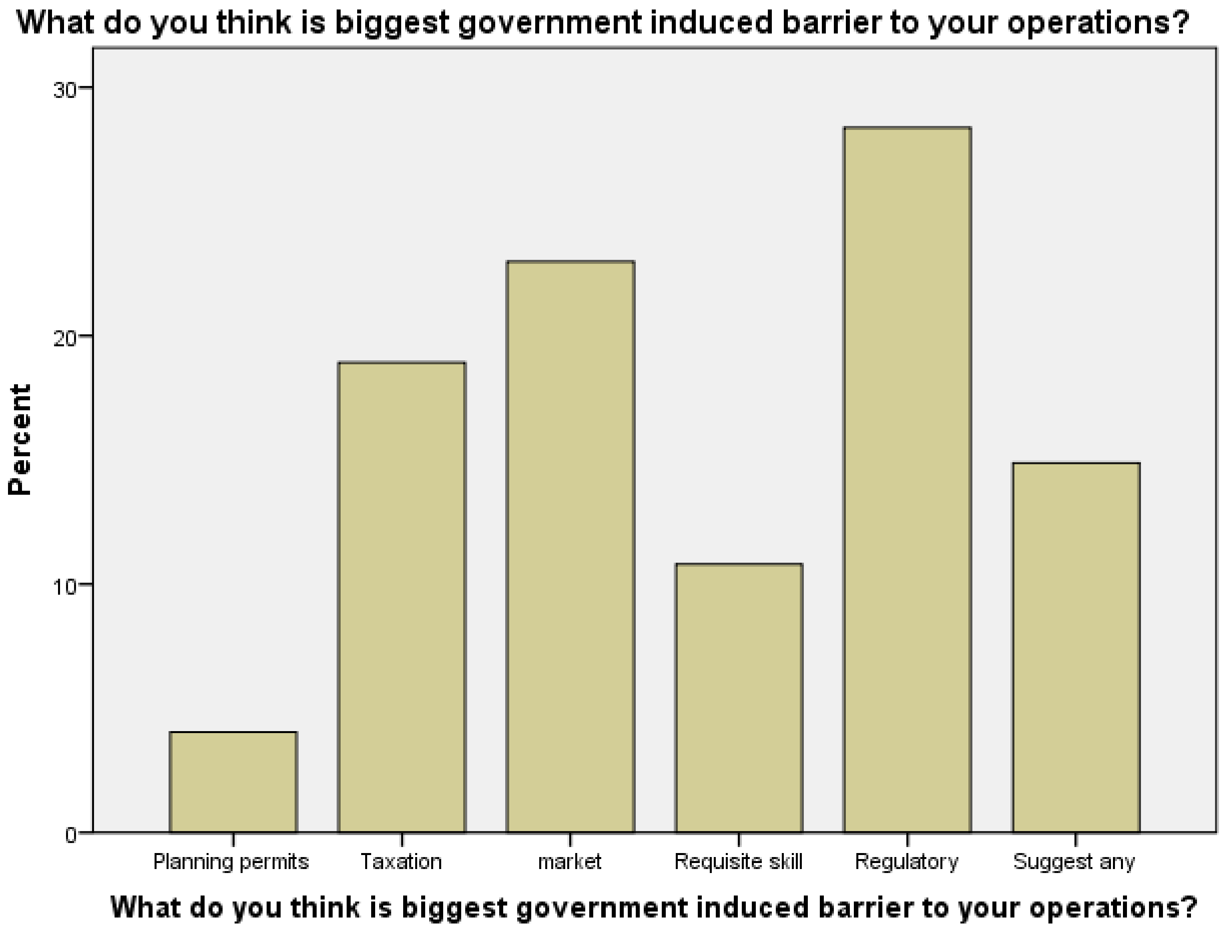

Figure 19: Bar chart - Biggest induced barrier to operations

Results from CHP-OPs respondents as shown in Table 30 shows that over 28% respondents consider regulatory as the biggest, followed by the market with 23%. Similarly, the bar chart in Figure 19 have a similar trend.

Q 16 - Private land owners are very receptive to CHP-DH projects

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Tend to agree	6	22.2	22.2	22.2
	Neither	7	25.9	25.9	48.1
	Tend to disagree	7	25.9	25.9	74.1
	Strongly disagree	1	3.7	3.7	77.8
	No answer	6	22.2	22.2	100.0
	Total	27	100.0	100.0	

Table 31: Land owners reception to CHP-DH projects

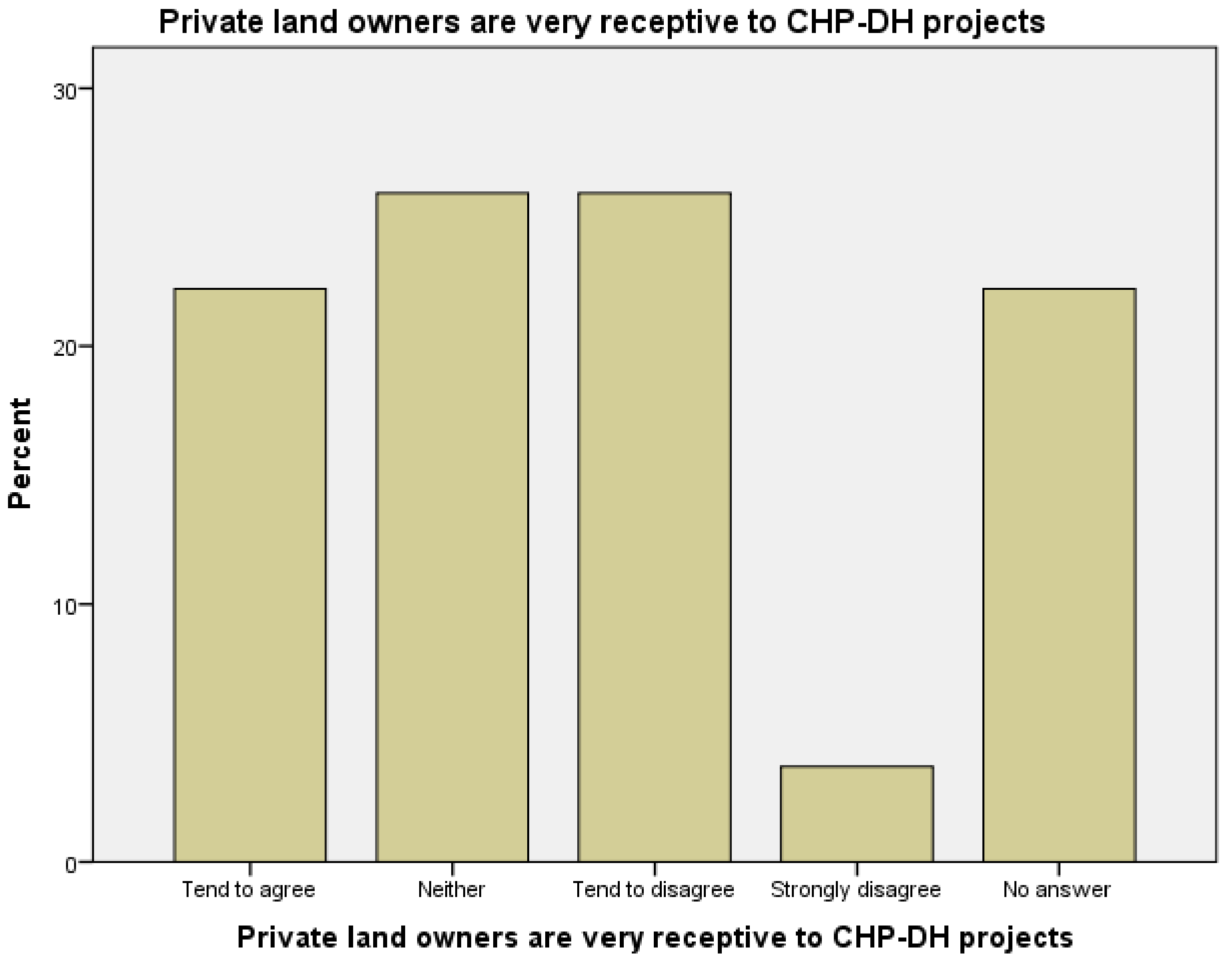

Figure 20: Bar hart - Private land owners reception to CHP-DH

Consultants were asked if they consider private land owners as receptive to the CHP-OPs projects. The results shown in Table 31 shows that respondents were strongly divided amongst tend to agree (~22%) and tend to disagree (~26%), especially when considering about 26% of respondents that are in neither position. Following the bar chart in Figure 20 also shows taller bar corresponding to the same.

Q 17 - Local authorities have the necessary capacity to engage energy services companies (ESCO) for their areas

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly agree	6	4.3	4.4	4.4
	Tend to agree	32	23.2	23.5	27.9
	Neither	21	15.2	15.4	43.4

	Tend to disagree	48	34.8	35.3	78.7
	Strongly disagree	19	13.8	14.0	92.6
	No answer	10	7.2	7.4	100.0
	Total	136	98.6	100.0	
Missing	System	2	1.4		
Total		138	100.0		

Table 32: LAs capacity to engage ESCOs

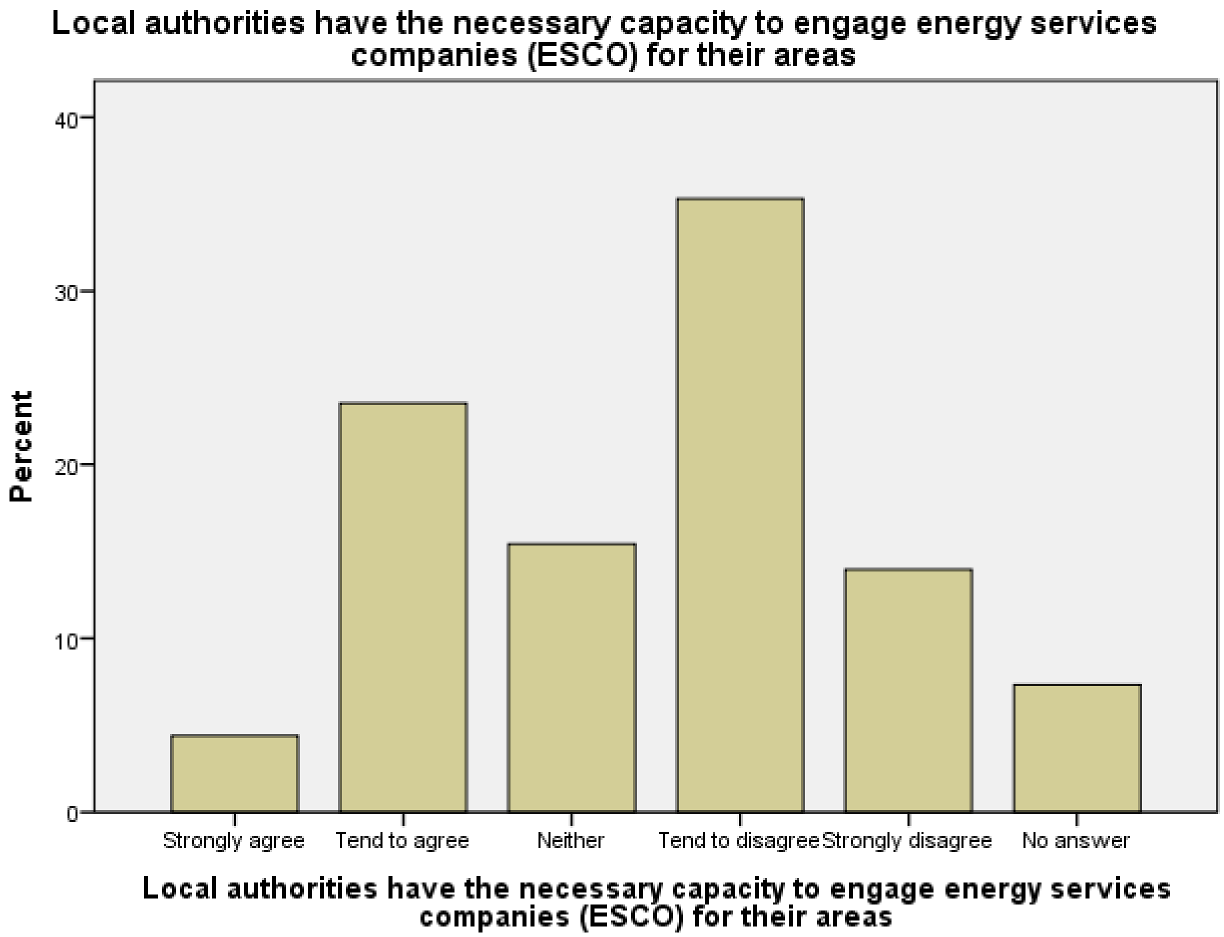

Figure 21: Bar chart - LAs capacity to engage ESCOs

LAs were asked if they think they have the necessary capacity to engage energy services companies for their areas. Results from Table 32, shows that 35% of respondents tend to disagree, while another ~24% tend to agree. When only 14% strongly disagree and 4.4% strongly agree. The bar chart in Figure 21 also shows a similar pattern.

Q 18 - Planning officers in the Local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants

			Group		Total
			LA	Consultants	
Planning officers in the Local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants	Tend to agree	Count	26	4	30
		% within Group	18.8%	14.8%	18.2%
		% of Total	15.8%	2.4%	18.2%
	Neither	Count	18	5	23
		% within Group	13.0%	18.5%	13.9%
		% of Total	10.9%	3.0%	13.9%
	Tend to disagree	Count	60	13	73
		% within Group	43.5%	48.1%	44.2%
		% of Total	36.4%	7.9%	44.2%
	Strongly disagree	Count	22	1	23
		% within Group	15.9%	3.7%	13.9%
		% of Total	13.3%	0.6%	13.9%
	No answer	Count	12	4	16
		% within Group	8.7%	14.8%	9.7%
		% of Total	7.3%	2.4%	9.7%
Total		Count	138	27	165
		% within Group	100.0%	100.0%	100.0%
		% of Total	83.6%	16.4%	100.0%

Table 33: Are LAs planning officers skilled enough

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	4.097[a]	4	.393
Likelihood Ratio	4.801	4	.308
Linear-by-Linear Association	.011	1	.917
N of Valid Cases	165		

a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is 2.62.

Table 34: Chi square - Are LAs planning officers skilled

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.158	.393

	Cramer's V	.158	.393
N of Valid Cases		165	

Table 35: Measure of association (effect size)

Results from Table 34 above shows that the expected count of the cells is 40% which is more 20% (i.e > 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 4.801 and its corresponding p value was 0.308>0.05 (likelihood ratio =4.801, df = 4, p = .308). Since the p value was greater than 0.05, we can conclude that, there is no significant difference between the LAs and consultants if the planning officers in the local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants. Therefore, we will fail to reject the null (Ho) hypothesis, which is planning officers in the local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants. Furthermore, we can draw upon the descriptive results from Table 33 above which indicates that about 43.5% of the LAs and 48.5% of the consultants expressed that they tend to disagree, while 15.9% of LA and 3.7% of consultants strongly disagree that planning officers in the local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants. This suggest that there is evidence that planning officers are not skilled enough to offer proactive guidance to CH-DH applicants. However, the support is weak due to the non-significant result, therefore the data are inconclusive.

Furthermore, drawing from the results of Table 35, the value of Cramer's V is 0.158, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study tends to be a small effect (i.e <0.2) according to Fritz et al. (2012).

Q 19 - I consider the existing process to receive planning consent to be transparent enough to gain the confidence of the applicants for CHP-DH projects and locals

			Group		
			LA	Consultants	Total
I consider the existing process to receive planning consent to be transparent enough to gain the	Strongly agree	Count	6	0	6
		% within Group	4.4%	0.0%	3.7%
		% of Total	3.7%	0.0%	3.7%
	Tend to agree	Count	54	12	66

confidence of the applicants for CHP-DH projects and locals		% within Group	39.7%	44.4%	40.5%
		% of Total	33.1%	7.4%	40.5%
	Neither	Count	29	6	35
		% within Group	21.3%	22.2%	21.5%
		% of Total	17.8%	3.7%	21.5%
	Tend to disagree	Count	16	4	20
		% within Group	11.8%	14.8%	12.3%
		% of Total	9.8%	2.5%	12.3%
	No answer	Count	31	5	36
		% within Group	22.8%	18.5%	22.1%
		% of Total	19.0%	3.1%	22.1%
Total		Count	136	27	163
		% within Group	100.0%	100.0%	100.0%
		% of Total	83.4%	16.6%	100.0%

Table 36: Transparent planning consent

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1.682[a]	4	.794
Likelihood Ratio	2.661	4	.616
Linear-by-Linear Association	.028	1	.867
N of Valid Cases	163		

a. 2 cells (20.0%) have expected count less than 5. The minimum expected count is .99.

Table 37: Chi square - Transparent planning consent

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.102	.794
	Cramer's V	.102	.794
N of Valid Cases		163	

Table 38: Measure of association (effect size)

Results from Table 37 above shows that the expected count of the cells is 20% (i.e = 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 2.661 and its corresponding p value was 0.616>0.05 (likelihood ratio = 2.661, df = 4, p = .616). Since the p value was greater than 0.05, we can conclude that, there is no significant difference between the LAs and consultants in considering the existing process to receive planning consent to be transparent enough to gain the confidence of the applicants for CHP-DH projects and locals. Therefore, we will fail to reject the null (Ho) hypothesis, which is the existing process to receive planning consent to be transparent enough to gain the confidence of the applicants for CHP-DH projects and locals. Furthermore, we can draw upon the descriptive results from Table 36 above which indicates that about 39.7% of the LAs and 44.4% of the consultants expressed that they tend to agree, while 4.4% of LA and 0% of consultants strongly agree that the existing process to receive planning consent is transparent enough to gain the confidence of the applicants for CHP-DH projects and locals. However, the support is weak due to the non-significant result, therefore the data are inconclusive.

Furthermore, drawing from the results of Table 38, the value of Cramer's V is 0.102, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study tends to be a small effect (i.e <0.2) according to Fritz et al. (2012).

Q 20 - In addition to planning permission there are many other consents that are required to commence development of a CHP-DH project, such as environmental permits or street works licence. There is room for a single consent regime or to at least reduce the consent

			Group		
			LA	Consultants	Total
In addition to planning permission there are many other consent that are required to commence development of a CHP-DH project, such as environmental permits or street works licence. There is room for a single consent regime or to at least reduce the consent	Strongly agree	Count	13	2	15
		% within Group	9.4%	7.4%	9.1%
		% of Total	7.9%	1.2%	9.1%
	Tend to agree	Count	60	14	74
		% within Group	43.5%	51.9%	44.8%
		% of Total	36.4%	8.5%	44.8%
	Neither	Count	23	4	27
		% within Group	16.7%	14.8%	16.4%
		% of Total	13.9%	2.4%	16.4%
	Tend to disagree	Count	20	0	20
		% within Group	14.5%	0.0%	12.1%
		% of Total	12.1%	0.0%	12.1%

	No answer	Count	22	7	29
		% within Group	15.9%	25.9%	17.6%
		% of Total	13.3%	4.2%	17.6%
Total		Count	138	27	165
		% within Group	100.0%	100.0%	100.0%
		% of Total	83.6%	16.4%	100.0%

Table 39: Single consent planning regime

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	5.695[a]	4	.223
Likelihood Ratio	8.791	4	.067
Linear-by-Linear Association	.110	1	.740
N of Valid Cases	165		

a. 4 cells (40.0%) have expected count less than 5. The minimum expected count is 2.45.

Table 40: Chi Square - Single consent planning regime

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.186	.223
	Cramer's V	.186	.223
N of Valid Cases		165	

Table 41: Measure of association (effect size)

Results from Table 40 above shows that the expected count of the cells is 40% (i.e = > 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 8.791 and its corresponding p value was 0.067>0.05 (likelihood ratio = 8.791, df = 4, p = .067). Since the p value was greater than 0.05, we can conclude that, there is no significant difference between the LAs and consultants that a single consent regime for planning is required. Therefore, we will fail to reject the null (Ho) hypothesis, which is that there is room for a single consent regime or to at least reduce the consent. Furthermore, we can draw upon the descriptive results from Table 39 above which indicates that about 43.5% of the LAs and 51.9% of the consultants expressed that they tend to agree, while 9.4% of LA and 7.4% of consultants strongly agree that the there is room for a single consent regime or to at least reduce the consent. However, the support is weak due to the non-significant result, therefore the data are inconclusive.

Furthermore, drawing from the results of Table 41, the value of Cramer's V is 0.186, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study tends to be a small effect (i.e <0.2) according to Fritz et al. (2012).

Q 21 - A conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced

			Group		Total
			LA	Consultants	
A conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced	Strongly agree	Count	12	2	14
		% within Group	8.8%	7.7%	8.6%
		% of Total	7.4%	1.2%	8.6%
	Tend to agree	Count	55	9	64
		% within Group	40.4%	34.6%	39.5%
		% of Total	34.0%	5.6%	39.5%
	Neither	Count	25	7	32
		% within Group	18.4%	26.9%	19.8%
		% of Total	15.4%	4.3%	19.8%
	Tend to disagree	Count	22	0	22
		% within Group	16.2%	0.0%	13.6%
		% of Total	13.6%	0.0%	13.6%
	Strongly disagree	Count	3	1	4
		% within Group	2.2%	3.8%	2.5%
		% of Total	1.9%	0.6%	2.5%
	No answer	Count	19	7	26
		% within Group	14.0%	26.9%	16.0%
		% of Total	11.7%	4.3%	16.0%
Total		Count	136	26	162
		% within Group	100.0%	100.0%	100.0%
		% of Total	84.0%	16.0%	100.0%

Table 42: A conveyor belt approach for planning

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	7.751[a]	5	.170
Likelihood Ratio	10.846	5	.055
Linear-by-Linear Association	1.044	1	.307
N of Valid Cases	162		

a. 5 cells (41.7%) have expected count less than 5. The minimum expected count is .64.

Table 43: Chi square - A conveyor belt approach for planning

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.219	.170
	Cramer's V	.219	.170
N of Valid Cases		162	

Table 44: Measurement of association (Effect size)

Results from Table 43 above shows that the expected count of the cells is 41.7% (i.e = 5), therefore the assumptions are violated, and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 10.846 and its corresponding p value was 0.055>0.05 (likelihood ratio = 10.846, df = 5, p = .055). Since the p value was greater than 0.05, we can conclude that, there is no significant difference between the LAs and consultants that a conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced. Therefore, we will fail to reject the null (Ho) hypothesis, which is that a conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced**.** Furthermore, we can draw upon the descriptive results from Table 42 above which indicates that about 40.4% of the LAs and 34.6% of the consultants expressed that they tend to agree, while 8.8% of LA and 7.7% of consultants strongly agree that a conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced. However, the support is weak due to the non-significant result, therefore the data are inconclusive

Furthermore, drawing from the results of Table 44, the value of Cramer's V is 0.219, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study tends towards a medium effect (i.e >0.2) according to Fritz et al. (2012).

7.2 Results - Barriers and Alternative LA roles

Q 22 - There should be a one-stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network

			Group			Total
			CHP Operators	Consultants	LAs	
There should be a one-stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network	Strongly agree	Count	33	5	35	73
		% within Group	37.1%	18.5%	25.4%	28.7%
	Tend to agree	Count	35	12	67	114
		% within Group	39.3%	44.4%	48.6%	44.9%
	Neither	Count	6	5	22	33
		% within Group	6.7%	18.5%	15.9%	13.0%
	Tend to disagree	Count	5	4	6	15
		% within Group	5.6%	14.8%	4.3%	5.9%
	Strongly disagree	Count	1	0	1	2
		% within Group	1.1%	0.0%	0.7%	0.8%
	No answer	Count	9	1	7	17
		% within Group	10.1%	3.7%	5.1%	6.7%
Total		Count	89	27	138	254
		% within Group	100.0%	100.0%	100.0%	100.0%

Table 45: One stop information

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.958[a]	10	.101
Likelihood Ratio	15.477	10	.116
Linear-by-Linear Association	.050	1	.823
N of Valid Cases	254		

a. 6 cells (33.3%) have expected count less than 5. The minimum expected count is .21.

Table 46: Chi square - One stop information

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.251	.101
	Cramer's V	.177	.101
N of Valid Cases		254	

Table 47: Measurement of association (effect size)

Results from Table 46 above shows that the expected count of the cells is 33.37% (i.e > 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 15.477 and its corresponding p value was 0.116>0.05 (likelihood ratio = 15.477, df = 10, p = .116). This suggest that there is no significant difference in the agreements of the respondents regarding there should be a one stop for the necessary information on different technologies to CHP and sources of heat to District Heating network. Hence, we will fail to reject the null (Ho) since there is evidence that there is no significant difference that there should be a one stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network. Consequently, from Table 45 above, we can observe that, 39.3% of the CHP operators, 44.4% of the consultants and 48.6% of the LAs tend to agree that there should be a one stop for the necessary information on different technologies to CHP and sources of heat to District Heating network. However, the support is weak due to the non-significant result, therefore the data are inconclusive.

furthermore, drawing from the results of Table 47, the value of cramer's v is 0.177, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is less than 0.2 so it's a small effect (i.e <0.2) according to Fritz et al. (2012).

Q 23 - Has the local authority developed heat maps for its area?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	46	33.3	33.3	33.3
	In development	31	22.5	22.5	55.8
	Considering	24	17.4	17.4	73.2
	Not considering	15	10.9	10.9	84.1

	No answer	22	15.9	15.9	100.0
	Total	138	100.0	100.0	

Table 48: LAs with heat maps

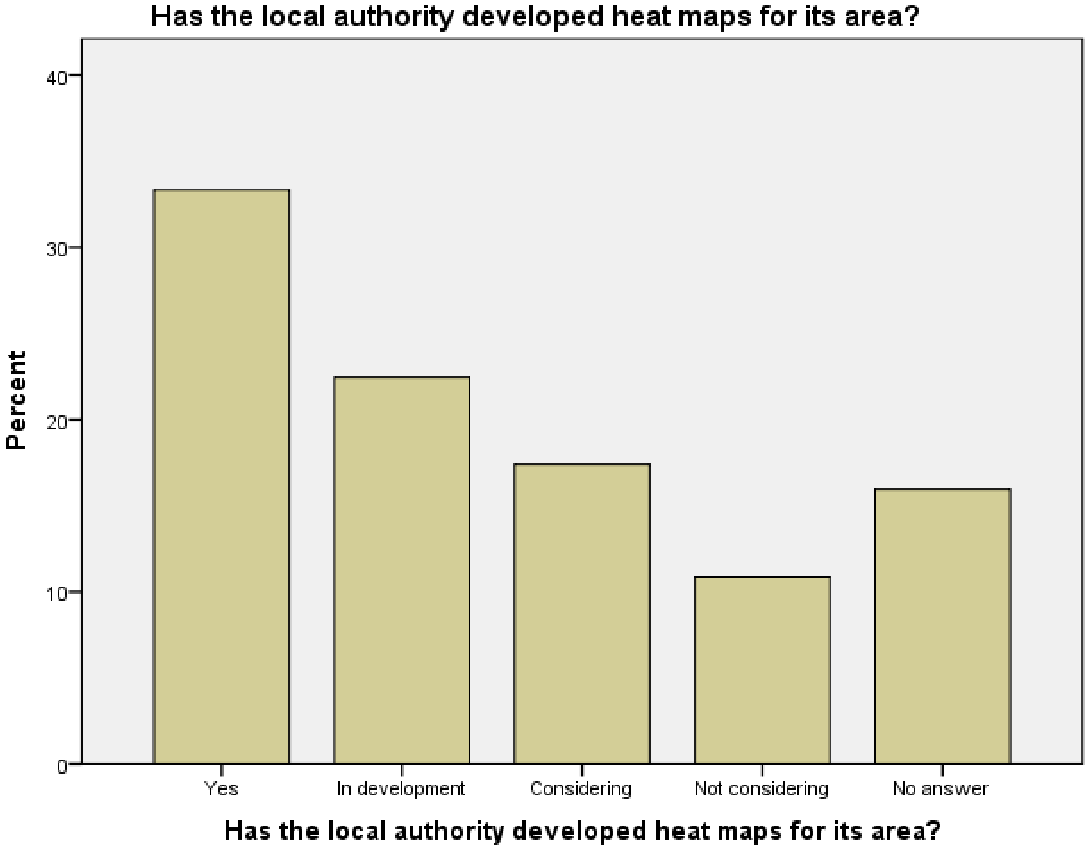

Figure 22: LAs with heat maps

From the Table 48 above we can observe that, 33.3% of the LAs expressed that, their local authority has developed heat maps for its area. Following the bar chart in Figure 22, it also shows taller bar corresponding to the same.

Q 24 -The absence of a national integrated CHP and District Heating strategy could hamper the growth of CHP/DH technology in the UK

			Group		
			LA	Consultants	Total
The absence of a national integrated CHP and District Heating strategy could hamper the growth of CHP/DH technology in the UK	Strongly agree	Count	37	3	40
		% within Group	27.4%	12.0%	25.0%
		% of Total	23.1%	1.9%	25.0%
	Tend to agree	Count	70	0	70
		% within Group	51.9%	0.0%	43.8%
		% of Total	43.8%	0.0%	43.8%

	Neither	Count	14	10	24
		% within Group	10.4%	40.0%	15.0%
		% of Total	8.8%	6.3%	15.0%
	Tend to disagree	Count	5	9	14
		% within Group	3.7%	36.0%	8.8%
		% of Total	3.1%	5.6%	8.8%
	Strongly disagree	Count	3	3	6
		% within Group	2.2%	12.0%	3.8%
		% of Total	1.9%	1.9%	3.8%
	No answer	Count	6	0	6
		% within Group	4.4%	0.0%	3.8%
		% of Total	3.8%	0.0%	3.8%
Total		Count	135	25	160
		% within Group	100.0%	100.0%	100.0%
		% of Total	84.4%	15.6%	100.0%

Table 49: Absence of a national integrated strategy for CHP-DH

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	58.945[a]	5	.000
Likelihood Ratio	58.209	5	.000
Linear-by-Linear Association	19.563	1	.000
N of Valid Cases	160		

a. 4 cells (33.3%) have expected count less than 5. The minimum expected count is .94.

Table 50: Chi square - Absence of national integrated strategy

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.608	.000
	Cramer's V	.608	.000
N of Valid Cases		161	

Table 51: Measurement of association (effect size)

Results from Table 50 above shows that the expected count of the cells is 33.3% (i.e > 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 58.209 and its corresponding p value was 0.000<0.05 (likelihood ratio = 58.209, df = 5, p = .000).

This suggest that there is a significant difference in the agreements of the respondents regarding the impact of the absence of a national integrated strategy on growth of CHP-DH in the UK. Hence, we will reject the null (Ho) since there is evidence that there is a significant difference between the LAs and consultants and therefore, we conclude that the absence of a national integrated CHP-DH strategy impacts on its growth in the UK. Consequently, from Table 49 above, we can observe that, 43.8% of the total respondents tend to agree, while 25% of the total respondents strongly agree that the absence of a national integrated CHP-DH strategy impacts on its growth in the UK. Furthermore, drawing from the results of Table 51 the value of Cramer's V is 0.608, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is greater than .5, and therefore it has large effect (i.e >.5) according to Fritz et al. (2012).

Q 25 - The UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems.

			Group			Total
			CHP Operators	Consultants	LAs	
The UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems.	Strongly agree	Count	21	6	23	50
		% within Group	23.9%	22.2%	16.8%	19.8%
	Tend to agree	Count	42	14	78	134
		% within Group	47.7%	51.9%	56.9%	53.2%
	Neither	Count	17	5	20	42
		% within Group	19.3%	18.5%	14.6%	16.7%
	Tend to disagree	Count	3	1	3	7
		% within Group	3.4%	3.7%	2.2%	2.8%
	Strongly disagree	Count	3	0	2	5
		% within Group	3.4%	0.0%	1.5%	2.0%
	No answer	Count	2	1	11	14
		% within Group	2.3%	3.7%	8.0%	5.6%
Total		Count	88	27	137	252
		% within Group	100.0%	100.0%	100.0%	100.0%

Table 52 :UK needs body of regulation

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	8.470[a]	10	.583

Likelihood Ratio	9.188	10	.514
Linear-by-Linear Association	1.154	1	.283
N of Valid Cases	252		

a. 9 cells (50.0%) have expected count less than 5. The minimum expected count is .54.

Table 53: Chi square - UK needs body of regulation

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.183	.583
	Cramer's V	.130	.583
N of Valid Cases		252	

Table 54: Measurement of association (effect size)

Results from Table 53 above shows that the expected count of the cells is 50% (i.e > 5), therefore the assumptions are violated and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 9.188 and its corresponding p value was 0.514>0.05 (likelihood ratio = 9.188, df = 10, p = .514). This suggest that there is no significant difference in the agreements of the respondents regarding the need for a body of regulation for the UK CHP-DH. Hence, we will fail to reject the null (Ho) that the UK needs a body of regulation concerning heat provision and its infrastructure such as DH systems, since there is evidence that there is no significant difference. Consequently, from Table 52 above, we can observe that, 53.2% of the total respondents tend to agree, while 19.8% of the total respondents strongly agree that the UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems. However, the support is weak due to the non-significant result, therefore the data are inconclusive. Furthermore, drawing from the results of Table 54, the value of Cramer's V is 0.13, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is less than .2 and therefore it has small effect (i.e < .2) according to Fritz et al. (2012).

Q 26 - It is likely this would require a regulator. Which body should act as the regulator? Group Crosstabulation

			Group			Total
			CHP Operators	Consultants	LAs	
It is likely this would require a regulator. Which body should act as the regulator?	Ofgem	Count	48	17	68	133
		% within Group	55.8%	63.0%	49.3%	53.0%
		% of Total	19.1%	6.8%	27.1%	53.0%
	Government	Count	8	3	29	40
		% within Group	9.3%	11.1%	21.0%	15.9%
		% of Total	3.2%	1.2%	11.6%	15.9%
	Another body (say who if possible)	Count	11	6	4	21
		% within Group	12.8%	22.2%	2.9%	8.4%
		% of Total	4.4%	2.4%	1.6%	8.4%
	No regulation is required	Count	3	0	7	10
		% within Group	3.5%	0.0%	5.1%	4.0%
		% of Total	1.2%	0.0%	2.8%	4.0%
	No answer	Count	16	1	30	47
		% within Group	18.6%	3.7%	21.7%	18.7%
		% of Total	6.4%	0.4%	12.0%	18.7%
Total		Count	86	27	138	251
		% within Group	100.0%	100.0%	100.0%	100.0%
		% of Total	34.3%	10.8%	55.0%	100.0%

Table 55: Which body should act as the regulator

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	24.600[a]	8	.002
Likelihood Ratio	26.911	8	.001
Linear-by-Linear Association	.319	1	.572
N of Valid Cases	251		

a. 4 cells (26.7%) have expected count less than 5. The minimum expected count is 1.08.

Table 56: Chi Square - Which body act as the regulator

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.313	.002
	Cramer's V	.221	.002
N of Valid Cases		251	

Table 57: Measurement of association (effect size)

Results from Table 56 above shows that the expected count of the cells is 26.7% (i.e > 5), therefore the assumptions are violated since its greater than 20% and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 26.911 and its corresponding p value was 0.001< 0.05 (likelihood ratio = 26.911, df = 8, p = .001). This suggest that there is a significant difference in the agreements of the respondents regarding who should act as the regulator. Hence, we will reject the null (Ho) since there is evidence that there is a significant difference. Consequently, from Table 55 above, we can observe that, about 55.5% of the CHP operators, 63.0% of the consultants and 49.3% of the LAs expressed that Ofgem will be their preferred regulator. Furthermore, drawing from the results of Table 57, the value of Cramer's V is 0.221, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is greater than .2 and therefore it has an effect tending towards medium (i.e > .2) according to Fritz et al. (2012).

Q 27 - There is a skill gap in the CHP and DH industry in the UK.

			Group		Total
			CHP operator	Consultants	
There is a skill gap in the CHP and DH industry in the UK.	Strongly agree	Count	14	7	21
		% within Group	16.1%	25.9%	18.4%
	Tend to agree	Count	48	11	59
		% within Group	55.2%	40.7%	51.8%
	Neither	Count	14	4	18
		% within Group	16.1%	14.8%	15.8%
	Tend to disagree	Count	7	1	8
		% within Group	8.0%	3.7%	7.0%
	Strongly disagree	Count	2	1	3
		% within Group	2.3%	3.7%	2.6%
	No answer	Count	2	3	5
		% within Group	2.3%	11.1%	4.4%
Total		Count	87	27	114
		% within Group	100.0%	100.0%	100.0%

Table 58: Skill gap in the UK

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	6.289[a]	5	.279
Likelihood Ratio	5.669	5	.340
Linear-by-Linear Association	.554	1	.457
N of Valid Cases	114		

a. 7 cells (58.3%) have expected count less than 5. The minimum expected count is .71.

Table 59: Chi Square - Skill gap in the UK

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.235	.279
	Cramer's V	.235	.279
N of Valid Cases		114	

Table 60: Measurement of association (effect size)

Results from Table 59 above shows that the expected count of the cells is 58.3% (i.e > 5), therefore the assumptions are violated since its greater than 20% and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 5.669 and its corresponding p value was 0.340 > 0.05 (likelihood ratio = 5.669, df = 5, p = .340). This suggest that there is no significant difference in the agreements of the respondents regarding skill gap in the UK CHP-DH industry. Hence, we will fail to reject the null (Ho), which says that there is a skill gap, since there is evidence that there is no significant difference. Consequently, from Table 58 above, we can observe that, about 55.2% of the CHP operators and 40.7% of the consultants tend to agree that, there is a skill gap in the CHP and DH industry in the UK. However, the support is weak due to the non-significant result, therefore the data are inconclusive. Furthermore, drawing from the results of Table 60, the value of Cramer's V is 0.235, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is greater than .2 and therefore it has an effect tending towards medium (i.e > .2) according to Fritz et al. (2012).

Q 28 - If you seem to agree to the above questions, please could you grade skills below according to your perceived deficiency levels in the UK

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Zscore: Design and Manufacture of DH pipes	CHP operator	61	-.0619477	1.00058297	.12811152
	Consultants	22	.1717641	1.00111534	.21343851
Zscore: Manufacture of CHP systems	CHP operator	63	-.0731393	1.00333175	.12640792
	Consultants	22	.2094445	.98280674	.20953510
Zscore: Business Development	CHP operator	62	.0202962	.93624019	.11890262
	Consultants	22	-.0571984	1.18388378	.25240487
Zscore: Construction of DH systems	CHP operator	62	-.0272443	.99936861	.12691994
	Consultants	22	.0767794	1.02123395	.21772781
	CHP operator	62	-.0156663	.99739873	.12666977

Zscore: Installation of CHP Systems	Consultants	22	.0441506	1.02953622	.21949786
Zscore: Operations and Maintenance	CHP operator	64	.0810061	.94903730	.11862966
	Consultants	22	-.2356540	1.12580103	.24002159

Table 61: Knowledge skill set - Groups statistics

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Zscore: Design and Manufacture of DH pipes	Equal variances assumed	.132	.718	-.939	81	.350	-.23371186	.24887187	-.72888881	.26146510
	Equal variances not assumed			-.939	37.169	.354	-.23371186	.24893485	-.73802454	.27060082
Zscore: Manufacture of CHP systems	Equal variances assumed	.007	.933	-1.143	83	.256	-.28258379	.24719295	-.77424063	.20907306
	Equal variances not assumed			-1.155	37.390	.256	-.28258379	.24471191	-.77824280	.21307524
Zscore: Business Development	Equal variances assumed	3.677	.059	.311	82	.757	.07749458	.24952226	-.41888469	.57387385
	Equal variances not assumed			.278	30.832	.783	.07749458	.27900905	-.49167391	.64666306
Zscore: Construction	Equal variances assumed	.046	.831	-.417	82	.678	-.10402372	.24940456	-.60016883	.39212140

of DH systems	Equal variances not assumed			-.413	36.256	.682	-.10402372	.25201998	-.61501888	.40697145
Zscore: Installation of CHP Systems	Equal variances assumed	.023	.880	-.240	82	.811	-.05981693	.24958157	-.55631419	.43668032
	Equal variances not assumed			-.236	35.944	.815	-.05981693	.25342561	-.57381569	.45418182
Zscore: Operations and Maintenance	Equal variances assumed	.139	.711	1.286	84	.202	.31666013	.24619697	-.17292955	.80624981
	Equal variances not assumed			1.183	31.879	.246	.31666013	.26773748	-.22878465	.86210490

Table 62: Knowledge skill set - Independent Sample test

**zscore of the variables was used for the t-test to capture the standardized difference between means of the two independent groups, which indicates the estimates of the effect size (cohen's d) to describe the level of variability accounted for by each independent variable (Gail M. Sullivan and Richard Feinn, 2012, Fritz et al., 2012). Furthermore, SPSS only captures the effect size in an independent sample test through using the zscore of the variables (see* Table 61,Table 62*).*

Considering results from Table 62, the p value for the levene's test for all skill set are all greater than .05 (p>0.5), suggesting that we can consider that equal variances are assumed for the variable and we can proceed to observe the corresponding the t-test values. The p value corresponding to the t-test in all skill set – Design and manufacture of DH pipes, Manufacture of CHP systems, Business development, construction of DH systems, installation of CHP systems and operations and maintenance are more than 0.05 (p>0.05). Hence, we can conclude that, there is no significant difference in the skill set between CHP operators and consultants.

However, in a view to further distinguish the proportion of variability of the various skill set and considering the profound effect of sample size on statistical significance and the independence of effect size from sample size (Fritz et al., 2012, Gail M. Sullivan and Richard Feinn, 2012). A further consideration of the effect size (Cohen's d) was noted, as only Business development and Operations and Maintenance skill set had positive effect sizes of 0.077 and 0.32 respectively (see mean differences in Table 62). According to Cohen (1992), business development with a 0.1 effect size equivalent shows a small effect but not trivial, while operations and maintenance have 0.32 effect size, which shows a near medium effect on the variability of the mean values. Therefore, this provides an opportunity for further research to increase the sample size with a view to achieve statistical significance and arrive at a more concrete theoretical and practical conclusion.

Q 29 - Please rank the following in the order you consider most likely to be the growth pathways for district heating networks in the UK,

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Zscore: New builds	CHP operator	77	.0126616	.99231793	.11308512
	Consultants	24	-.0406225	1.04488903	.21328708
Zscore: Urban centres	CHP operator	78	-.0030019	.98199544	.11118909
	Consultants	25	.0093660	1.07519080	.21503816
Zscore: Sub-urban areas	CHP operator	79	-.0511626	1.03803921	.11678854
	Consultants	24	.1684101	.86138264	.17582900
Zscore: Industrial Areas	CHP operator	82	.0295663	1.02604184	.11330737
	Consultants	26	-.0932476	.92581933	.18156811
Zscore: Remote areas	CHP operator	79	-.0144046	.98886859	.11125641
	Consultants	26	.0437679	1.05186762	.20628821

Table 63: Likely growth pathways for CHP-DH systems – Group statistics

Independent Samples Test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
								95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper

Zscore: New builds	Equal variances assumed	.491	.485	.227	99	.821	.05328411	.23489797	-.41280444	.51937265
	Equal variances not assumed			.221	36.867	.827	.05328411	.24141173	-.43592205	.54249026
Zscore: Urban centres	Equal variances assumed	.300	.585	-.054	101	.957	-.01236790	.23095881	-.47052806	.44579226
	Equal variances not assumed			-.051	37.709	.960	-.01236790	.24208351	-.50256474	.47782894
Zscore: Sub-urban areas	Equal variances assumed	4.752	.032	-.942	101	.349	-.21957263	.23320681	-.68219222	.24304695
	Equal variances not assumed			-1.040	45.178	.304	-.21957263	.21108150	-.64466630	.20552103
Zscore: Industrial Areas	Equal variances assumed	.806	.371	.544	106	.588	.12281388	.22581466	-.32488564	.57051339
	Equal variances not assumed			.574	46.105	.569	.12281388	.21402228	-.30796410	.55359185
Zscore: Remote areas	Equal variances assumed	1.109	.295	-.256	103	.798	-.05817258	.22711940	-.50861033	.39226517
	Equal variances not assumed			-.248	40.559	.805	-.05817258	.23437751	-.53166394	.41531878

Table 64: Likely growth pathways for CHP-DH systems – independent sample test

**zscore of the variables was used for the t-test to capture the standardized difference between means of the two independent groups, which indicates the estimates of the effect size (cohen's d) to describe the level of variability accounted for by each independent variable (Gail M. Sullivan and Richard Feinn, 2012, Fritz et al., 2012).*

Furthermore, SPSS only captures the effect size in an independent sample test through using the zscore of the variables (see Table 63,Table 64*).*

Considering the results from Table 64, the p value for the levene's test for all the growth pathways are all greater than .05 (p>0.5) except for sub-urban which had a p value of 0.032 (p<0.5). Therefore, we can proceed to consider the p values in the t-test for the assumed equal variances for the variables with p values higher than 0.05 (p>0.05), while we consider the p values for equal variances not assumed in the t-test for sub-urban. The p value corresponding to the t-test in new builds, urban centres, sub-urban, industrial areas and remote areas are all more than 0.05 (p>0.05). Hence, we can conclude that, there is no significant difference in the various growth pathways between CHP operators and consultants.

However, in a view to further distinguish the proportion of variability of the various growth pathways and considering the profound effect of sample size on statistical significance and the independence of effect size from sample size (Fritz et al., 2012, Gail M. Sullivan and Richard Feinn, 2012). A further consideration of the effect size (Cohen's d) was noted, as only new builds and industrial areas had positive effect sizes of 0.1 and 0.12 respectively. According to Cohen (1992), new builds with a 0.1 and industrial areas with a 0.12 effect sizes, both shows a small effect but not trivial, on the variability of the mean values. Therefore, this provides an opportunity for further research to increase the sample size with a view to achieve statistical significance and arrive at a more concrete theoretical and practical conclusion.

Q 30 - Is there an adopted energy efficiency strategy for your local authority

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	76	55.1	57.1	57.1
	In development	25	18.1	18.8	75.9
	Considering	19	13.8	14.3	90.2
	Not considering	6	4.3	4.5	94.7
	No Answer	7	5.1	5.3	100.0
	Total	133	96.4	100.0	
Missing	System	5	3.6		
Total		138	100.0		

Table 65: Is there adopted energy efficiency strategy

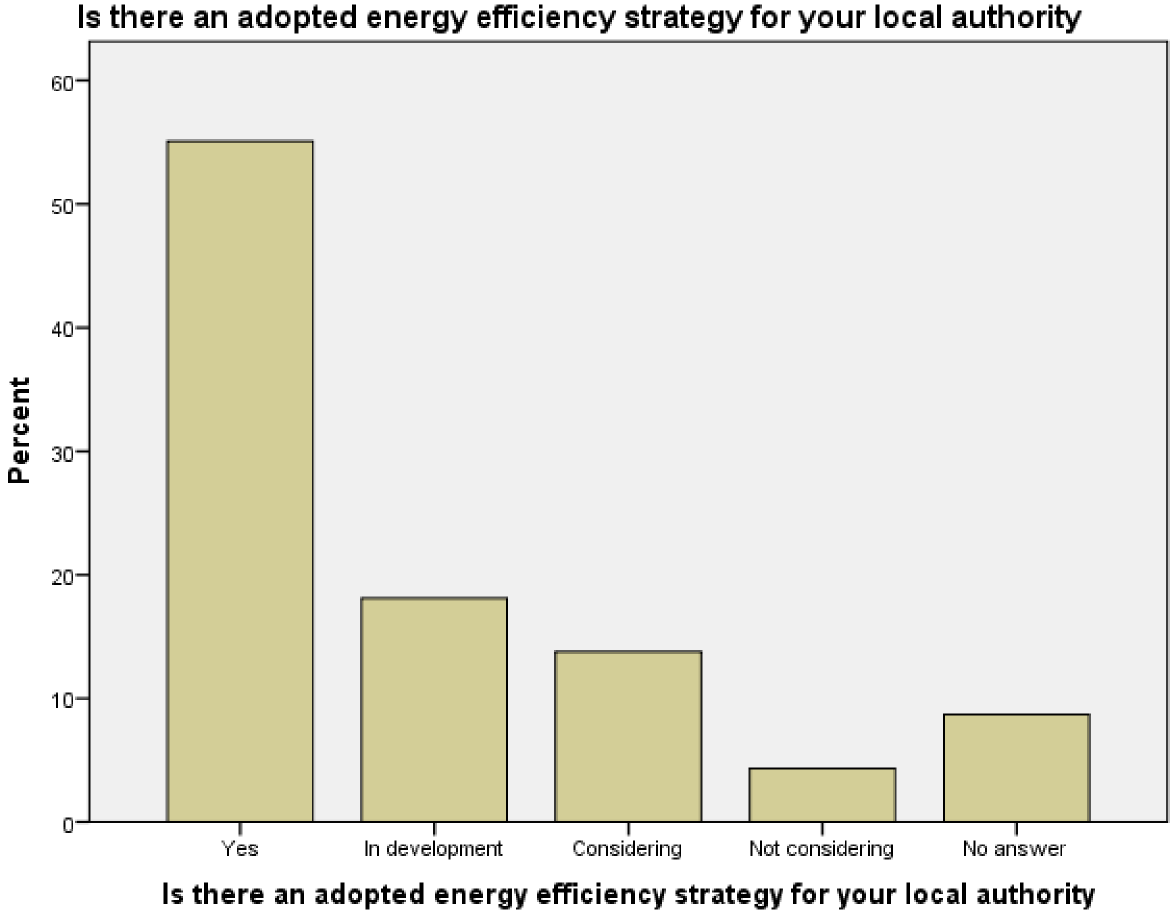

Figure 23: Is there adopted energy efficiency strategy

From the following the results from Table 65 and Figure 23, we can observe that 57.1% of the LAs expressed that there is an adopted energy efficiency strategy of their local authority. Following bar chart also shows the bars corresponding to the same.

Q 31 - If there is one, is CHP-DH part of the strategy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	27	19.6	21.1	21.1
	Somewhat	51	37.0	39.8	60.9
	No	31	22.5	24.2	85.2
	No Answer	19	13.8	14.8	100.0
	Total	128	92.8	100.0	
Missing	System	10	7.2		
Total		138	100.0		

Table 66: Is CHP-DH part of strategy

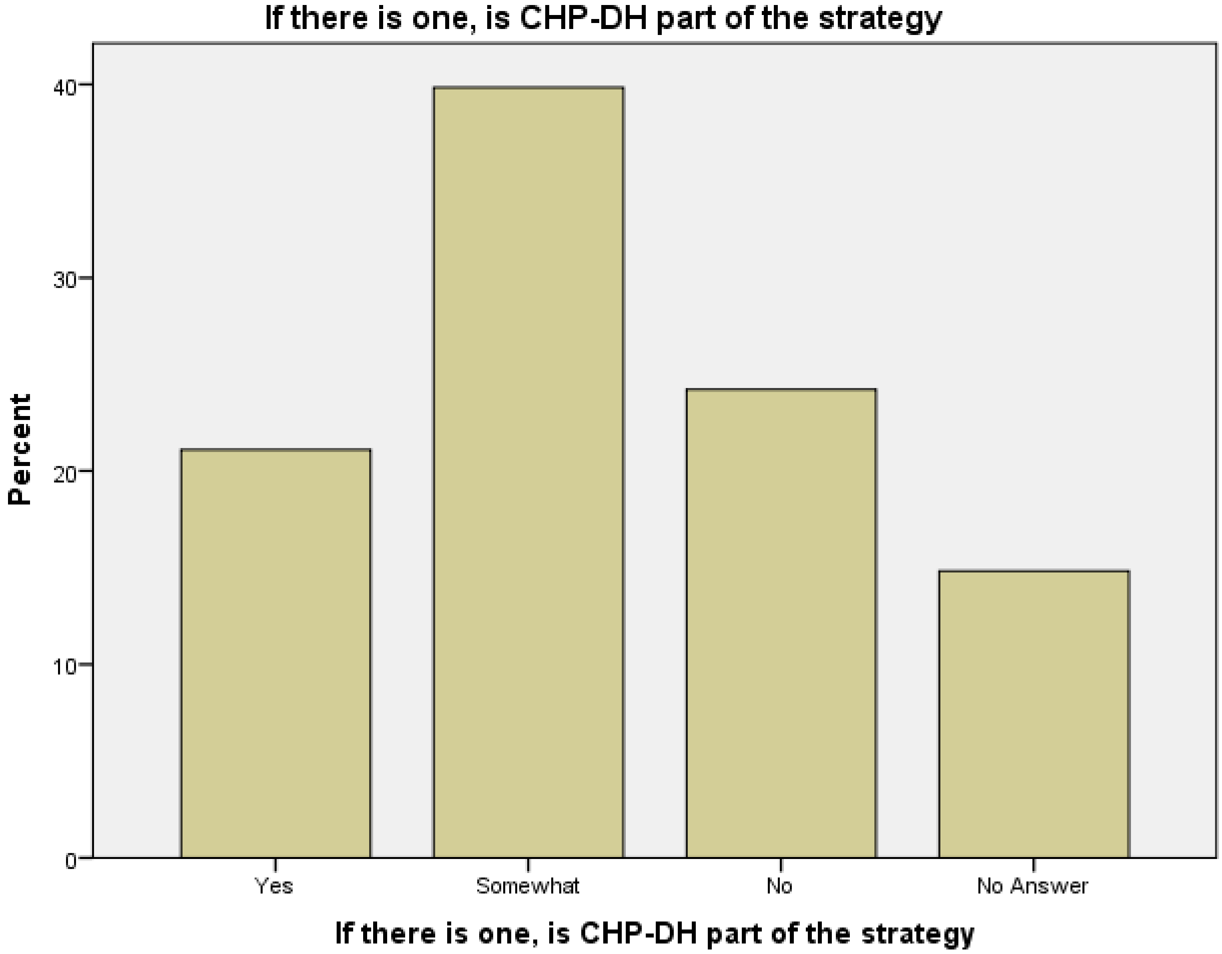

Figure 24: Bar Chart - Is CHP-DH part of strategy

From the following the results from Table 66 we can observe that 21.1% of the LAs expressed that CHP–DH is a part of their strategy. While 39.8% says its somewhat and another 24.2% said no. Following bar chart in Figure 24 also shows the bars corresponding to the same.

Q 32 - Does the local authority provide any support/planning guidance for CHP-DH development?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes, Please comment	24	17.4	17.4	17.4
	Under development	32	23.2	23.2	40.6
	No	54	39.1	39.1	79.7
	No answer	28	20.3	20.3	100.0
	Total	138	100.0	100.0	

Table 67: LA planning guidance for CHP-DH

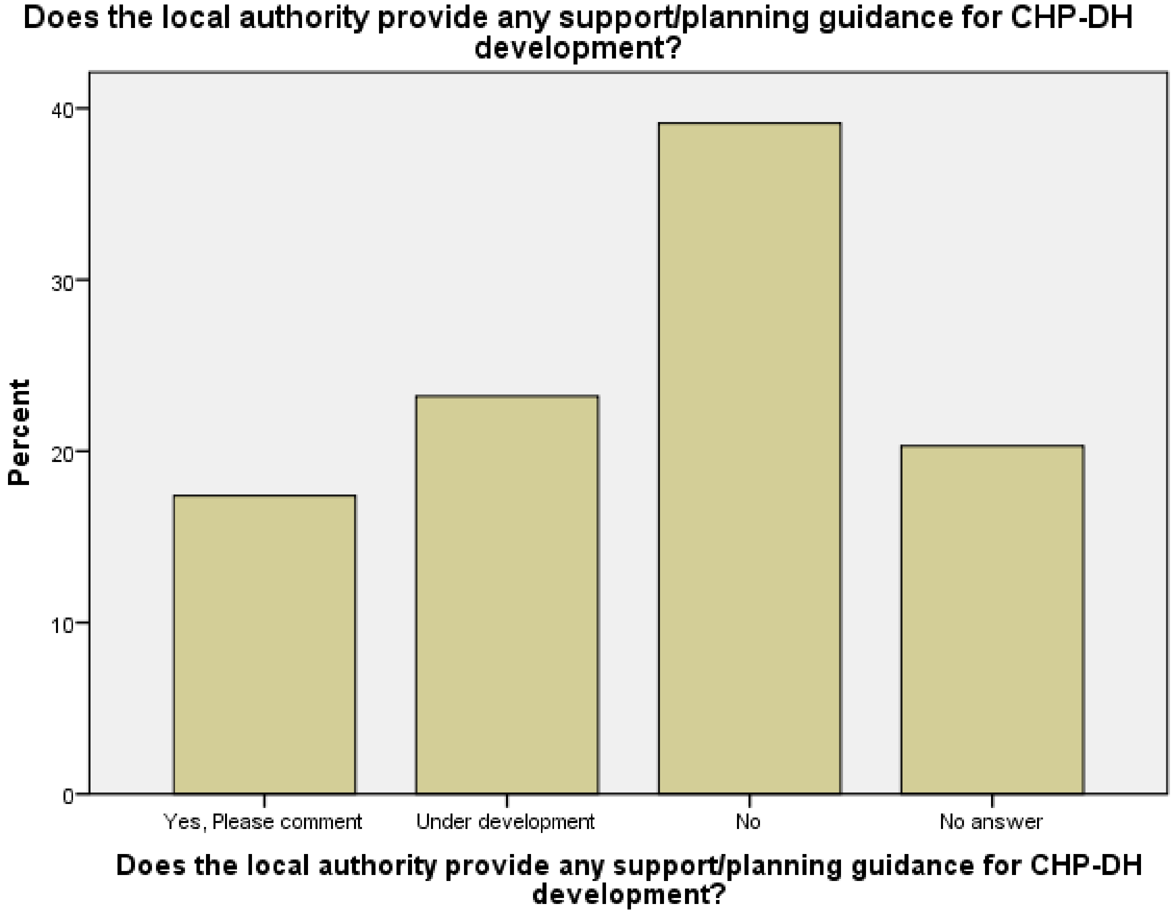

Figure 25: Bar Chart - LA planning guidance for CHP-DH

From the results in Table 67 and Figure 25, we can observe that, 39.1% of the LAs expressed that, there is no local authority to provide any support/ planning guidance for CHP–DH development. Following bar chart also shows the bars corresponding to the same.

Q 33 - Do you experience a slow or defaulting payment on your heat (counter party risk)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes sometimes	3	3.2	3.8	3.8
	Yes but rarely	7	7.4	8.8	12.5
	Not at all	10	10.5	12.5	25.0
	No answer	60	63.2	75.0	100.0
	Total	80	84.2	100.0	
Missing	System	15	15.8		
Total		95	100.0		

Table 68: Experience default in heat payment

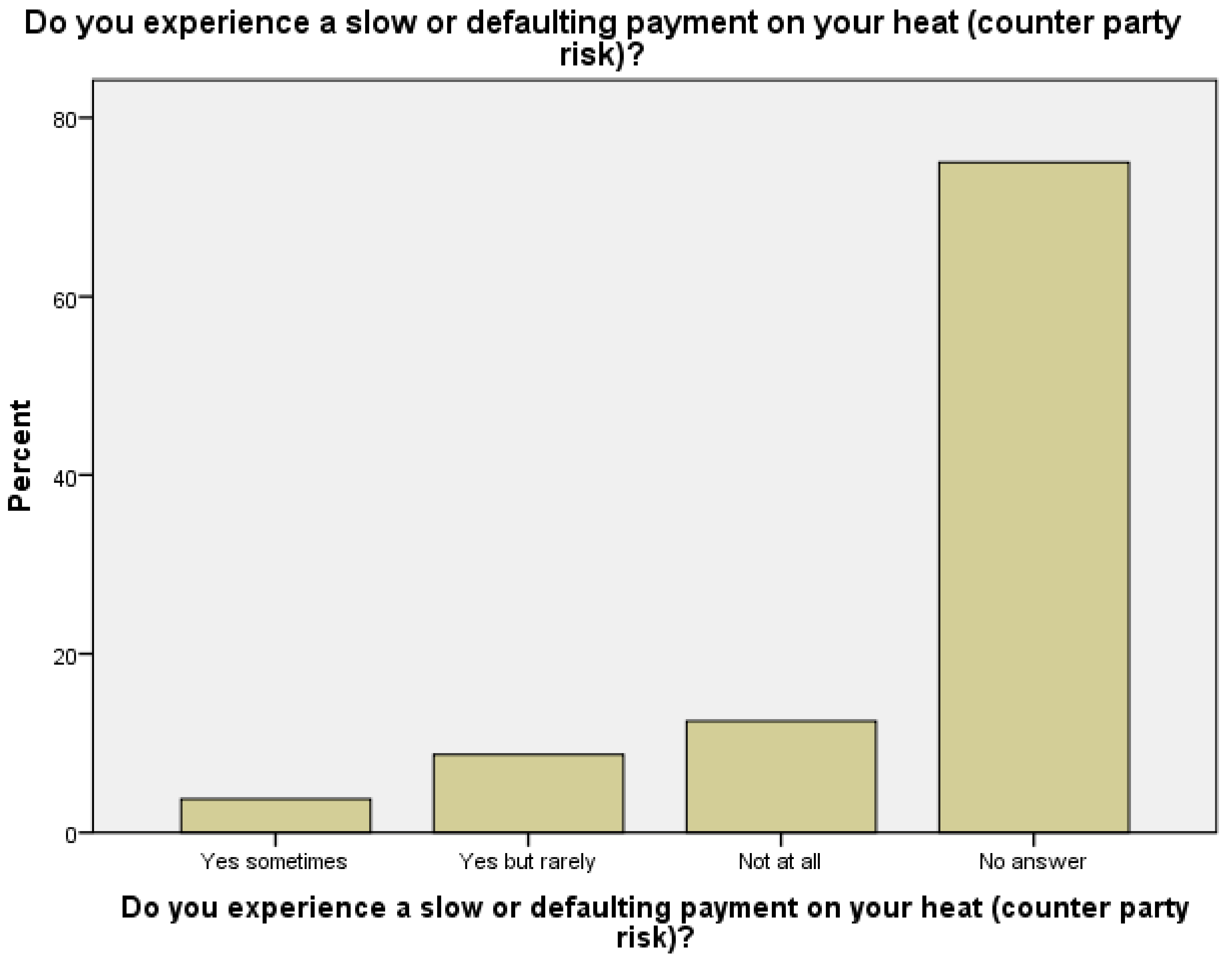

Figure 26: Bar chart - Experience default in heat payment

From the results in Table 68 and Figure 26 above, we can observe that 75% of respondents did not respond to the question on experience on slow or default of payment on heat. Therefore, the results cannot be taken further. Hence its inconclusive. Following bar chart also shows the bars corresponding to the same.

Q 34 - Do you experience disputes with your heat customers?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes sometimes	5	5.3	6.2	6.2
	Yes but rarely	11	11.6	13.6	19.8
	Not at all	18	18.9	22.2	42.0
	No answer	47	49.5	58.0	100.0
	Total	81	85.3	100.0	
Missing	System	14	14.7		

Total	95	100.0		

Table 69: Experience of dispute with heat customers

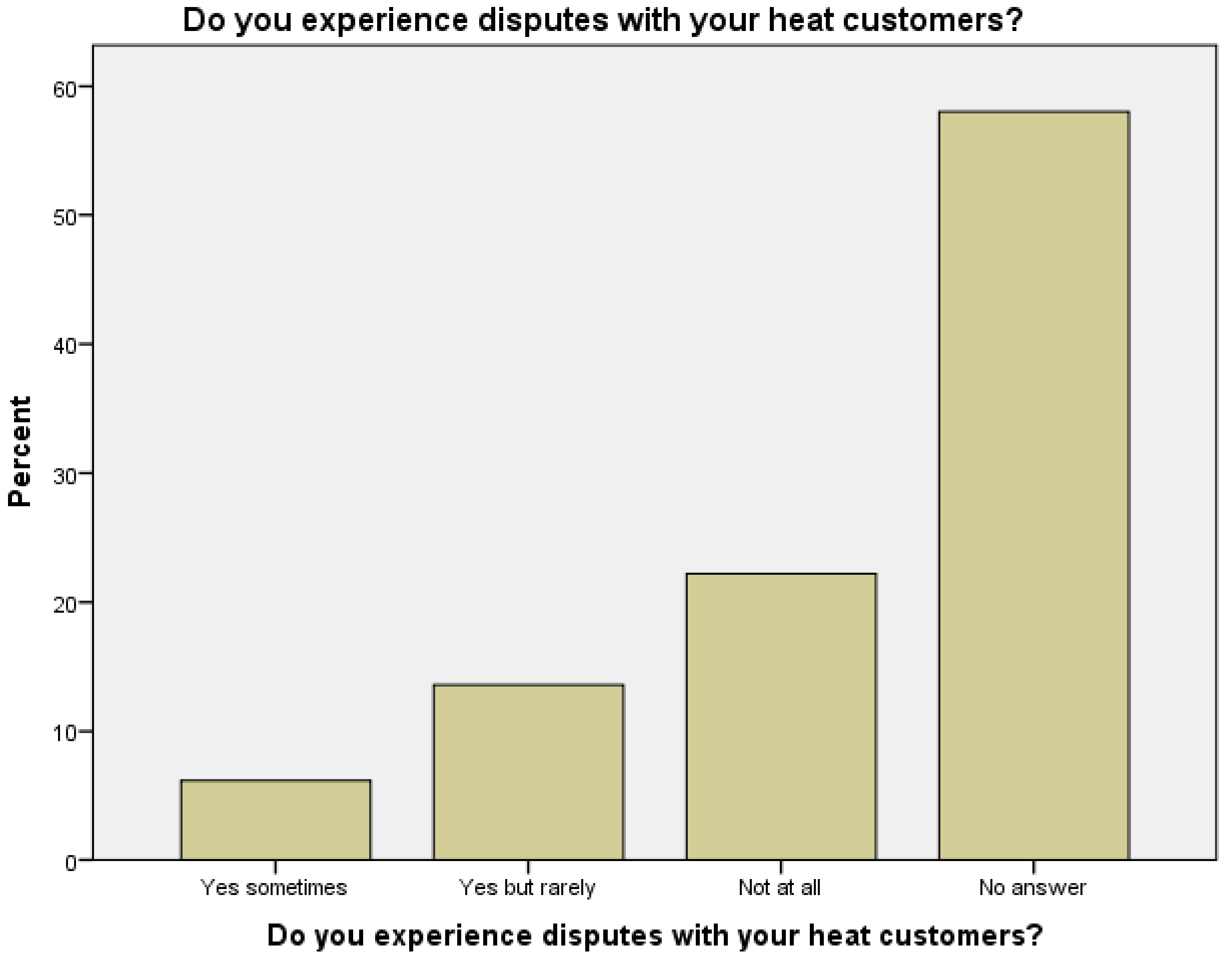

Figure 27: Bar chart - Experience disputes with heat customers

From the results in Table 69 and Figure 27, we can observe that 22.2% of respondents expressed that not at all, while 13.6% thinks that yes but rarely, with another 3.6% saying yes but sometimes that they do experience disputes with their heat customers. However, 58% did not respond to the question. Therefore, the results cannot be taken further. Hence its inconclusive. Following bar chart also shows the bars corresponding to the same.

Q 35 - Do you experience difficulty in finding a suitable counterparty with which to trade electricity (Market risk)?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes always	1	1.1	1.3	1.3
	Yes sometimes	3	3.2	3.8	5.0
	Yes but rarely	1	1.1	1.3	6.3
	Not at all	19	20.0	23.8	30.0
	No answer	56	58.9	70.0	100.0
	Total	80	84.2	100.0	
Missing	System	15	15.8		
Total		95	100.0		

Table 70: Experience in trading electricity

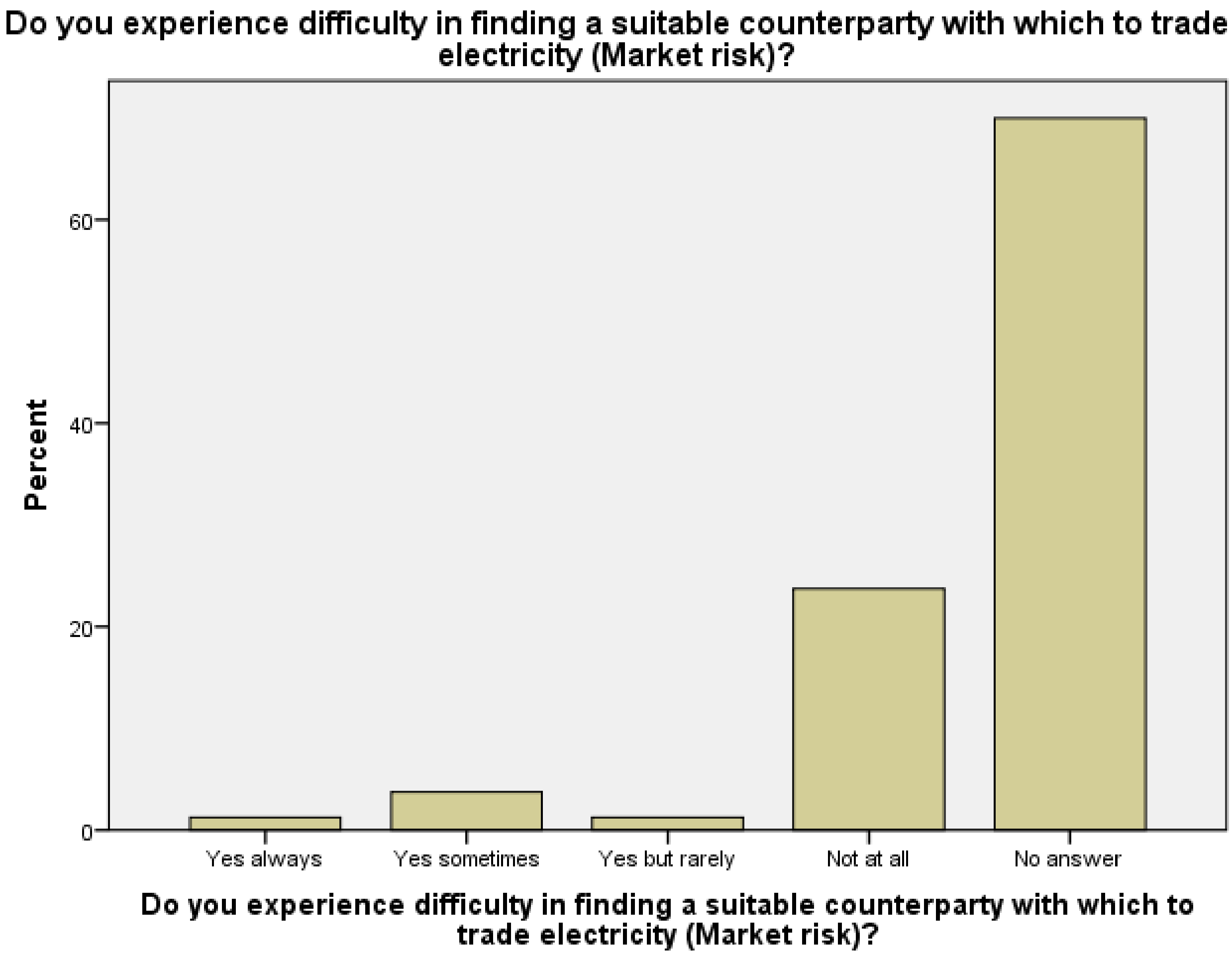

Figure 28: Bar chart - Experience in trading electricity

From the results in Table 70 and Figure 28, we can observe that 23.8% of respondents expressed that not at all, while 3.8% thinks that yes but sometimes, with another 1.3%

saying yes but rarely that they do experience difficulties finding a suitable counterparty to trade electricity with. However, 70% did not respond to the question. Therefore, the results cannot be taken further. Hence its inconclusive. Following bar chart also shows the bars corresponding to the same.

Q 36 - If some or all of your electricity is traded, do you experience a slow or defaulting payment on your electricity (counter party risk).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes always	1	1.1	1.3	1.3
	Yes sometimes	4	4.2	5.0	6.3
	Yes but rarely	2	2.1	2.5	8.8
	Not at all	19	20.0	23.8	32.5
	No answer	54	56.8	67.5	100.0
	Total	80	84.2	100.0	
Missing	System	15	15.8		
Total		95	100.0		

Table 71: Experience default in electricity payment

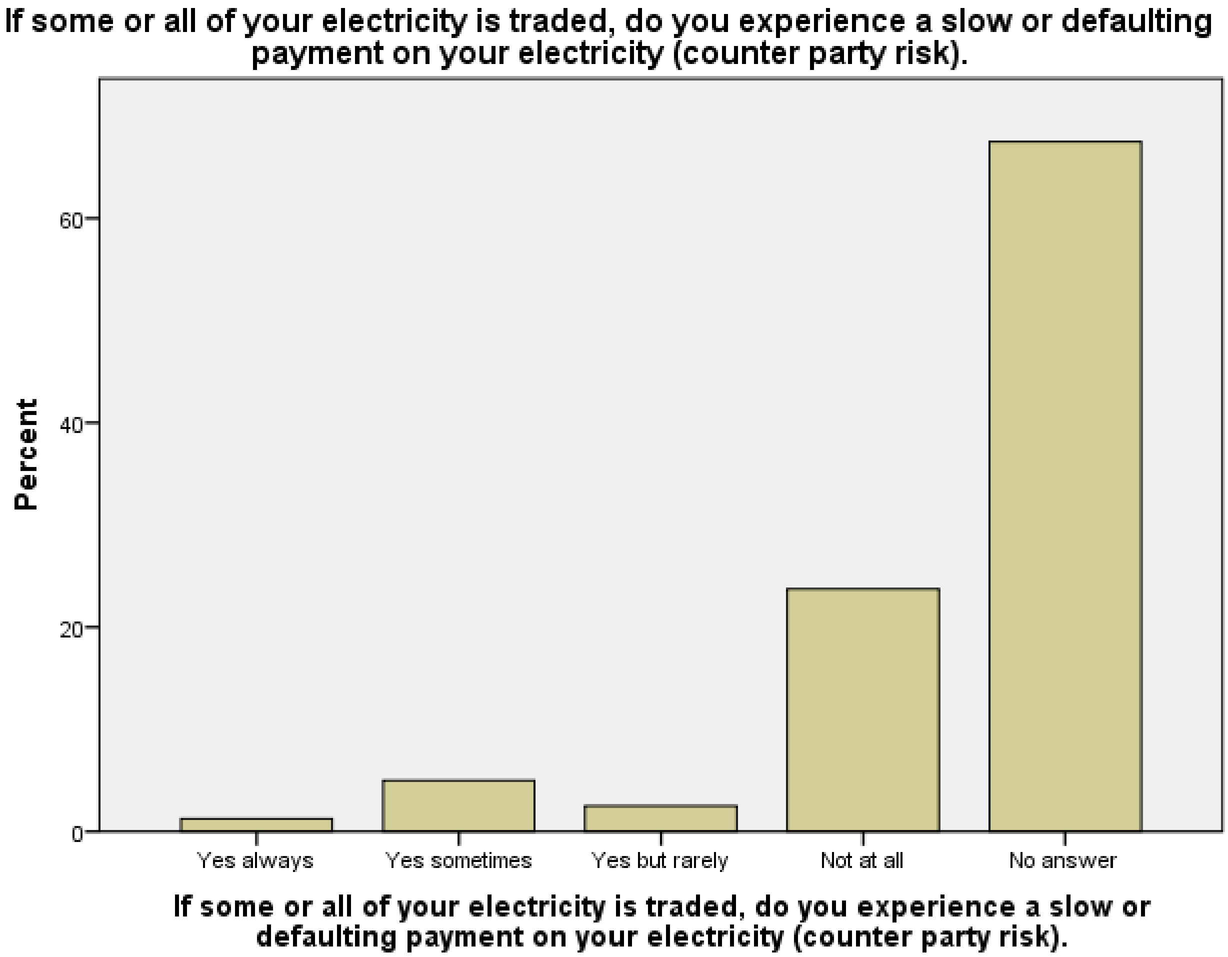

Figure 29: Bar chart - Experience in default of electricity payment

From the results in Table 71 and Figure 29, we can observe that 23.8% of respondents expressed that not at all, while 5% thinks that yes but sometimes, with another 2.5% saying yes but rarely that they do experience difficulties in payment for electricity traded. However, 67.5% did not respond to the question. Therefore, the results cannot be taken further. Hence its inconclusive. Following bar chart also shows the bars corresponding to the same

7.3 Results – Governance mechanism

Q 37 - Which Government scheme do you consider as the most effective in driving the penetration of CHP/DH

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Energy Company Obligation	3	11.1	11.1	11.1
	Enhanced Capital Allowance	4	14.8	14.8	25.9
	Renewable Heat Incentive	5	18.5	18.5	44.4
	Renewable Obligation	1	3.7	3.7	48.1
	Community Energy Saving Programme	5	18.5	18.5	66.7
	Climate Change Levy exemption	4	14.8	14.8	81.5
	No answer	5	18.5	18.5	100.0
	Total	27	100.0	100.0	

Table 72: Government Scheme considered as most effective

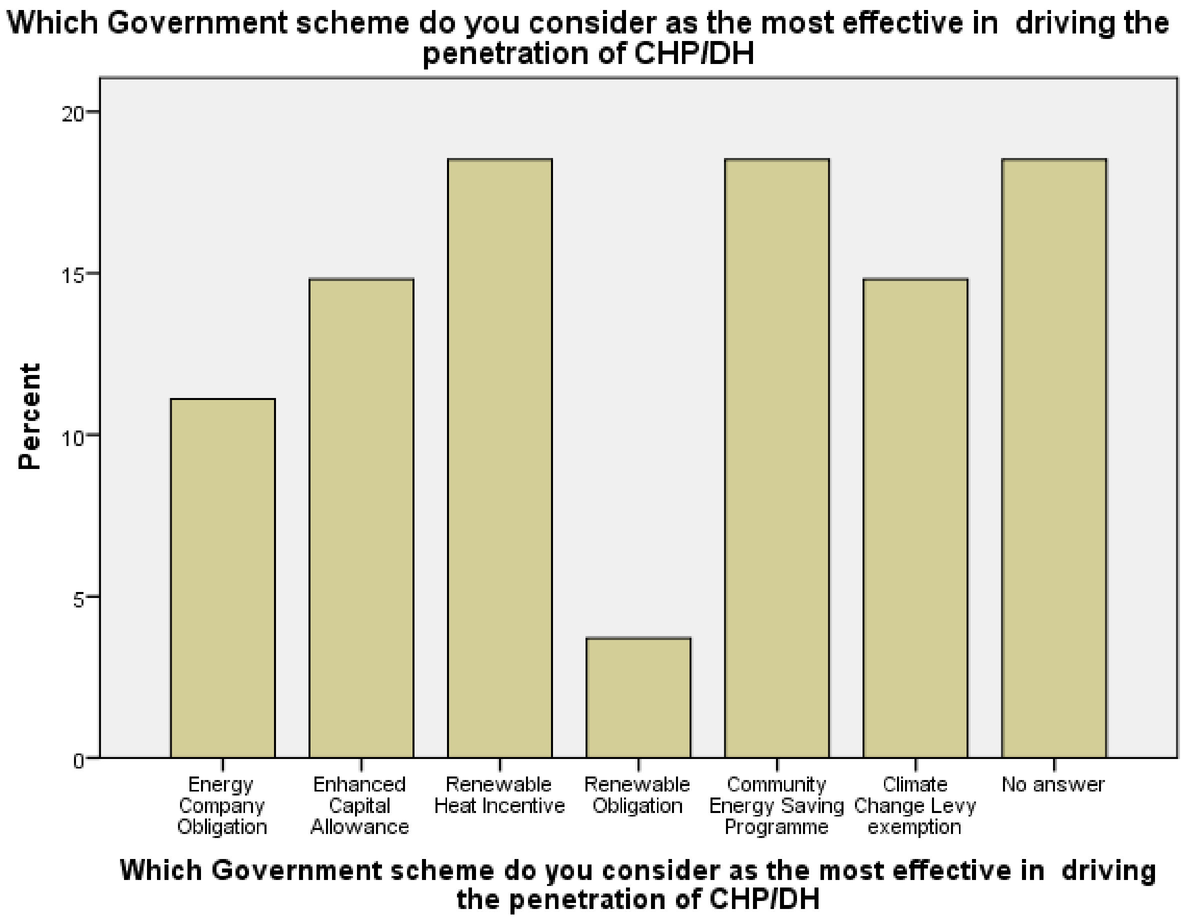

Figure 30: Bar Chart - Government scheme considered as most effective

Results from Table 72 and Figure 30, we can observe that, 18.5% of the consultants considers community energy saving programme, another 18.5% considers renewable heat incentive, while another 18.5% chose not to answer. This suggest that the result is not clearly in favour of any mentioned scheme especially as 18.5% decided not to participate in this question. Following bar chart also shows the bars corresponding to the same.

Q 38 - The EU ETS is a long-term incentive for CHP-DH systems

		Frequency	Percent	Valid Percent	Cumulative Percent
	Strongly agree	3	3.2	3.4	3.4
	Tend to agree	26	27.4	29.5	33.0
Valid	Neither	15	15.8	17.0	50.0
	Tend to disagree	18	18.9	20.5	70.5
	Strongly disagree	11	11.6	12.5	83.0

	No answer	15	15.8	17.0	100.0
	Total	88	92.6	100.0	
Missing	System	7	7.4		
Total		95	100.0		

Table 73: EU ETS as long-term incentive

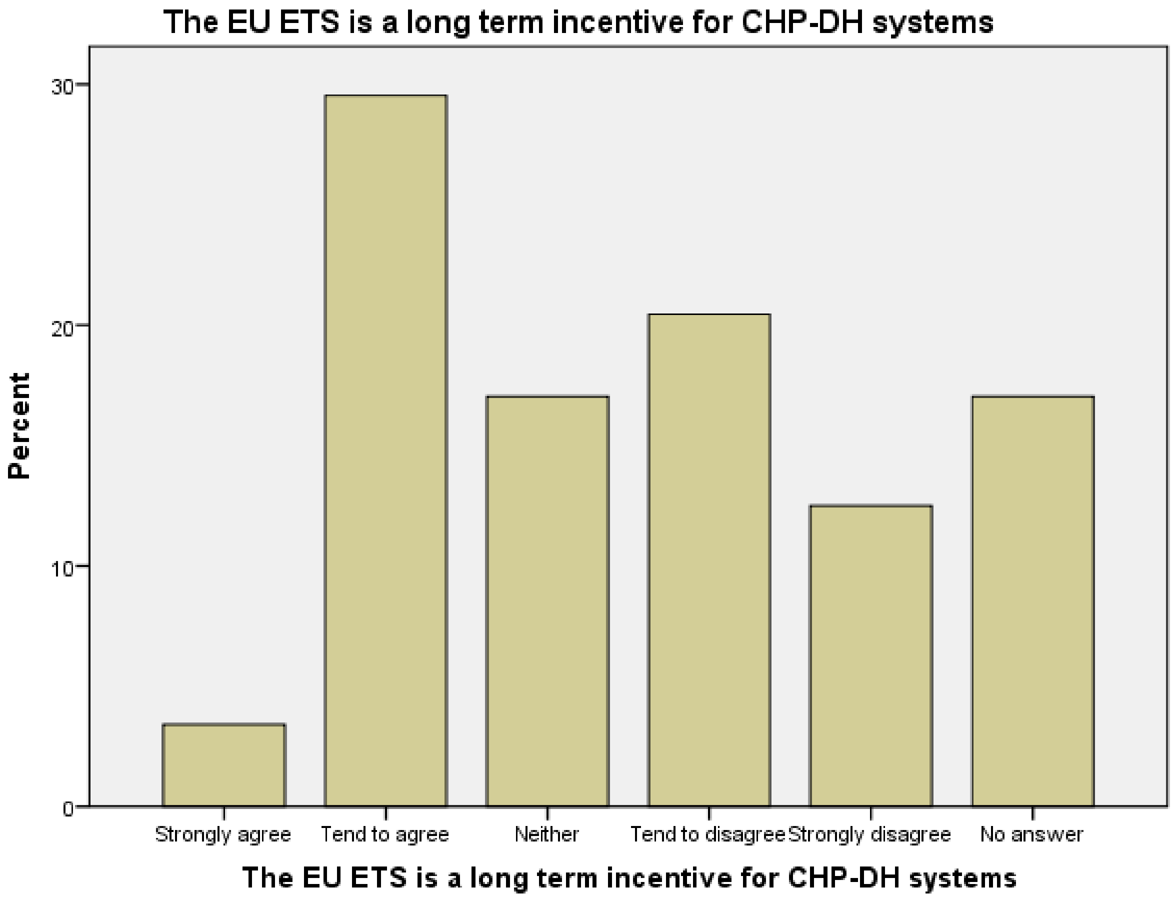

Figure 31: Bar Chart - EU ETS as long-term incentive

From the following the results from Table 73 and Figure 31. we have observed that 27.4% of the respondents tend to agree that the EU ETS is a long-term incentive for CHP – DH systems.

Q 39 - CHP's in your system participate in ancillary service provision to the electricity grid (percentage)

Ancillary service provision	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10

Yes	14 (15.4)	4 (13.8)	3 (27.3)	1 (16.7)	1 (25.0)	1 (33.3)	1 (33.3)	1 (33.3)	1 (50.0)	2 (66.6)
No	66(72.5)	22 (75.9)	8 (72.7)	5 (83.3)	2 (50.0)	2 (66.6)	2 (66.6)	2 (66.6)	1 (50.0)	1 (33.3)
No answer	11 (12.1)	3 (10.3)	1 (16.7)	1 (16.7)	1 (25.0)	0	0	0	0	0

Table 74: CHPs participate in ancillary service provision

Results from Table 74 suggest that most of the operators don't participate in ancillary service provision to the electricity grid.

Q 40 - If you do above. What type of ancillary services? (percentage)

Type of ancillary services	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Short Term Operating reserve (STOR)	6 (46.2)	1 (6.3)	2 (22.2)	1 (10.0)	1 (33.3)	1 (50.0)	2 (66.6)	1 (50.0)	1 (50.0)	1(33.3)
Frequency response services	0	0	0	5 (50.0)	0	0	0	0	0	0
Reactive power services	1 (7.7)	0	0	0	0	0	0	0	0	1 (33.3)
Other	0	3 (18.8)	1 (11.1)	0	0	0	0	0	0	0
No answer	6 (46.2)	12 (75.0)	6 (66.7)	4 (40.0)	2 (66.7)	1 (50.0)	1 (33.3)	1 (50.0)	1 (50.0)	1 (33.3)

Table 75: What type of ancillary

Results from Table 75 above suggest that majority of the CHP-DH operators different sites had no answer for the type of ancillary service.

Q 41 - The renewable heat incentive (RHI) should stimulate the required growth of CHP-DH in the UK

			Group		Total
			CHP operator	Consultants	
The renewable heat incentive (RHI) should stimulate the required growth of CHP-DH in the UK	Strongly agree	Count	12	2	14
		% within Group	13.8%	7.4%	12.3%
	Tend to agree	Count	37	10	47
		% within Group	42.5%	37.0%	41.2%
	Neither	Count	16	2	18
		% within Group	18.4%	7.4%	15.8%
	Tend to disagree	Count	12	6	18
		% within Group	13.8%	22.2%	15.8%
	Strongly disagree	Count	6	6	12
		% within Group	6.9%	22.2%	10.5%
	No answer	Count	4	1	5
		% within Group	4.6%	3.7%	4.4%
Total		Count	87	27	114
		% within Group	100.0%	100.0%	100.0%

Table 76: RHI as incentive to CHP-DH

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	7.972[a]	5	.158
Likelihood Ratio	7.561	5	.182
Linear-by-Linear Association	3.295	1	.070
N of Valid Cases	114		

a. 6 cells (50.0%) have expected count less than 5. The minimum expected count is 1.18.

Table 77: Chi square - RHI as incentive to CHP-DH

Symmetric Measures

		Value	Approximate Significance
Nominal by Nominal	Phi	.264	.158
	Cramer's V	.264	.158
N of Valid Cases		114	

Table 78: Measure of association (effect size)

Results from Table 77 above shows that the expected count of the cells is 50% (i.e > 5), therefore the assumptions are violated since its greater than 20% and we will use likelihood ratio values instead of the chi square figures. The likelihood ratio value was 7.561 and its corresponding p value was 0.182 > 0.05 (likelihood ratio = 7.561, df = 5, p = .182). Since the p value is more than 0.05, there is evidence that there is no significant difference in renewable heat incentive (RHI) stimulating the required growth of CHP – DH in the UK between the CHP operators and consultants. Hence, we will fail to reject the null (Ho), which is renewable heat incentive (RHI) should stimulate the required growth of CHP – DH in the UK

Therefore, following Table 76, we can observe that about 42.5% of the CHP operators and 37.0% of the consultants tend to agree that the renewable heat incentive (RHI) should stimulate the required growth of CHP – DH in the UK. However, the support is weak due to the non-significant result, therefore the data are inconclusive. Furthermore, drawing from the results of Table 78, the value of Cramer's V is 0.264, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is greater than .2 and therefore it has an effect tending towards medium (i.e > .2) according to Fritz et al. (2012).

7.4 UK Governance mapping

The development and penetration of CHP-DH systems in the UK energy landscape requires governance if it is to contribute to environmental, social and energy targets. The achievement of diffusion of CHP-DH systems is dependent on the governance mechanisms deployed that can influence its penetration (Hillman et al., 2011). Drawing upon several data on the governance structure and mechanisms that are prevailing in the electricity and heat sectors in the UK, a UK governance map was articulated. The governance map as shown in Figure 32 below will attempt to capture these mechanisms that impact on the development and diffusion of CHP-DH systems in the UK.

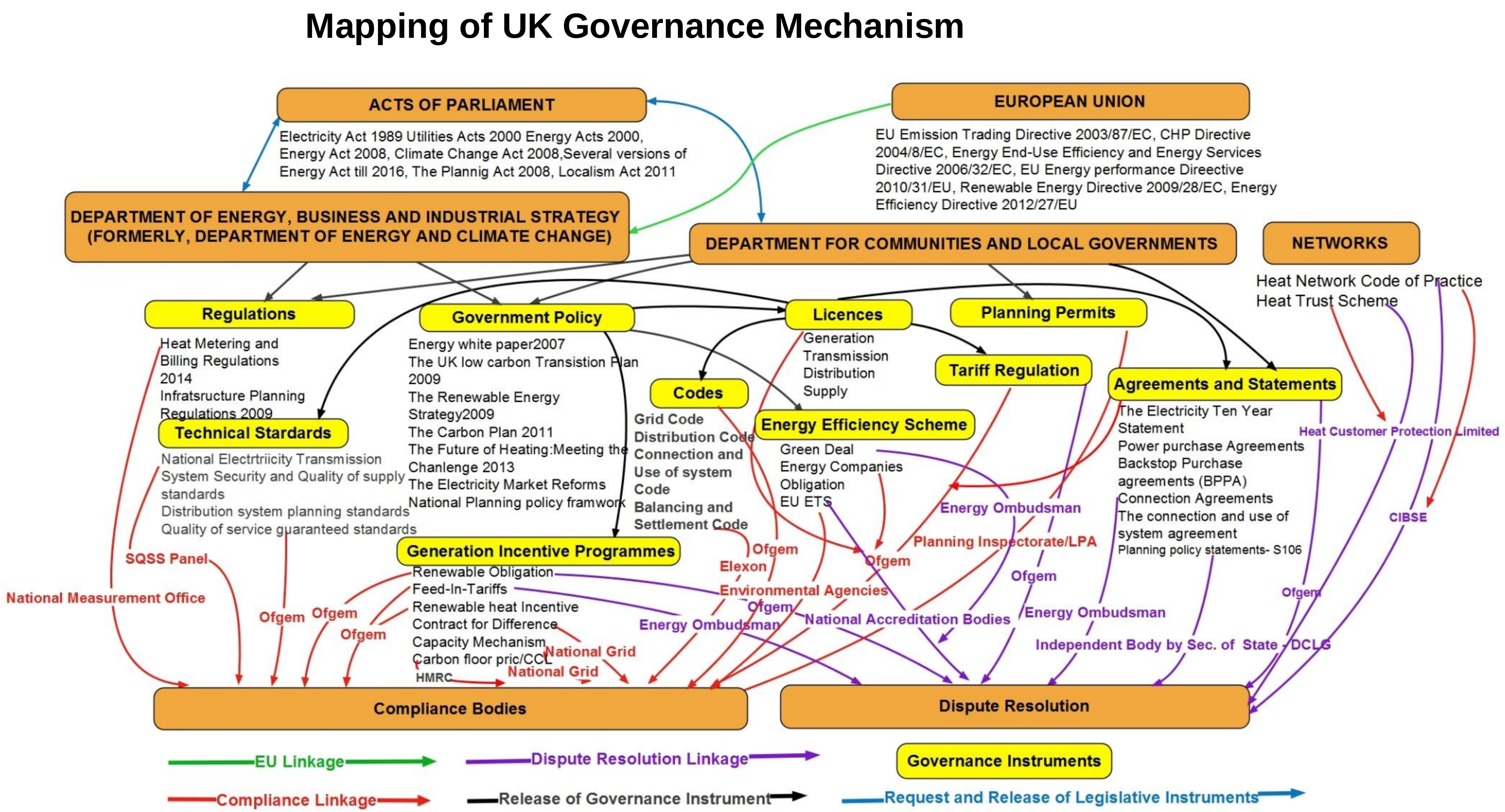

Figure 32: UK CHP-DH Governance map

In reference to the UK CHP-DH governance map in Figure 32, the green colour depicts the multi-level governance of CHP-DH systems in the UK between the EU and UK, which is usually carried out by the Department for Business, Energy and Industrial Strategy DBEIS (formerly Department of Energy and Climate Change (DECC)). EU legislation mandates the UK to further develop regulations and policies with a view to meeting national obligations and targets. These regulations and policies are legalised through the UK's own legislative arm. The blue linkages depict these legislative governance instruments that govern the interaction of actors and networks in the development and diffusion of CHP-DH systems in the UK.

The two major departments at the state level that impact on CHP-DH systems the most in the UK are DBEIS and Department for Communities and Local Government (DCLG). DBEIS is responsible for legislation which establishes electricity, gas and heat regulation while DCLG has oversight of the national planning regime. Their responsibilities are carried through various governance instruments which are depicted in black. An additional network of actors, including industry networks in the UK CHP-DH industry have articulated governance instruments to self-regulate the industry in the absence of a state driven regulation.

These governance instruments are administered, and an avenue is provided for feedback on disputes and non-compliance by actors. The schematic has provided compliance and dispute resolution boxes to reflect these concerns and the route or agencies that monitors compliances and access dispute resolutions are depicted in red and purple respectively.

Finally, the governance mapping of CHP-DH industry also represents the institutional actors that have one role or the other to play in the CHP-DH arena and seeks to simplify an overview of the interactions between the institutions, actors and networks in the technological innovation system of CHP-DH in the UK.

8.0 Results and Discussion - CHP-DH Landscape and Risk Profile

8.1 Introduction

CHP-DH technology has been mentioned as part of the solution portfolio to the UK's energy trilemma of energy security, affordability and sustainability by both scholars and government ((BIS/DECC, 2009, DECC, 2013a, DECC, 2014, Kelly and Pollitt, 2010, Ricardo-AEA, 2013, Ricardo-E&E, 2015, Ricardo-AEA, 2014, Toke and Fragaki, 2008, Pöyry, 2009). The role of CHP-DH technology is further reinforced through various multi-level governance mechanisms from the European Union (EU). These include the EU Cogeneration Directive (EU, 2004a) to incentivise member states on generation of useful heat from CHPs and the EU Energy Efficiency Directive (EED) (EU, 2014), which mandates member states to set binding energy savings targets of 20% by 2020. Many of these studies also discuss the opportunities that CHP-DH system portends in the UK, its potential and how regulatory frameworks can be harnessed to increase its use. However, little evidence has been presented which explores the operational and market landscapes that hold in the UK and the drivers underlying these landscapes. Some studies suggest ESCOs (Energy Service Companies) as a preferred governance structure to deliver the benefits of CHP-DH system for the UK in meeting its energy target (Hannon et al., 2013, Soroye and Nilsson, 2010, Bertoldi et al., 2006, Boait, 2009, Marino et al., 2011, Sorrell, 2007). Consequently, the knowledge of the landscapes of CHP-DH technology in the UK is sparse and the prevailing underlying drivers of the governance pattern seeks more understanding.

This chapter will seek to investigate the landscapes through interviewing key stakeholders operating in CHP-DH systems in the UK. It shall attempt to identify the drivers that play critical roles in determining operational and market choices and the dominant governance structure. This is with a view to suggesting a more optimal governance structure that can be adopted to deliver more systems and increase their diffusion. This chapter will also seek to outline a better understanding of the types of risk that militate against the diffusion of CHP-DH systems in the UK by asking respondents to attach weights to 21 risk profile developed in chapter 7, Table 26 and also set the scene for further discussion in the next chapter on the barriers to the penetration of CHP-DH systems in the UK.

8.2 Prevailing Landscape of the CHP-DH industry

8.2.1 Operational Landscape

Considering that CHP-DH produces two major energy vectors, electricity and heat, understanding the capacity landscape of the energy vectors in the UK would provide insight into the preference of developers, drivers and barriers such as those that emanate from grid infrastructure. Furthermore, the knowledge of the operational landscape shall offer more incites on the impact of governance mechanisms that influences capacity uptake. Such as capacity market mechanism which allows only CHPs between 2-50MW to participate, though smaller plants can be aggregated to the minimum capacity of 2MW (DECC, 2014k). Therefore, the research sought the dominant electrical capacity portfolios across operators with as much as ten sites broken into five major groups: <5MWe, 6-10MWe, 11-50MWe, 51-100MWe, >100MWe.

The results from a statistical – descriptive analysis of the responses as seen in chapter 7, Table 11 from the questionnaire suggests that the dominant percentage of CHP electrical capacity sizes for all sites is less than 5MWe. For instance, 73.9% (136) of the 184 total sites being operated by respondents are on less than 5MWe indicating this is the dominant clustering in the electrical portfolio for CHP in the UK. Furthermore, Table 11 also shows that the next dominant size are plants of over 100MW with 12% (22) of the total site. Perhaps more importantly these represent more than 60% of capacity, which is consistent with a Government annual energy report which suggest that over 80% of CHP schemes are less than 5MW but over 60% of electrical contribution from CHP come from plant that are over 10MW (DECC, 2015c). Table 11 also indicates that there are few organisations that operate multiple sites and large capacities, evidence of a landscape dominated by small individual systems. Additionally, it suggests that the CHP electrical market resides with few large organisations that would mostly likely contribute their capacity through the transmission grid rather than the distribution grid.

Several studies had defined CHP plants of <5MWe as predominantly reciprocating engines, usually with low heat to power ratios and producing low grade heat (Pöyry, 2009, Carbon Trust, 2010, Ricardo-AEA, 2013).Therefore, another deduction from Table 11 is that the prime movers in CHP schemes are predominantly reciprocal engines because of their small sizes, which indicates that there are more schemes (quantity) in the UK that provide low grade heat for space and water heating than process heat. However, the small proportion of large capacity CHP plants which are over 100MWe band, representing over 60% of electrical production from CHP, indicate that greater CHP electrical capacity is being produced from gas and steam turbines as prime movers, with less capacity from reciprocal engines. These gas and steam turbines are usually associated with higher heat grades and high heat to power ratio. The results in Table 12 will clarify the extent of coupling between the electrical and heat production landscapes.

The profile for heat capacities of the network across the respondents, as seen in Table 12 shows a similar trend to Table 11. Out of a total of 94 respondents representing 178 sites, 106 sites (~60% of the sites, ~12% total heat production) have a heat operation <5MWth. However, almost 40% of heat comes from large producers (>100MWth heat capacity). Table 12 also shows that there are few multiple site operators of heat networks, indicating a landscape dominated by single heat network operators. The combination of both Table 11and Table 12 does indicate that the UK CHP-DH landscapes are dominated by silos or individual schemes.

The operational mode of CHP can either be electrically, least cost/standby or heat led. The dominant mode of operation of CHPs in the UK was sought so as to be able to understand the underlying factors that determine the dominant choice of operational mode. Generally, in determining the mode of operation of CHPs by the plant owners, two prevalent criteria come in to play namely: technical (infrastructure) and economic (market) (Kavvadias et al., 2010). Results from the questionnaire suggest that the dominant mode of operation of CHPs in the UK is heat led. This is shown in Table 13, where 104 (58%) are heat led, while 61 (34%) are electricity led from a total of 165 sites operated by respondents.

The deduction from Table 13 also shows that meeting heat demand is likely to be more of a concern than producing electricity. In part this seems likely to be because for CHPs to obtain good quality certification from CHP Quality Assurance (CHPQA), a government agency, demands that heat is not seen to be wasted (Ricardo-AEA, 2013). Respondents have attributed to this trend to varying reasons. Such as net financial benefit of the overall system, electricity export not viable and some are led by heat contracts. Electricity export was often hinged on regulatory barriers. Such as electricity license regime which prohibits CHP-DH systems to supply themselves more than 2.5MWe through the public distribution network unless they sell their excess electricity to a supplier then buy it back to use or through a private network (DTI, 2005, Ofgem, 2008a). Therefore, the electricity license regime which acts as a disincentive for high electrical capacity from CHPs over 2.5MWe to the grid may have contributed to more systems opting for heat led than electricity led, so that they meet their heat demand as a priority and import more electricity. The other reason could be the absence of a city-wide heat network.

Consequently, the extent of connectivity of the CHP-DH systems was sought, with a question concerning the average length of pipes in operational heat networks. Responses from CHP-DH operators in Table 14 suggests that out of the 187 sites registered in the survey, 94 sites (~50%) have network lengths of less than 1km. This indicates that the CHP-DH industry in the UK is predominantly made up of silo systems suggests that heat production and distribution is dominated by non-interconnected small-scale systems and minimal linking of heat network infrastructures. This absence of networked heating systems can be taken as indicating a system failure resulting from institutional failures that constitute barriers to innovation to develop heat governance infrastructures such as lack of heat regulation (Foxon, 2007 pg:134). This also supports an argument that the CHP-DH industry may exhibit "missing institutional link" (Edelenbos, 2005).

A major insight arising from the data is that CHP-DH investors may not benefit from economies of scale in the UK as a result of the small-scale focus created by the institutional and regulatory failure (Pöyry, 2009, Ricardo-AEA, 2014). The implication of this is that the efficiency of these systems is not optimum since heat production and demand cannot easily be distributed across systems, resulting in higher average installation costs, which could be reduced by interconnectivity. This also suggests that the CHP-DH industry may show signs of inefficiency which can result in higher heat price (Le Grand, 1991) due to higher average installation cost resulting from low inter-connectivity of heat networks. Another, interpretation is that average heat-to-power ratio of the systems appears to be near one-to-one with marginal variation in ratio, suggesting that the CHPs used in the UK are predominantly low heat to power ratio plants with little contribution from coal. Suggesting also that most of the heat from CHP-DH systems are mainly used for low temperature heating in space and water heating rather than process heating. This is also collaborated with a Government observation that CHP-DH systems have little usage in the process heat industry and supported by Government's data which also suggest that about ~69% of energy consumed for heating in the UK is for space and water heating with only about ~18% used for high and low temperature process heating (DECC, 2013a)

8.2.2 Market Landscapes

In understanding the economic landscape, this research sought to investigate the state of CHP-DH industry in the UK. In responding to the question of what the level of maturity of the CHP-DH system is in the UK. A total of 164 responses were received which was made up of 137 CHP-DH operators and 27 consultants. Statistical results from Table 16 shows that the chi square value was 23.37 and its corresponding p value was 0.000<0.05 (chi square =23.37, df = 4, p = .000). Since the p value was less than 0.05, we have evidence that, there is a significant difference in the level of maturity in the UK district heating supplier chain between the CHP operators and consultants. Therefore, we can draw upon the descriptive results from Table 15, which indicates that about 30.7% of the CHP operators and 77.8% of the consultants expressed that the level of maturity in the UK district heating is at infancy but growing. Hence, there is evidence to conclude that the level of maturity of the CHP-DH industry in the UK is at infancy stage but growing.

The infancy market status reflects the low penetration of CHP-DH systems in the UK, which the Government collaborates to, that the scale of DH in the UK is low and that's why the industry is allowed to be self-regulated and not driven by regulation, but the Government do recognise that there is a system failure which needs to addressed to enhance its selection environment (DECC, 2013a). However, Government's emphasis is on reducing the market barriers by deploying public finance to crowd in private finance, without wholly considering the non-market barriers, such as internalising low carbon gains, thereby only considering techno-economic conditions and not socio-economic such as fuel poverty reduction, which contributes to the systemic failure as well (Webb, 2014). Therefore, the Government's position is further reinforcing the path dependency of the large centralised energy market, which disincentives distributed energy systems like CHP-DH systems (Hawkey et al., 2013, Woodman and Baker, 2008). A further consequence is that the heat market in the UK is neither a top-down steering model nor market-based competition, largely due to lack of regulatory infrastructures. Heat market in the UK differs considerably from the market for electricity largely due to the fact the large majority of heat produced is consumed locally (on site) or wasted, therefore there is a negligible quantity of heat that is from a third party which makes most UK heat producers the same consumers. Hence a limited market for heat as a product.

Therefore, there is evidence that the UK CHP-DH market is a nursing market in the phases of market formation. The thematic view of respondents is that the investment in the CHP-DH industry to move it from the current nursing market to the desired mass market so as to enable it compete with the incumbents (Andersson and Jacobsson, 2000) would depend on regulatory infrastructures and availability of volume. A supplier iterated this also in respect to market volume and investment.

"It's all about market volume. If manufacturers feel the market is big enough, they will invest" DHP3

However, in spite of the infancy status or current nursing market and lack of a regulatory framework to signpost development and govern transaction, the CHP-DH industry is experiencing some growth in the sector as reflected in this research that it is in infancy but growing. For instance, the market growth has led to the opening of the first DH pipe manufacturer in the UK in 2012.

"May 2012 is when we opened our UK factory…….. We're the only one, yeah. No, we're the only one. We use it as marketing. Obviously it's a key selling point for customers" DHP3

Hitherto, all DH pipes were all imported from Europe into the UK, which respondents from this research claims cost an additional 1% to 3% for transportation. Suggesting that the cost of DH pipes may well reduce as more factories are opened in the UK. Furthermore, another respondent that is a DH pipe supplier to the UK market claims an annual growth of ~20% from 2013 - 2014 and the respondent suggest that the UK DH pipe supplier market increased from the previous dominant four (LOGSTOR, Isoplus, Power-Pipe, and Brugg) to around ten in 2015.

"You'd get everybody maybe anything between 1% and 3% of the overall cost would actually be transportation costs" DHP1

Other pointers are that the CHP-DH market is growing and shows signs of enormous potential for further growth is the impressive balance sheets that CHP-DH development companies presents as their turnover surges, which is even attracting recognition from financial watch dogs (Vital energi, 2014). While several schemes are billed for expansion as mentioned by respondents and not to mention the over a hundred CHP-DH schemes awaiting development from the HNDU sponsored CHP-DH projects through feasibility grants to LA schemes.

In considering the extent of CHP-DH operator's participation in the electricity market, the research sought to investigate how CHP-DH operators trade their electricity. The result is depicted in Table 18 which shows that of the 191 sites registered by respondents, 126 of the sites (~66%) consume their electricity on site. This also explains the trend in Table 19 and Figure 15 where almost 55% of respondents send their electricity from CHP-DH systems only via private wires, while another 19% of respondents mostly use private wires.

Combining the trend in both Table 18 and Table 19 suggests that CHP-DH operators are not incentivised to export electricity, for instance at times when the local electricity demand is low, they are constrained to export but rather they mostly import electricity from the grid. Many CHPs may be locked out of electricity trading due to the high entry barrier such as high cost of IT requirement for standard electricity supply license owners and the challenges of self-supply restriction in the licensing condition. A CHP-

DH operator with almost 2000 properties highlighted to the difficulty of supplying themselves because they didn't have a private network and a standard electricity licence.

"We're selling off our own electricity, yet we can't supply using our own electricity, because of the way the market is".CDHOP3

Under the UK Electricity Order 2001, electricity generators under 5MW are exempted from requiring generator, distribution and supply licences but however, electricity generators are limited to supplying not more than 2.5MW to domestic customers and 5MW to business customers without having a supply licence. This is known as the class order exemption 2001 (DTI, 2005, Ofgem, 2008a). However, if the electricity supply is through a private network, such restriction doesn't exist. Secondly, when CHP-DH operators procure the services of a supplier it generally cost them a discount of about 10-20% of the wholesale electricity market price, which typically constitutes the cost of trading, balancing cost, administrative cost, long term risk and profit margin (Handley, 2013). A common example was the collapse of a CHP-DH scheme connected to the Leicester citywide district-heating scheme when it failed to secure a supply contract for the sale of its electricity for its CHP plant (Kelly and Pollitt, 2010). This restriction of electricity supply volume on CHP-DH system of 5MW and below indicates the adverse consequence of electricity regulation on CHP-DH operators.

A private network is therefore seen as an opportunity to optimise the operation of CHP-DH systems as it allows developers/operators to remove barriers on supplier self-restriction and minimise Distribution Network Operators (DNO) charges when they supply through public networks. However, when the CHP-DH system is improvised into a developed city with varying locations of load, it becomes uneconomical to build private wire except new builds or centralised load. An example of a private network being used to make savings on energy prices is Woking Council. Woking has about 80 private networks and saves 5-10% on energy prices from electricity generated from their CHPs compared to market rates (DTI/Ofgem, 2007). Therefore, because of these restrictions as enumerated by various respondents, CHP-DH systems in the UK are not incentivised to size their CHPs to consider the wider electricity market but rather local heat requirement. Additionally, CHP-DH operators don't want to put their CHPQA (CHP quality assurance) certification at risk by wasting heat and since there is usually no external heat market.

In understanding the economics and management (integrated or separate) characteristics, the research sought the dominant economic and management models being adopted in the UK CHP-DH industry. This is with a view to align the result with other drivers of the system and understand the triggers for the reasons of the choices. This research sought from the CHP-DH operators what sort of economic model was adopted in their operations. Out of a total of 94 sites that provided answers to the questionnaire, 62 (~42%) sites are operated as fully commercial, while 6 (~4%) sites are partially commercial with profit caps and 26 (~18%) sites are non-profit as seen in Table 20.

To strengthen the above results, the research sought to understand the heat customer profile of the CHP-DH industry and the result depicted in Table 21 reinforces the earlier observation on the economic models adopted. Out of 161 sites that responded, 15 sites are domestic, while 26 sites are industrial. Out of the remaining, 67 respondents are from commercial sites and 53 respondents are from mixed sites. Research results shows that most of the respondents with commercial sites are located at universities and hospitals.

The deduction from these two sets of results (Table 20 and Table 21) are that firstly, CHP-DH developers are keen to hedge their heat risk with commercial portfolios which would support the right business model to attract developmental finance. Secondly, the blurred role of the state/LAs in the governance of CHP-DH has given the private sector the position of steering (setting the rules through networks) and rowing (delivering the systems) due to governance failure, leaving the private-led networks to initiate governance instruments like the heat network code and protection scheme. This is imperative because private actors are driven by profit and not social objectives such as fuel poverty, which makes the commercial model a more obvious economic model for them to deliver the services. Thirdly, the absence of state heat regulation leaves the industry to be regulated through laissez-faire (little or no interference from the state/LA), allowing the industry to respond to government failure by picking areas of development that match their economic preference. Fourthly, to reduce the risk of debt collection from the domestic sector especially social housing schemes as will be made apparent later in this research, commercial customers seem an obvious attraction as they exhibit greater certainty in heat bill payment. Fifthly a financial barrier such as high cost of capital and reduced funding from the state to the LAs contribute to hindering LAs to initiate CHP-DH systems, meaning most CHP-DH systems are supported by the private sector. Lastly, the development pattern of CHP-DH systems in the UK suggests that it is in misalignment with Government's affordability goal for the reduction of fuel poverty with more commercial schemes based techno-economic goals rather than socio-economic (Webb, 2014).

ESCO (Energy Service Company) models have been mentioned severally as suitable for delivering sustainable and environmental goals (Hannon et al., 2013, Marino et al., 2011, Soroye and Nilsson, 2010). Others have credited ESCOs as possible solutions to increase the penetration of low carbon technologies such as CHP-DH and reduce barriers to energy efficiency (Bertoldi et al., 2006, Boait, 2009). However, in spite of its benefits the UK has no consensus form of ESCO and therefore no policy trust towards it either (Julian, 2014, APBenson, 2011). Consequently, the shape of ESCOs and governance structure on CHP-DH systems are site specific and largely depend on the actor's perspective on risk. Elsewhere in chapter 5, the difference between Energy Service Providers (ESP) and ESCO were highlighted and the three major types of ESCO ownership structures, which are private led, joint venture or public led were also discussed. Also highlighted in chapter 5 are the two major forms of economic models of ESCOs, which are guaranteed savings or shared savings type.

Therefore, this research sought to ascertain management models of operations or dominant ownership structure from the CHP-DH operators. Results from Table 22 did not offer clear indication of the type of management model adopted by the respondents due to the high value of no answer. However, from the respondents that responded, more respondents indicated a fully integrated energy services company (ESCO) model as the management model adopted depicted as in Table 22. Out of the 65 sites that responded, 44 sites (~70%), are fully integrated ESCOs, while 6 sites have separate production, distribution and supply entities and 11 sites are same production and distribution with different supply. Furthermore, only 1 site is same production and supply with different distribution, while 3 sites are same distribution and supply with different production.

This results suggests that CHP-DH firms are vertically integrated monopolies through ESCO vehicles suggesting minimal competition throughout the value chain from production, transmission, distribution, and supply to metering of heat. Westin and Lagergren (2002) suggests that vertically integrated ESCOs that have monopolies of heat production, distribution and supply may have the strong temptation to always maximise profit and transfer higher cost to customers, since they are not faced with any price threat externally. Secondly, they have the potential to exhibit allocative inefficiency (suboptimal heat production and bad heat quality), especially in the absence of industry wide regulation (Westin and Lagergren, 2002, Le Grand, 1991). However, CHP-DH industry in both Norway and the Netherlands have ESCO models similar to the UK but with a vital deviation as to leadership or ownership. In both countries (Norway and the Netherlands) CHP-DH ESCOs are predominantly led or started by the municipalities, while UK LAs seems to have marginal presence in the CHP-DH industry with most ESCOs privately led. This suggestion was further reinforced as the participation of LAs in the CHP-DH industry was investigated and LA respondents were asked about their participation.

Table 23 and Figure 16 shows that over ~46% of LAs respondents are sure they have a CHP-DH project in their locality, while about ~15% of LA respondents don’t know if they have one and another. While about 40% of LAs don’t have a CHP-DH project in their area at all. Consequently, the research sought if the LAs are directly involved in the CHP-DH project. Results from Table 24 and Figure 17, only 10% of the LAs are currently involved with CHP-DH projects in their locality with almost another ~33% are involved in an on-going project with almost another ~25% considering their involvement and ~22% not considering at all. The results from both Table 23 and Table 24 suggest limited participation of LAs in CHP-DH systems. Consequence upon the narrative from the research results, CHP-DH systems are predominantly run by private led ESCOs for commercial goals by securing funds on their balance sheets with limited roles of the LAs. The narrative also suggests that a shared savings ESCO model seems more dominant as against guaranteed savings model in the CHP-DH industry. Further discussion on the UK’s LA existing role is in the next chapter.

8.3 Risk profile of CHP-DH industry in the UK

It is often said that no project is without a risk but requires potential investors to seek ways to reduce it, live with it or transfer it, but it is not ignorable (Lam et al., 2007).

Many commentators have projected risk in different light such as, sense of lack of certainty (Ward and Chapman, 2003), likelihood of an adverse event (Mills, 2001) and uncertainty of interactions amongst stakeholders (Green, 2001). In all these perspectives of risk the common theme is uncertainty but the one with the most relevance to this research is the definition advanced by Green. In this definition Green (2001), looks at risk from three perspectives. (a) Uncertainty of decision – the focus here is the interaction between the various actors, (b) Uncertainty of environment – the concern here is the financial and cost implication and lastly (c) Uncertainty of objectives - concern about the policy impact and clarity of objectives. The next step in looking at the potential future of CHP-DH in the UK was to consider the major factors that constitute uncertainty in the development of CHP-DH systems from an operator, local authority and consultant perspective. This is imperative because, how the risks are identified and allocated to all parties determines the success of the project. In enumerating the risk to be highlighted for allocation, only the humanly induced risk is considered here, rather than natural risk, according to the classification by Edwards and Bowen (1998). The choice of humanly induced risk is borne out of the fact that this research is investigating a technological system within a humanly organised governance system and not outside.

A list of 21 risk factors were enumerated for respondents to rate according to what they considered as the most militating risk factor to investment in CHP-DH projects. A total of 260 correspondents participated in the survey, of which CHP-OPS were 95, LAs were 138 and Consultants were 27. The result from an inferential statistical analysis using Analysis of Variance (ANOVA) in SPSS as seen in Table 26 showed that out of the 21 risk factors, 7 factors were statistically significant with a p value that is less than 0.05.

Risk Factors	**P value**	**Measure of effect**
Heat off-take risk	0.041	Towards medium
Land acquisition and compensation	0.005	Towards medium
Availability of finance	0.012	Towards medium
Cost of finance	0.02	Towards medium
Planning permission risk	0.049	Towards medium
Delay in planning permission	0.037	Towards medium
LAs experience in PPP	0.013	Towards medium

Table 79: Risk Factor Table

Drawing from the results of the statistical analysis in Table 26, there is evidence that Heat off take risk, land acquisition and compensation, availability of finance, cost of finance, delay in planning permission, planning permission risk and Local authority experience in Public Private Partnership/Public Finance are significant risk factors that militate against the investment in CHP-DH projects. Furthermore, results from Table 28, which captured the measure of the contribution of each risk factor to the observed variables. The summarized results in Table 79 above shows the risk factors with a p values lower than 0.05 and their measure of contribution to the observation, with all 7 risk factors showing a near medium strength of effect. However, land acquisition and compensation have the largest effect and closely followed by availability of finance.

CHP-DH infrastructure is characterised by high initial capital and low marginal return that makes the investment fully recoverable after many years, which makes it less attractive to investors (Balcombe et al., 2013, Kelly and Pollitt, 2010, Aronsson and Hellmer, 2009). Therefore, availability of finance had featured in several studies as a critical barrier to the development of CHP-DH systems (Kelly and Pollitt, 2009, Williams, 2010, Kelly and Pollitt, 2010, UNEP, 2015, Pöyry, 2009). The qualitative data from interviewed CHP-DH actors also collaborated with a theme of lack of cheap finance. Which many expressed in various ways such as abandoned projects due to low rate of return to access private finance, difficulties of borrowing due to cuts from central government, high cost of borrowing to achieve social objectives, premium cost on heat off-take risk and absence of public support capital to provide total control by LAs as seen in Figure 33.

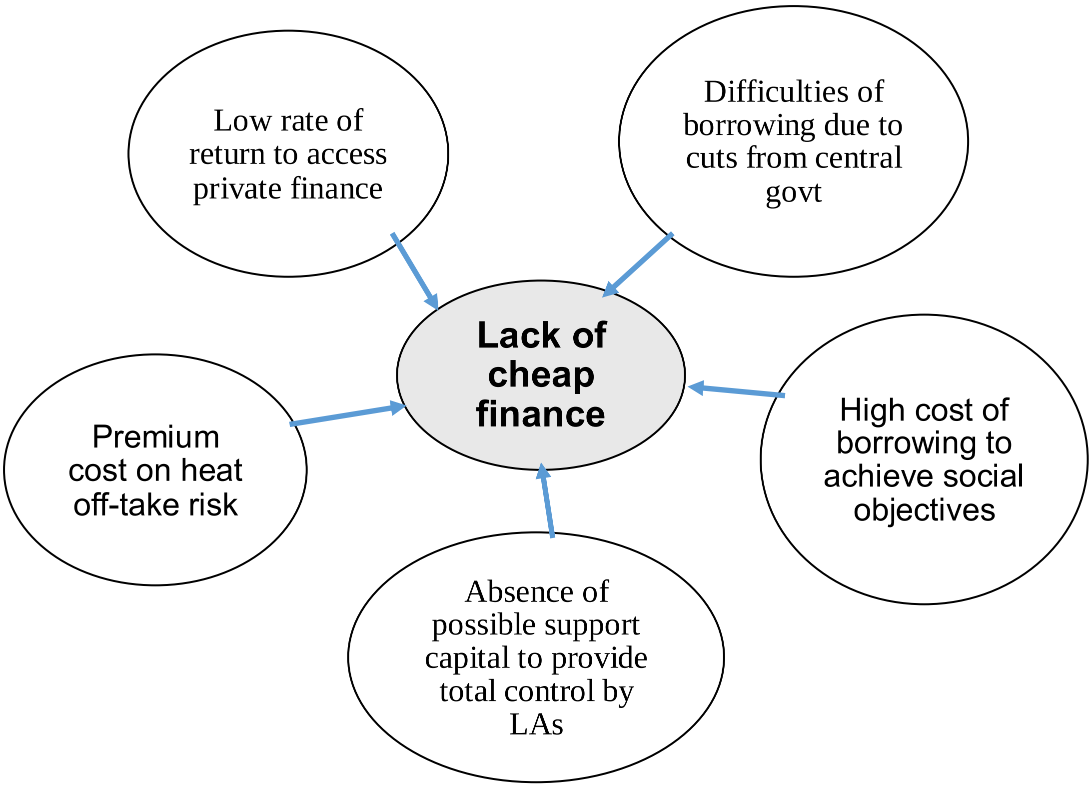

Figure 33: Common theme on finance from qualitative data

The theme may have captured both availability of finance and cost of finance as significant risk to CHP-DH development in the UK deduced from the quantitative results and many also considers that this can only be provided by the government. Consequently, these risks (availability of finance and cost of finance) have been further discussed in section 9.3 as one of the roles the LAs can a play significant role to ameliorate it.

I think probably, everything I've been told, it's about the financial. The cost of financing. For low-interest loans, you need low-interest loans for district heating to make a return on investments worthwhile. One of the issues are that there's not enough access to low-interest loans…….They need to have more low-interest loans available for these schemes to be able to show the return on investments. (DHP1)

That was the single biggest driver…….As soon as the money became available then people were mobilized to help put a robust business case together.(CDHOP4)

I think capital funding from central government kick starts schemes will probably be the key driver in the end (CDHO15)

Furthermore, another risk factor that was highlighted that can militate against the investment of CHP-DH system in the UK is heat off-take. This was collaborated, when consultants were asked to rank the dominant challenge to the construction of CHP-DH systems in the UK. The results from the Table 29 and Figure 18, shows that 44% of consultants considers heat load as their dominant challenge while 24% considers lack of capital as their dominant factor challenging the construction of CHP-DH systems in the UK. This suggest that consultants consider heat load as their major challenge. Similarly, some LA interviewees held similar views to also collaborate the importance of heat off-take to the development of CHP-DH systems. For instance, the citation from an LA respondent below, considers the availability of heat load as even more significant risk than lack of capital because they consider a down-up deterministic approach, where revenue stream will determine investment on the project and not capital. This may be part of why heat off-take has been thrown up as a potential risk to the development of CHP-DH systems in the UK. This is further reinforced by the lack of heat grid in cities to facilitate widespread heat transaction and lack of heat governance infrastructure. Nonetheless, qualitative suggest that revising local policies to capture CHP-DH systems and creating DH zones to mandate customers to connect to DH networks may ameliorate this risk.

In a way, funding is the least of the problems, in a way. The real problem is actually getting the guaranteed revenue. It's getting the heat. The heat sale risk is the main problem for all the schemes (LA5)

"It could pass planning laws, for example, that require connection to district heating units in new developments, that kind of thing" CDHOP15

Planning was also thrown up as part of the risk profile that militates against investment in CHP-DH projects in the UK. The risk of planning permission denial and delay in planning permission were the varieties of planning captured in the risk profile which was earlier captured in chapter 2 as one of the barriers that militate against the penetration of CHP-DH in the UK. In part because of the undue delays in getting agreed planning instruments (Bottini et al., 2013). Such as the difficulties experienced by Thameswey Energy (an ESCO wholly owned by Woking Borough Council) in gaining permission to lay pipes in Melton Keynes (Hawkey, 2009). Furthermore, development of DH networks compulsorily requires planning permission for new CHP-DH projects, because they are not under the permitted development rights, unlike the electricity and gas networks that does not require one. Therefore, planning applicants run the risk of denial or delay.

However, responses from the interviewees were split between planning being a facilitating instrument or a blocking instrument. As some in LAs opined that they are looking at the future and overall picture of the community, which would seek to capture several concerns. Such as emission, noise, social, master plan and land control and not a single spot or location. So, in as much they want to promote low carbon energy, the overall community concern and plans is paramount. While many of non-planners consider them as blockers to the penetration of CHP-DH because of their role in denial or delay in planning permission due to lack of knowledge and the requisite experience in CHP-DH deployment.

"They see the need to do it as part of their planning policy, in other words, it's part of reducing carbon emissions locally and creating future proof to networks, and all that. Not all of them have that kind of vision. It's not built into their planning policy then it's not going to go forward" LA5

"Yeah, I think the planning is certainly an issue that we have faced internally because we actually have to apply to our own planning department within the council for permission to build these systems. They have created a lot of problems for us. Probably it's because it's a very new industry. There's no kind of standards of what's expected of a district heating system. Within the planning laws, you get a lot of work called permitted development" CDHOP15.

A further investigation was conducted quantitively on the role of planning officers and procedure to the penetration of CHP-DH systems in the UK, where the views of LAs and consultants were sought on the statement that planning officers in the LAs are skilled enough to offer proactive guidance to CHP-DH planning permits. The results in Table 33 show indicate that 43.5% of the LAs and 48.5% of the consultants expressed that they tend to disagree, while 15.9% of LAs and 3.7% of consultant strongly disagree. Indicating the view that planning officers are not skilled enough to offer proactive guidance to CHP-DH applicants. However, due to the non-significant statistical result in Table 34 with a p of 0.308>0.05, the result has a weak support and therefore would require further analysis. Similarly, the same group of respondents were faced with the statement that the existing process to receive planning consent to be transparent enough to gain the confidence of the CHP-DH applicants. Results from Table 36 shows that 39.7% of LAs and 44.4% of the consultants expressed that they tend to agree, while 4.4% of the consultants strongly agree that the existing process to receive planning consent is transparent enough to gain the confidence of the applicants for CHP-DH projects. However, due to the non-significant statistical result in Table 37 with a p of 0.616>0.05, the result has a weak support and therefore would be considered inconclusive. Nonetheless, planning was further discussed in chapter 9 as a critical role that LAs may play to facilitate the penetration of CHP-DH system in the UK.

Another risk revealed by the statistical analysis that may militate against investment in CHP-DH systems in the UK was land acquisition and compensation. A further quantitative investigation was conducted when LAs respondents were faced with a statement that private land owners are very receptive to CHP-DH projects. Results from the descriptive statistics in Table 31 are not conclusive as there was no dominant view in this respect. As 25.9% of respondents tend to disagree, while 22.2% tend to agree and another 25.9% hold neither view. However, the qualitative data suggest that there is little that can be done with regards to decisions on private landed property.

Lastly, the lack of LAs experience in public private partnership was also considered as a risk that would militate against investment in CHP-DH systems in the UK. A further investigation was conducted when LA respondents were faced with a statement that LAs have the necessary capacity to engage energy services companies (ESCO). The statistical results as revealed in Table 32, shows that 35% of respondents tend to disagree, while 24% tend to agree. When 14% also strongly disagree and 4.4% strongly agree. This suggest that majority of LA respondents thinks that they don't have the necessary capacity to engage energy services companies. This is also reinforced by the turnover of, and reduction in, skilled staff in the LAs since the beginning of the financial crisis with many LAs respondents indicating that they now have increased responsibilities, while some say of merging departments within councils and across councils. This is collaborated with a citation from an LA below.

"I know lots of other local authorities who are losing skilled staff because of budgetary constraints" LAPLAN2

However, some LAs had devised ways to reduce this barrier by collaborating with Universities or NGOs within their locality to further improve their knowledge base and help inform their decision. For instance, according to a respondent the collaboration between University of Exeter and Exeter City Council had greatly impacted on the development of planning routes and requisite capacity to increase the deployment of CHP-DH systems. While many LA interviewees had to engage the services of external consultants at a huge cost to improve their capacity in this respect. Therefore, the opportunities this research offered to LAs without academic institutions is to explore the opportunities to collaborate with NGOs or industry bodies. This is with a view to improve capacity in engaging ESCOs in their locality.

Summarily, the seven (7) risks that have been thrown up by the quantitative analysis that militates against the investment of CHP-DH in the UK was further collaborated by the qualitative analysis. Suggesting further credibility to the prevalence of these risks. However, LAs may play greater roles as the prime movers of CHP-DH system in the UK to ameliorate some of these risks. The next chapter captures those potential roles.

8.4 Conclusion

The CHP-DH landscape in the UK is dominated by heat led silo schemes with little interconnection with other schemes. Partly due to the requirement for CHPQA certification to encourage use of heat generated and the class order exemption 2001 which prohibits CHPs to sell more than 2.5MWe (domestic)/5MWe (business) to themselves through a public distribution network without a standard electricity supply license (DTI, 2005, Ofgem, 2008a).

Therefore, most schemes from respondents deliver their electricity through private wire to be consumed on site and are mostly governed by fully vertically integrated ESCOs. The research suggests that the dominant ownership structure of the ESCOs are mainly private led and economically, the UK CHP-DH industry is dominated by commercial schemes suggesting they are more structured as shared savings with the ESCOs bearing both technical and credit risk. This dominant governance arrangement of full vertical integration suggests that the CHP-DH industry in the UK may have the potential to exhibit allocative inefficiency (suboptimal heat production and bad heat quality), which can be aggravated by the absence of heat regulation.

Furthermore, the seemly minimal participation of LAs in most ESCOs may be inimical to the diffusion of CHP-DH systems because without strong buy-in and a leadership role by the LAs, the ESCO may lack the potential to develop city-wide schemes to effectively couple supply and demand. In part because of the large anchor loads LAs possess across the area and with strong ability to locate and coordinate other potential customers.

The next chapter shall to seek discuss other perceived barriers by the respondents with possible mitigations and the roles LAs can play to significantly influence the diffusion of CHP-DH systems in the UK.

9.0 Discussion – Barriers and Alternative LA roles

9.1 Introduction

Chapter 8 had discussed the UK landscape for CHP-DH in terms of capacity, operation, ownership structure and the dominant forms of risks that permeate the industry. Risk factors were identified during the descriptive phase of this research and were subsequently inserted into a risk matrix during the exploratory phase of the research with a view to seeking respondents' assessment to identify those risk factors with the greatest impact on investment of CHP-DH systems in the UK. Other barriers have been identified that impacts the construction and operation of CHP-DH systems in the UK.

This sets the scene for the discussion on these barriers and possible ways to mitigate them. Many studies have discussed the various barriers that militate against the diffusion of CHP-DH systems in the UK (Kelly and Pollitt, 2009, Russell, 2010, Kelly and Pollitt, 2010) but limited work has been done on how alternative governance routes will mitigate these barriers. The literature review highlighted a number of barriers, but this chapter will focus on the dominant barriers that has been identified during from both the quantitative and qualitative processes.

Subsequently, a discussion on the various roles LAs can play in diffusing the penetration of CHP-DH systems in the UK will be undertaken. Even though several publications have attempted to highlight the roles LAs can play in contributing to energy and environmental targets (Bulkeley and Kern, 2006, Bale et al., 2012, Hawkey et al., 2013, Lemon et al., 2013, Hall et al., 2014, Julian, 2014, Hawkey et al., 2014, Webb et al., 2016b) but few have had CHP-DH systems as the technology in focus and the role LAs can play to contribute to energy and environmental targets through facilitating the diffusion of CHP-DH systems.

9.2 Dominant Barriers

9.2.1 Information Asymmetries

The absence of complete information concerning CHP-DH systems was identified during the literature review as a barrier to the diffusion of CHP-DH systems in the UK, suggesting that information is not available to all except at an extra cost. Jaffe and Stavins (1994) found that lack of information can affect the adoption of a technology, while Pindyck and Rubinfeld (2001) argue that high transaction costs arising from information asymmetries can lead to market failure. More specific to the energy field, Brown (2001) presents evidence that a lack of correct and complete information can also lead to suboptimal investment in energy efficiency technology. Similarly, in the UK information on CHP-DH systems is mainly provided by the Heat Network Delivery Unit (HNDU), ADE (formerly the CHPA), UKDEA, CIBSE and the Heat Network Partnership in Scotland (HNP). However, the information on CHP-DH in the UK is incomplete and not harmonised.

Furthermore, in response to the EU Energy Efficiency Directive, the UK introduced the Heat Network (Metering and Billing) Regulations (HNR) 2014 which mandates all DH systems to be registered by April 2015 with a view to improve information availability in the industry, but this only permits registration of systems from commencement of operation as indicated in Section 3 paragraph 2b of the HNR (UK Legislation, 2014). This means that collation of CHP-DH systems data under development will still be problematic because businesses wishing to plan new schemes will still face a transaction cost to get information. Larsson (2006) had previously highlighted the lack of CHP-DH data in the UK and it appears that this has not significantly improved. Also in a recent studies by various independent bodies on consumer protection from DH systems, a common theme in these reports is that of non-clarity and transparency of heat bills as a vital concern to heat customers (CA, 2016, Which?, 2015).

This was further reinforced by the qualitative data that there is a theme identified as lack of information on CHP-DH systems in the UK. This was captured in various aspects by the interviewees such as, lack of where to go and ask questions about CHP-DH system, not enough knowledge available outside, lack of energy usage and CHP-DH systems data, lack of communication amongst CHP-DH practitioners, lack of CHP-DH systems knowledge amongst developers and consultants. A citation is captured below from one of the interviewees.

"There's no requirement for people to register, so there's always going to be missing pieces of data on our database or anyone's database. There's no benefit for district heating schemes to register and no requirement for them to register, either with the government or with us, so any database built is always going to be incomplete" ASSO1

This informed a quantitative question for the CHP-DH operators, Consultants and LAs, 'Is there a need to have a one-stop shop for information on CHP-DH systems and sources of heat to District Heating network'. Results from the statistical analysis in Table 45, we can observe that, 39.3% of the CHP operators, 44.4% of the consultants and 48.6% of the LAs tend to agree that there should be a one stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network. However, the support is weak due to the non-significant result $p = .116$ ($.116 > 0.05$) in Table 46, therefore the data are inconclusive.

In response to lack of information in this arena, the UK government has recently established a community energy unit at DBEIS (Formerly DECC) to serve as a one-stop shop for information on community energy, including CHP-DH technology. This will host information on the various energy sources that communities can harness, with a focus on heating opportunities including the RHI (DECC, 2014). However, it is not clear if it will host a CHP-DH system register and play the role of an official clearing house for information on CHP-DH systems in the UK. Furthermore, another attribute to information asymmetries from the qualitative data is the absence of information arising from lack of data on heat load in the UK. The Department of Energy and Climate Change (DECC) in DBEIS, through the Heat Network Delivery Unit – HNDU (England and Wales), has developed heat maps which can assist investors in discerning heat distribution and suppliers across England and Wales, while Heat Network Partnership (HNP) of Scotland has developed a similar heat map for Scotland

(Bale et al., 2014) These heat maps are intended to assist investors in producing initial reports and not detailed energy data for investment decision. However, respondents from various spheres believe that these heat maps can be improved upon to provide a more detailed and updated data to facilitate investment decisions. Specifically, how the industry will be able to get heat load data which is vital information for development of CHP-DH systems from the LAs in-spite of the national heat map. From amongst the respondents within this theme (lack of energy data), below is a citation from an operator.

"The key point is, you know, the one bit of information that local authorities need to be able to plan these types of local energy systems is not available and that is building level energy consumption…….That's the one thing that nobody seems to be able to get from the energy suppliers" CDHOP14

Thus, the industry thinks that the heat maps need a deeper level of, and more updated, information to be more relevant to potential CHP-DH investors with minimal transaction cost. This is hinged on the fact that up-to-date energy consumption pattern of the load is part of the information from the heat map which usefully informs design and investment decisions for any DH project. The national heat map doesn't seem to currently provide this. This may be another instance where the intention of a mechanism is not reaching its full potential because of a weak interaction between the structural components of the CHP-DH system. In this case the role of the energy companies and the LA are blurred. So invariably the impact of a national heat map may not transcend a viewing tool to see geographical spread of heat load without a more in-depth role for both the energy companies and local authorities.

The results from the descriptive statistics in the Table 48 shows that, 33.3% of the LAs expressed that, their local authority has developed heat maps for its area. While 22.5% says that their heat map is under development, and 17.4% are considering developing one with another 10.9% not considering. Following the bar chart in Figure 22, it also shows taller bar corresponding to the same. This suggest that many LAs may soon have a heat map for their area. However, how useful these maps may be to make decisions such as investments, depends on how much energy data that can be assessed. Nonetheless, the smart meter roll out programme by the Government, would seek to capture building level energy data through the installation of estimated 53 million smart electricity and gas meters by 2020 (DECC, 2015t).

However, the access to energy data from the smart meters will still be a significant challenge as LAs are not part of the governance structure that manages the data with Smart Data Communications Company Limited (DCC), the licensee from the Government. DCC are licensed to host smart meter inventory but can access energy data from the meters if given consent by the customer to pass on the data to other requested parties, but these parties must have signed up to the Smart Energy Code, which governs their interaction before it can use the DCC route to access energy data from these meters. This limits access, as it regards privacy and may require legislation. However, discussion is ongoing on how LAs can access the data if required. Alternatively, LAs can register with Smart Data Communications Company Limited (DCC) as a user. It is also imperative to recognise that there may be issues surrounding confidentiality of energy data by dwellers and this may be where the LAs could come in to assure residents of the confidentiality of the data if permitted by the resident. This possible information hub to feed into a heat map may require stakeholder debate and eventual legislation to mandate Ofgem or the energy suppliers or DCC to keep and share such information for development of energy project. LAs may exhibit lack of skill and finance to actively partake in accessing and collating such data for energy planning/maps, but it may be useful to open the opportunity to address such challenges through interaction with other actors including the state. Nonetheless, the smart metering programme of the Government may provide a useful input to an energy database that may reduce information asymmetries for the CHP-DH industry.

There is a growing importance for local heat planning by local authorities, for example, with the London model aiming to drive investment and offer clarity of demand to district heating investors. If LAs develop local heat planning/maps it shall provide sufficient information on planned heat demand/location, sources and distribution routes. Therefore, the imperative development of local heat maps with a frequent update is a vital information tool to promote the adoption of CHP-DH systems.

9.2.2 Policy/Regulation

The pillars of the UK's energy policy framework are emission reduction, security of supply and affordability. The UK's energy policy framework is traditionally centrally evolved, coupled with EU Directives to members states to provide national goals. Therefore, the state provides the strategic direction to reach the collective national targets which makes energy policies from the LAs as more complimentary to national policy framework (Bale et al., 2012, Keirstead and Schulz, 2010). The thrust of UK regulation on electricity market has been economic through competition with the regulatory and policy framework been criticised to perpetuate lock-in by the centralised plants which often discriminates against decentralised plants like CHPs, culminating in the market not leveraging on the ability of CHPs to reduce nodal peak loads and improve security (Neuhoff and Twomey, 2008 pg: 268). Also importantly is that the regulatory and policy framework of electricity market has been largely short term in part due to government and regulatory institution's penchant for competition over social and environment causes (Woodman and Baker, 2008). These short term policies precipitates uncertainties (Wood and Dow, 2011) that stifle innovation in investment resulting in tightening capacity margin and increased margin for legacy plants like coal plants to further lock in the decentralised system (Helm, 2014b). However, heat is still awaiting a regulating framework to govern the market from the state, except for self-regulating mechanisms by industry networks and therefore it's largely unregulated by the state.

These policy and regulatory uncertainties have also resulted in many energy policy goals being missed or targets abandoned which often leads to several versions of consultations, regulations and policies (Pearson and Watson, 2012). For instance, the change of roll out dates and funding routes within the RHI scheme attracted criticism from industry actors for undermining the market. This can be seen as partially due to change of government resulting in change of renewable energy policy but at least in part due to political recalcitrance (Connor et al., 2015). The uncertainty that permeates the policy and regulation landscape often precipitates risk to investors which must be managed to give rise to potential viable projects. Alternatively, investors will find alternative routes by investing in lobbying or be patient till the regulatory tide calms down (Grubb and Newbery, 2008 pg. 297). However, the results from the statistical analysis on risk factors that would militate against investment in CHP-DH in the UK did not throw up policy uncertainty as a risk factor, because it had a p value greater than 0.615 (0.615>0.05) (see Table 26). Therefore, results from the quantitative analysis does not support policy uncertainty as a dominant risk factor in the UK.

However, when CHP-DH operators were asked what the biggest barrier to their operations was. Results from the quantitative analysis in Table 30 and Figure 19, suggest that, 28.4% of operators considers regulatory as their biggest barrier, while 23% considers market, 18.9% considers taxation, 10.8% considers skill and another 4.1% considers planning as their biggest barrier to the operations of their CHP-DH systems in the UK. This suggest that over ~47% of operators of CHP-DH systems consider regulatory/taxation as the biggest barrier to their operations. Furthermore, the qualitative data from CHP-DH operators also echo a similar concern.

"…in terms of regulatory requirements, they are quite onerous in terms of us having to comply with the various CHPQAs and EU ETS and all that sought of thing…….They do tend to fiddle around with these things quite a lot and that's quite difficult ... I mean, once you're running with a CHP district heating system, you really haven't got an awful lot of choice. You have to live with whatever changes come about, but if you're trying to set one up at the start and trying to forward look 10 years, there's definitely a difficult decision to be made, shall we say, on the basis of trying to predict what the regulatory framework's going to be" CDHOP7

An example of regulatory impact to CHP-DH operations was a recent announcement by the treasury of the removal of CCL benefits for generation of renewable electricity (HM Treasury, 2015) with a 24 days' notice (Simkins, 2015). The impact on renewable generators was so substantial that two operators of large renewable heat and electricity plants, Drax group and Infinis Energy lost 28% and 37% respectively of their share values on the day of announcement, subsequently leading the companies to take the matter to court to seek redress (Simkins, 2015). The companies asked the court why such a vital aspect of the CCL regime was being withdrawn in just 24 days' notice before the issue of LECS ended by 1 August 2015. Interestingly, they lost the case, because in the eye of the law the decision by the treasury was proportionate since it was seemly done in the interest of the public to reduce budget deficit (ELM, 2015). Nonetheless, this is a classical instance of how sudden regulatory amendment can shock financial models and sow uncertainty for future investment. To add to this, CHP had hitherto received Enhanced Capital Allowance (ECA) (writing off 100% capital tax on first year), but will no longer enjoy it if they sign up for either FiT or RHI from April, 2014 (HMRC, 2011a) distorting their future business model.

A vital antidote to uncertainty in governance is the development of a comprehensive policy framework with the capability to withstand unanticipated outcomes (Tietenberg, 1976 pg 141). Many energy white papers and frameworks have given credence to the potential for CHP-DH to contribute to decarbonisation goals in the UK energy sector but none has advanced or contained a joined-up strategy to deploy them (DECC, 2011, DDD, 2012, DECC, 2011c, HM Government, 2010, DECC, 2013a). Secondly, state energy policies do not form a holistic fit with LAs and the latter are not incentivised to strategically evolve long-term energy frameworks (Bale et al., 2012). This research therefore sought the perspective of both the LA and Consultant groups on the impact of the absence of a national integrated CHP-DH strategy. Results from statistical analysis in Table 50 suggest that there is a statistical difference between the responses from respondents on the impact of the absence of a national integrated CHP-DP strategy with p = 0.000 (0.000 < 0. 05). Consequently, from the results in Table 49, we can observe that, 43.8% of the total respondents tend to agree, while 25% of the total respondents strongly agree that the absence of a national integrated CHP-DH strategy impacts on its growth in the UK. Furthermore, drawing from the results of Table 51 the value of Cramer's V is 0.608, which suggest that the measure of association or effect size that shows the proportionality of variability of the groups within the study is greater than .5, and therefore it has large effect (i.e >.5) according to Fritz et al. (2012). Hence, there is evidence that the absence of a national integrated CHP and DH strategy could hamper the growth of the technology in the UK.

This suggest that there is a desire for a long-term and joined-up policy framework for the industry, else the CHP-DH sector is unlikely to fully neither contribute to the overall energy and environmental goals of the country nor reach its full potential. Furthermore, as noted earlier HNs in the UK are currently not regulated, rather they are driven in part by local planning policies and by individual actors' contracts. Government acknowledges that they are not driven by regulation suggesting this is at least in part because of the relatively small-scale of the sector to the present; they do however recognise that there is a system failure (DECC, 2013a). The only indirect regulation on CHP-DH systems is the HN (metering and billing) regulation of 2014. This seeks to offer some direction on metering and registration of DH networks. However, some industry actors consider it too little and inadequate, especially as it relates more to of billing than debt recovery. A CHP-DH operator opined:

"I find the regulations we've got isn't really worth the paper it's written on. It's not good enough. Yes, there is right of entry but there's only rights of entry to install meters. It doesn't state debt is included on that….Yeah, that's the biggest issue in my opinion is at the moment is rights. Obviously protection for us, also protection for the residents" CDHOP 3

However, some other respondents think otherwise. The core of their argument is that the market is still small and growing and therefore there is little need for industry-wide regulation to steer its growth but rather what is needed is more guidance, as suggested by this interviewee.

"I also think there needs to be room for the industry to innovate without regulation. At the moment, so that somebody doesn't come along with a load of regulation that prevents innovation that stifles growth….may be what we need are better guidelines ….I think ultimately we will need regulation, but not so we've got critical mass. Not till you're up to a point where you're still talking, 5 to 10% of the country demand heat" LA4

The debate above clearly indicates that the industry may be divided, though more thinks the CHP-DH industry needs regulation from the state, however experience in the Netherlands and Norway CHP-DH models shows that regulatory instruments were used to stimulate incremental innovation in the CHP-DH industry to accelerate it to its present status (Blok, 1993, Kempegowda et al., 2012). The research further sought a quantitative response from the CHP-DH actors (all groups) if the industry requires a regulation. Results from the statistical analysis in Table 52, shows that 53.2% of the total respondents tend to agree, with only 2.8% tend to disagree. While 19.8% of the total respondents strongly agree and another 2% strongly disagree that the UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems. This suggest that the industry may require a body of regulation concerning heat provision in the UK. However, the support is weak due to the non-significant result of $p = 0.514$ ($0.514 > .05$), therefore the data are inconclusive.

Therefore, there is no evidence that the industry requires a regulation for heat provision and its infrastructure in the UK. However, when respondents were asked that if a regulation were to be introduced. Which body would be the preferred regulator for heat in the UK. Results from the statistical analysis in Table 56 suggest that there is a statistical difference between the responses from respondents on which body should act as the regulator with $p = 0.002$ ($0.002 < .05$). Consequently, from the results in Table 55, we can observe that, about 55.5% of the CHP operators, 63.0% of the consultants and 49.3% of the LAs (53% of total) expressed that Ofgem will be their preferred regulator. Furthermore, drawing from the results of Table 57, the value of Cramer's V is 0.221, which suggest that measure of association or effect size that shows the proportionality of variability of the groups within the study is greater than .2 and therefore it has an effect tending towards medium (i.e > .2) according to Fritz et al. (2012). Hence there is evidence that Ofgem is the preferred regulator for heat by UK CHP-DH industry.

The results suggest a strong preponderance of stakeholders believe that the regulatory function for heat should reside with the current electricity and gas regulator, Ofgem, this may be due to the prior experience of Ofgem in regulating energy and networks such as administering RHI scheme. Secondly, it could be that the industry actors would prefer to communicate with an already known regulator that would host all regulatory requirements for gas, electricity and heat so as eliminate conflicting requirements (Jamasb et al., 2008 pg 94). Thirdly, this will also reduce start-up costs for the regulators and fourthly, residing inside Ofgem may create avenues for cross pollination of knowledge and experience. This one-stop regulatory house for gas, electricity and DH is consistent with the Netherland's Authority for Consumer and Markets (ACM).

9.2.3 Depletion of Social Housing by LAs

Market barriers are factors that are not necessarily market failures but which constitute obstacles to the penetration of innovative technologies or slow their diffusion (Brown, 2001). The literature review identified a number of factors which align with this thought path, but one for which evidence emerged in the exploratory phase of the research was the sale of social housing blocks/flat by local authorities in the UK. Government data suggests that LA owned housing stock available for renting has been depleting over an extended period indicating that the number of houses that LAs own are on the downward side as shown in Figure 34.

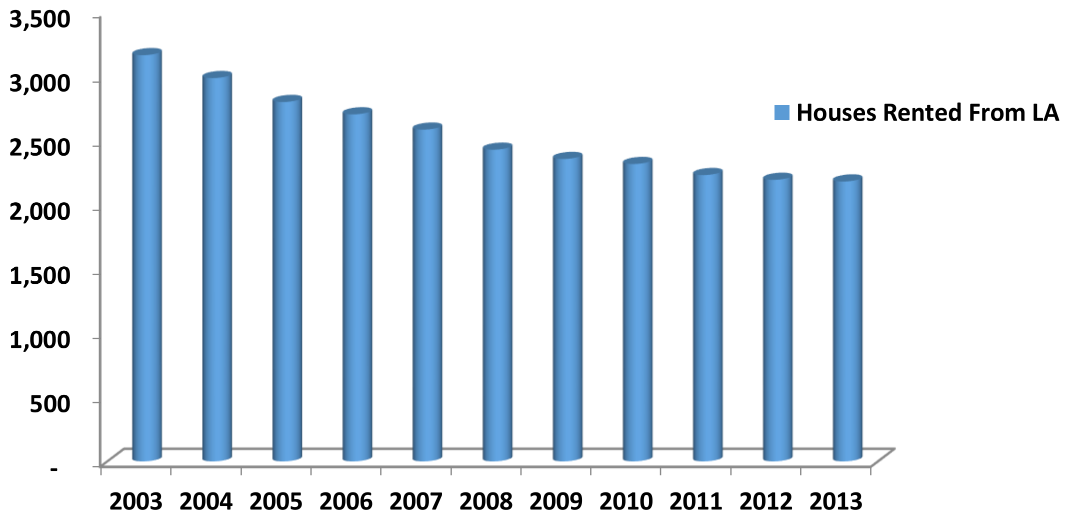

Figure 34: Houses Rented from LAs

Source: (DCLG, 2015a)

Housing stock has been a catalyst for the development of CHP-DH systems by local authorities in their locality, as these assets act as an anchor load, guaranteeing the scheme the inertia of available long-term heat load (Russell, 1993, Kelly and Pollitt, 2009, Hawkey et al., 2013). However, evidence from this research tends to suggest that these loads, large storey domestic buildings or other social housing stocks are changings hands, either through transfer to housing associations or to fully or partially devolved arms' length companies as with Torfaen council in Wales and many more in England. Some LAs are demolishing their social housing stock, as in Glasgow, while others are selling them off. When the representative of one English council was asked as to the relationship with the administration of their housing stock, it was suggested that.

"We haven't got any relationship at all between us. It's completely sold off to a private company" LA1

However, councils in Scotland now desist from sale of council houses as the response from a council in Scotland indicates:

"In Scotland they've changed the law back and you can't buy council houses anymore" LA2.

In a similar vein, the Welsh government has also introduced a legislation to stop the sale of council houses by January, 2019 (WG, 2018). However, the feeling in England appears to be different as councils are more bothered about adjusting to financial cuts by selling off houses and the 2016 housing and planning bill's silence on transfer of local housing stock may suggest this trend may continue in England.

An investigation by the Guardian newspaper on the sale of housing by councils revealed that 130,000 homes have been sold in the last decade despite the need for more social housing. It also revealed that between 2013 and 2014 councils sold off 11,261 homes but only built 10,840 (Booth and Clark, 2015).

However, the UK Government's housing and planning bill seeks to legalise the gradual enforced sale of 1.3 million housing association owned homes to private owners through an extended right-to-buy scheme in order to encourage purchase of homes rather than renting (DCLG, 2015c). This implies more homes will be sold off to private tenants, further depleting social housing stock. The Labour Party feels that the bill will cause almost 200,000 homes to be sold by 2020 (Booth, 2016).

The point of note is not if the new housing bill is bad or good, but what its impact on the growth of CHP-DH systems will be. The trend for selling social housing schemes to the private sector will eventually deny local authorities potential future anchor loads to help provide the desired long term heat off-take for CHP-DH investments and the much-desired inertia for LAs to lead the development of the systems. It will also weaken the LAs ability to reduce fuel poverty in their locality because of reduced stake in the CHP-DH development.

Therefore, considering that the sale of housing stock by LAs is mainly driven by financial consideration with a view to respond to cuts from the state. This research suggests an alternative pathway that would capture this motivation and as well as mitigate the non-availability of housing stock barrier by making these housing stock available for future district heating connection. This may entail LAs to be mandated by the state to include in their sale/lease agreement with external parties a mandatory provision of connection to district heating, whenever DH is made available or provided but not obliged to consume the heat as its obtained in Norway. which will still make LAs make revenue from the sale of the houses but still make the houses available for DH connection. Secondly, these housing stock could be designated to be within DH network zones by the LAs and as such any sale/lease agreement would capture this provision that such housing schemes will always be considered for DH connection whenever DH is made available. The applicability of these pathways would entail the modification of these housing stock to be DH ready within an agreed time line by the buyers or the LAs before the sale and the state shall allow the LAs to decide the route to follow if it's either to apply these houses stock in DH zoning areas or just leave it to the realm of conditions of house sale

9.2.4 Heat Debt Recovery

The key drivers for the growth of CHP-DH systems are primarily economic (lower energy bills), environmental (carbon reduction) and social (reducing fuel poverty). A recent Government report recognised the need to stimulate innovation in energy policies by considering the impacts of environmental, economic and social objectives on fuel poverty (DECC, 2015u). It defined fuel poverty as any dweller who would have to spend more than 10% of their annual income on energy, which includes heating to a reasonable standard (DECC, 2015k). The latest data from Ofgem suggest that fuel poverty has been on the increase from 4.4million (17%) households in the UK under the fuel poverty in 2013 being the peak after 2009 to 4.5million since 2003 data collation (Ofgem, 2016a) and the UK has adopted centralised heating systems has one of the strategies to reduce fuel poverty by 2030 compared to present levels (DECC, 2015u).

A recent study by Hills (2012) also suggested a centralised heating system might be an option to address fuel poverty. Some CHP-DH systems have been built to address fuel poverty in their locality such as Aberdeen City Council and Woking Council (EST, 2004, BRE, 2003, Hawkey et al., 2013). However, qualitative data from this research had highlighted that some CHP-DH schemes are struggling to survive financially as they focus on delivering the objective of fuel poverty, largely because some tenants struggle to pay their heating bill, leaving some DH operators running on tight financial ropes. Hence constituting a barrier to the successful operation of many CHP-DH systems in the UK. As captured by one of the interviewees below:

"There have been a lot of problems with getting the end users to pay up for their heat. It's made a loss, year on year. A substantial loss. The current conversion to biomass is an attempt to reduce that loss" LA 8.

Similarly, another housing association with a DH network had similar concerns:

"Collection, and obviously that's our biggest issue at the moment……. We have a few home owners. With the homeowners we've had to cut off one or two, but the rest of them, there's nothing we can do. We just go around and ask them to pay even though they're not" CDHOP 3

However, this barrier could not be reinforced further from the quantitative results. As CHP-OP operators were asked if they experience a slow or defaulting payment on their heat. Results from Table 68 and Figure 26 show that 75% of respondents did not respond to the question on experience on slow or default of payment on heat. Therefore, the results cannot be taken further. Hence its inconclusive. Subsequently, CHP-DH operators were also asked if they experience disputes with their heat customers. Results from Table 69 and Figure 27, shows that 22.2% of respondents expressed that not at all, while 13.6% thinks that yes but rarely, with another 3.6% saying yes but sometimes that they do experience disputes with their heat customers. However, 58% did not respond to the question. Therefore, the results cannot be taken further. Hence its inconclusive.

Nonetheless, some interviewees suggested that the application of smart metering was very useful in abating this challenge, but a further research on the impact of heat debt on CHP-DH operators may be necessary, considering the impact of heat revenue to the financial survival of the schemes.

9.2.5 CHP-DH Skill Deficiency

Lack of skill and knowledge in the CHP-DH industry was identified as another theme from the qualitative research as many schemes struggle to get the appropriate skill at various levels of development of CHP-DH systems. The acquisition of expertise by organizations in various areas of the technology is vital to diffuse incremental change in enhancing its objectives (North, 1990). Therefore, skills accumulated by organisations can affect the growth trajectory of CHP-DH systems by enhancing the regulatory capacity and institutional structures.

Inadequate knowledge and skill within the CHP-DH industry as highlighted by the research spans across the whole chain of the industry, as different actors echoed similar fears in relation to knowledge and skill within the industry. The research therefore investigated this barrier with a view to highlighting the skill gap intensity of the different areas within the value chain of the CHP-DH industry.

Firstly, CHP-DH operators and consultants were asked if there is a skill gap in the UK's CHP-DH industry. Statistical results from Table 58 shows that about 55.2% of the CHP operators and 40.7% of the consultants tend to agree (51.8% total group) that there is a skill gap in the CHP and DH industry in the UK. However, the support is weak due to the non-significant result as seen in Table 59, which shows a p value of 0.340 (0.340 > .05) therefore the data are inconclusive.

Secondly, CHP-DH operators and consultants were asked that if they agree that there is a skill gap then they should grade the deficiency of skills according to the enumerated skill sets. Statistical results from Table 62, the p value for the levene's test for all skill set are all greater than .05 (p>0.5), suggesting that we can consider that equal variances are assumed for the variables and we can proceed to observe the corresponding t-test values. The p value corresponding to the t-test in all skill set – Design and manufacture of DH pipes, Manufacture of CHP systems, Business development, construction of DH systems, installation of CHP systems and operations and maintenance are all more than 0.05 (p>0.05). Hence, we can conclude that, there is no significant difference in the skill set between CHP operators and consultants. Therefore, the data are inconclusive.

However, in a view to further distinguish the proportion of variability of the various skill set and considering the profound effect of sample size on statistical significance and the independence of effect size from sample size (Fritz et al., 2012, Gail M. Sullivan and Richard Feinn, 2012). A further consideration of the effect size (Cohen's d) was noted, as only Business development and Operations and Maintenance skill set had positive effect sizes of 0.077 and 0.32 respectively (see mean differences in Table 62). According to Cohen (1992), business development with a 0.1 effect size equivalent shows a small effect but not trivial, while operations and maintenance have 0.32 effect size, which shows a near medium effect on the variability of the mean values. Therefore, this provides an opportunity for further research to increase the sample size with a view to achieve statistical significance and arrive at a more concrete theoretical and practical conclusion even though there was strong qualitative evidence as seen below.

Nonetheless, from the qualitative data, various actors expressed skill deficiencies to capture various aspects of skill set. Such as for example an equipment supplier in the CHP-DH industry expressed his in this form…

"There are unique challenges in the fact that you have to educate and inform consultants, specifiers, contractors sometimes to deal with district heating. I will say this, I think there's a lack of knowledge about it." EQPSUP

Builders are also not left out in the knowledge and skill gap as expresses by a CHP-HP operator…

"it's not particular well known with the developers and builders. They don't really understand it. To get them to understand the mechanics of the system and understand that they have to make some design changes in order to deliver the return temperatures we require can be quite a challenge, and we very, very rarely achieve it". CDHOP2

Other actors expressed skill shortage in putting together the legal aspects of a transaction regarding CHP-DH operations such as the operators below:

"Yeah, then you get onto the tricky bit which is the legals. Believe it or not we still haven't signed the agreement… Yes. The legals just ran on and on" CDHOP10

The challenge in getting through the legal bit of the transaction in a system like CHP-DH is that it usually involves several iterative interactions with many actors and the absence of standard formats to engage both the operators and consumers even makes it more challenging. This can be collaborated by a not too recent report on the Coventry city CHP-DH scheme where complex and lengthy contractual issues posed as key difficulties to the success of the project (HCA, 2011).

Another area highlighted during the qualitative research was the lack opportunities to get training for employees through training courses and apprenticeship schemes to expose actors to best practice techniques. Below is citation from an operator who bemoaned his frustration in finding a training programme for his personnel.

"We're struggling to find some training to actually get someone trained up. Yeah, I think that's why skills had been mentioned as an extremely serious problem" CDHOP15

"we're finding it quite difficult to find an appropriate course to send someone on. It'll be like an apprenticeship for example. We want to send someone on an engineering type of apprenticeship. It's proving quite difficult to find something appropriate" CDHOP15.

Training needs for the CHP-DH industry are in two directions because CHP-DH is a coupled system of CHP and HN. The first is training in CHP systems and the second is training in heat networks. Skill development for CHP systems are delivered by the equipment suppliers as there are various manufacturers in the CHP landscape and most often they have maintenance contracts for their equipment. While the HN is slightly different because aside from the pipes (for which pipe manufacturers provide in-house training on an individual basis), developers need to understand the underlying design principles and overall system performance criteria in order to deliver an integrated efficient system.

However in response to lack of unifying standard of practice and skill shortage in the industry, CIBSE and ADE as "complementary institutions" (Williamson, 2000) and supported by DECC with some other industry players have developed an ethical code known as the Heat Networks Code of Practice (HNCP) which is internalised to trigger an institutional change that will only be drawn from the activities of industry players that have signed up. Launched in July 2015 it is hoped that the HNCP will drive the industry technical requirements and customers' expectations in delivering a cost effective and efficient district heating system. The partnership between CIBSE and ADE also resulted in agreement that CIBSE would evolve accredited training schemes to propagate the knowledge behind the code. So, in 2015, CIBSE began the first industry led training modules, which includes a course known as 'Introduction to HNCP' and a more detailed course. CIBSE has also approved Bosch (an industry player in the CHP-DH landscape) to conduct training on heat networks.

Nonetheless, in-spite of the introduction of these training courses by CIBSE would seem not to satisfy the appetite of the industry and there is still not standard apprenticeship scheme to accompany the HNCP. Even though in a service-based economy like the UK, skills acquisition through trainings most often overrides apprenticeship (Brannen, 2005). More importantly the CHP-DH industry entails demonstration of practical skills in design, construction, operation and maintenance of the system. This underpins the importance of an apprenticeship scheme for the industry as this would contribute to the CHP-DH industry's learning-by-doing index as more people develop hands-on skills within the industries which is a vital component of system innovation (Elzen et al., 2004a pg 288). Nonetheless, the current CIBSE approach is a welcome development and more time may be needed to assess it's impact on the development of skill for the CHP-DH industry, but it could be enhanced with a more frontline and collaborative role by the government, universities and industry networks in evolving an accredited apprenticeship scheme to enhance skill development for the CHP-DH industry.

Summarily, in-spite of the qualitative evidence of various categories of skill shortage and the statistical results that shows that business development and operational and maintenance skill sets have positive effect sizes, there is no statistical evidence that there is skill shortage in the CHP-DH industry. In part due to the sample size investigated. Hence, a further research is recommended to achieve statistical significance.

9.2.6 Scale of housing development

CHP-DH systems are developed on the basis of financial scalability; therefore, the scale of housing development may impact on its diffusion. A building scheme that is intended to be served by CHP-DH has to allow a rate of return on investment of at least 10% to attract private finance, drawing upon Government estimates of 10-20% commercial discount rate for HN (Hawkey and Webb, 2016 pg:122). This research heard divergent views on what the scale should be before it becomes economical to proceed. One view from respondents was that the average number of houses should be from 500 and above while another view held that it should be about 1000. However, the common theme is that it should be a minimum of 500 houses before it becomes financially scalable to develop a housing scheme with a CHP-DH system, suggesting that the density of development by builders also plays a role in diffusion of CHP-DH systems. A citation from an interviewee below captures this thought path.

"basically anything over a thousand houses might work with district heating" LAPLAN

Drawing upon data from the Local Government Association (LGA), in 2012/13 a total of 3,057 housing development schemes obtained planning permission to provide

165,903 new homes (LGA, 2013). This provides an average of 54 new houses per scheme tending to suggest the average housing development would be uneconomical for DH. This signifies that the volume of houses per scheme built by developers also constitutes a barrier to signpost developers to CHP-DH systems. This is further reinforced by the death of the zero carbon homes policy of the government, which would have driven developers to adopt CHP-DH to meet the policy requirement. In a recent report by RTPI (2013), they argue that in the last decade, the housing development density in the UK has been at it lowest since the post war era, largely due to lesser participation in house development by the LAs resulting from state budget cuts. This barrier is more severe in councils that don't already have a CHP-DH network, as the availability of the HN impacts on the economics positively.

In understanding the role of housing density, the research also sought to find out what is the development growth path of CHP-DH systems in the UK with a view to ascertain if respondents consider new builds as one of the areas that could be critical to the diffusion of CHP-DH systems.

Considering the statistical results from Table 64, the p value for the levene's test for all the growth pathways are all greater than .05 ($p>0.5$) except for sub-urban which had a p value of 0.032 ($p<0.5$). Therefore, we can proceed to consider the p values in the t-test for the assumed equal variances for the variables with p values higher than 0.05 ($p>0.05$), while we consider the p values for equal variances not assumed in the t-test for sub-urban. The p value corresponding to the t-test in new builds, urban centres, sub-urban, industrial areas and remote areas are all more than 0.05 ($p>0.05$). Hence, we can conclude that, there is no significant difference in the various growth pathways between CHP operators and consultants.

However, in a view to further distinguish the proportion of variability of the various growth pathways and considering the profound effect of sample size on statistical significance and the independence of effect size from sample size (Fritz et al., 2012, Gail M. Sullivan and Richard Feinn, 2012). A further consideration of the effect size (Cohen's d) was noted, as only new builds and industrial areas had positive effect sizes of 0.1 and 0.12 respectively. According to Cohen (1992), new builds with a 0.1 and industrial areas with a 0.12 effect sizes, both shows a small effect but not trivial, on the variability of the mean values. Therefore, this provides an opportunity for further research to increase the sample size with a view to achieve statistical significance and arrive at a more concrete theoretical and practical conclusion.

In summary, this barrier provides input for a further study which would possibly examine the impact of house market scale against CHP-DH technology on the national emission target and the environment at large.

9.3 Possible roles of UK Local Authorities in the CHP-DH arena

Cities which are jurisdictions of LAs account for approximately two-thirds of the world's primary energy consumption (Keirstead and Schulz, 2010) indicating that LAs can play significant roles in contributing to national goals of developing a low-carbon economy and meeting national energy obligations (Keirstead and Schulz, 2010, Kelly and Pollitt, 2011, Bulkeley et al., 2011, Carbon Trust, 2012b). In part, this is because of the strategic position the LAs hold in developmental projects by virtue of being the custodians of the planning powers and the right to promote the social, economic and environmental well-being of their community.

CHP-DH schemes are more driven by the public than the private sector (Goth, 2010) with LAs championing the growth of CHP-DH systems globally through participation and policies (UNEP, 2015). For instance, municipalities owned and still owns many CHP-DH schemes in both the Netherlands and Norway suggesting that municipalities were at the centre of its growth (Deloitte, 2015, Juhler, 2013).

In contrast, there are only a handful of examples of local authority led CHP-DH systems in the UK (Lerwick, Westminster, Sheffield, Nottingham, Kirklees, Peterborough, Woking, Leicester, Southampton, Birmingham, Newcastle, Fife, Coventry, London and Aberdeen councils) of the 418 councils in the UK. However, many private single CHP-DH systems in UK such as universities and hospitals are seeking to be interconnected or grow organically to city-wide scheme on the back of the LAs such as in Exeter or Edinburgh.

In investigating the level of coverage and participation of LAs in CHP-DH systems. LAs were asked if there was any CHP-DH project in the area covered by their LAs. Results from Table 23 and Figure 16 shows that 45.8% of respondents are sure that CHP-DH system is installed in their area, while 39.7% of respondents say not all and another 14.5% don't know if there is one. Indicating that less than half of the LAs have CHP-DH systems in their area. When asked if they are directly involved, only 10.1% of the respondents say they are involved, while 33.3% are currently in the process of getting involved and 25.4% are considering getting involved, with another 21.7% of the respondents not considering getting involved, as shown in Table 24 and Figure 17.

Drawing on results from Table 24 and Figure 17, less than 50% of LAs respondents have been or are currently involved in any CHP-DH scheme (43.4%). Furthermore, during this research, a government agency reiterated that the over a hundred DH schemes that HNDU had facilitated to feasibility stage, none had come to development stage as at the time of this report, which may still leave us in the band of 10% of the LAs. In part because of how viable the schemes may be or finance related issues. An interviewee from government re-echoed a similar view.

"Even though we've been in operation for eighteen months none of our projects have got us far as business case yet and so there will probably be another couple of years before we see the first network supported by HNDU come to market and get built" GOVT 1

Therefore, the next step was to investigate which roles the LAs as a part of the governance hierarchy in the UK can play either by ways of evolving governance structures or mechanisms to reduce the impacts of various barriers. This is with a view to suggest roles LAs can play as a prime mover to influence the penetration of CHP-DH TIS systems in the UK and what mechanisms could be adopted to stimulate innovation that would positively impact on the rate of diffusion of CHP-DH systems?

These roles may mean that the LAs could play significant roles in the energy market of electricity and heat with also strategic roles in coordinating the interaction of actors. These roles have been divided into five broad areas as highlighted below, which include:

- Strategy and Planning
- Local Umbrella institution
- LAs as electricity supplier
- LAs in the heat market
- LAs in financing of CHP-DH systems

9.3.1 Strategy and Planning

The strategic position of LAs as developers of anchor loads and custodians of the socio-technical fabric, which includes the behavioural pattern, businesses and infrastructural growth path of their locality, places them as imminent partners to realise national climate change targets. In a bid to extract commitment and partnership from the LAs in achieving the national targets, the state and the LAs in 2011 agreed in the Nottingham declaration that they will work together to develop strategies to monitor energy and emissions reductions at the local level. This aims to create the opportunity for a bottom-up approach for the state to actualise its national targets rather than a top-down approach. The process of a deliberate and consistent interaction usually precipitates an outcome borne out of a strategy which is clear with buy-in from stakeholders (Worrall et al., 1998).

There have been four major national strategy statement/documents with implications for CHP-DH systems. These are (1) The Climate Change – UK programme in 2000 (DETR, 2000), (2) The Future of Heating: A Strategic Framework for low carbon heat in the UK (DECC, 2012), (3) The Community Energy Strategy (DECC, 2014) and (4) Next steps to heat policy (CCC, 2016). The first (Climate Change – UK programme), set a target of 10,000MWe of CHP by 2010 while the fourth one (Next steps for heat policy) sets a target of connecting 250,000 homes to DH by 2020. However, none had a joined-up target for CHP-DH system. One of the key ways to assess the performance of a TIS is to identify the factors that will influence the direction of growth through set targets (Bergek et al., 2008b pg. 94). The absence of CHP targets in three out of the four strategy statements and the absence of DH targets in three of the four documents suggests a disconnect between these strategy documents and expectations.

Considering that there is statistical evidence as seen in Table 49 and Table 50 that the absence of a national integrated strategy for CHP-DH systems could hamper the growth of CHP-DH systems in the UK, reiterates the importance of a joined-up strategy. Furthermore, state evolved energy framework and strategy which leads to energy polices at the LA level are often optional and largely self-selecting rather than obligatory, meaning many LAs are non-participants in national energy frameworks (Bale et al., 2012). Since LAs in the UK consider energy strategies as the prerogative of the state (Keirstead and Schulz, 2010), in part because the state energy policy regime does not incentivise local energy strategy (Bale et al., 2012).

However, an increasing number of LAs are beginning to take frontline positions in the governance of energy in their locality as residents are increasingly exposed to fuel poverty (Peters et al., 2011, Kelly and Pollitt, 2011). They are also increasingly seeing the need for sustainable energy strategies to capture distributed energy technologies to lower energy bills, improve living standards, create jobs and reduce emissions. These strategies by the LAs are the instruments to encapsulate energy, environmental and social ambitions to meet national goals which also may include the adoption of CHP-DH systems. Therefore, respondents from LAs were asked if they have an energy efficiency strategy in their locality. Results from Table 65 and Figure 23 shows that 57.1% of respondents replied in the affirmative, while 18.8% say such a strategy was under development and almost 14.3% say they are considering developing one, with 4.5% saying that they are not considering such a strategy.

It is evident that many LAs have or plan to have energy efficiency strategies. However, in developing these strategies, the tension between departments, such as what this research has observed between the energy/sustainable and planning departments on what should be the priority can result in unclear coordination (Peters et al., 2011). This blurs the strategic role of LAs in delivery, except where there is a focused political leadership and genuine buy-in from employees on the outcomes (Kelly and Pollitt, 2011).

The LAs were then asked if CHP-DH is part of the energy efficiency strategy. Only 21.1% of respondents said its part of their strategy, almost twice as many saying its somewhat integrated (39.8%), and with about another quarter saying it's not part of their strategy (24.2%) with as seen in Table 66 and Figure 24.

The LA responses suggest that there is an alignment issue between the expectations of local strategies and CHP-DH systems as many LAs don't see the need to capture it as part of their strategies. This result in many LAs not taking up the strategic role to offer the desired direction and coordination that CHP-DH systems require to link its benefits with energy targets, indicating that most LAs strategies are experiencing signs of governance failure due to non-alignment of strategies. Schrank and Whitford (2011) argue that governance failure is often precipitated by the weak interaction of "environmental factors" and "human factors" and partly because of bounded rationality of actors. This could partly be that most energy managers at the LAs are bounded by their historical knowledge of energy system and if they don't know CHP-DH systems before they are employed, this may inform their stance on the exclusion of CHP-DH systems from strategies. This is also reinforced by the turnover of, and reduction in, skilled staff in the LAs since the beginning of the financial crisis. Where staffs have increased responsibilities energy/sustainable managers may now oversee two or three different council areas as evident during this research. An LA staff member hinted during an interview that they fell into the job by chance without any knowledge:

"I know lots of other local authorities who are losing skilled staff because of budgetary constraints…I would say I came to district heating without any knowledge of it whatsoever. I've kind of learned on the job" LAPLAN2 .

This supports Kelly and Pollitt (2011) position that many LAs involved in energy have focussed on delivery of energy-related services rather than strategic coordination and integrated approach, and that they therefore take little or no strategic role in energy provision.

The framework to these strategies in relation to the diffusion of CHP-DH systems is usually through the context of the planning system. Planning permission and delay in planning had been highlighted as one of the risk factors that militate against investment in CHP-DH systems in the UK (See Table 28). Therefore, there is statistical evidence that the industry is concerned about delay in getting permissions and the risk of not getting planning approval at all.

Furthermore, qualitative data had also highlighted planning as a key impediment to the penetration of CHP-DH systems largely because CHP-DH system is not part of permitted development order and more then often prevailing planning system is targeted at new builds, while there is little relevance to existing builds and as such its often a bespoke approach to each scheme. A few citations below to reflect on the planning risk theme as discussed.

"There's no kind of standards of what's expected of a district heating system. Within the planning laws, you get a lot of work called permitted development. Certain things are just allowed to happen because you had no clear benefit. District heating is not amongst those things" (CDHOPS15)

"And therefore, the current planning system which is mostly focused on new build rather than existing, means that it doesn't look at that and support it, in maybe the way that it could. So it's more of, that we probably need to rethink the way that we look at planning and how planning can support district heating" (LA2)

Therefore, planning conditions could be revised to reflect the role of CHP-DH systems as done by some LAs already from the qualitative data. Such as in Croydon, Leicester. Planning conditions are not only used to compel builders to develop CHP-DH systems but also to signpost others to connect to available DH systems. LAs can also negotiate and appeal to new and existing builders to connect to DH systems in the context of corporate social responsibility like the Southampton DH system (Gearty, 2008). Alternatively, LAs could map out CHP-DH zones or concession areas with a mandate to connect all buildings to DH networks but not obliged to use the heat from the DH networks as its obtained in Norway through the use of planning (Patronen et al., 2017, Aanensen and Fedoryshyn, 2014). The landscape in the UK is increasingly changing as many new large-scale builders are not given planning permission except they agree to the terms of development with conditions inserted into as a planning condition with LA, effectively using planning to "push" for the development of low carbon infrastructures like CHP-DH system.

Some LAs have made reservation that they can't really push new builders legally to use CHP-DH or connect to one since all they have is the planning permission to build. In some cases, developers' sign up to the agreement then declare it to be economically or technically infeasible to use the CHP-DH system. An LA lamented the limitations:

*"You can't develop a scheme on the back of just planning requirements, simply because they'd never give you the money to invest on the scheme on the back of that because they're not watertight. We recognise the fact that we've done is much as we can through planning, but there is a limit. You can't actually force people to have a scheme".*LA5

Contrastingly, another council have succeeded in taking a developer to court who reneged on the agreement to connect to a DH scheme. They have inserted clauses into the S106 agreement document to seal up the contract.

"Through the legal agreement, we say you must do district heating. Then, we go on to enforce it against developers who don't comply with that agreement. It's a contract, at the end of the day. We're happy to share the clauses with other authorities……. We've been through enforcement on it" LAPLAN 1

In addition to the planning documents, LAs have found useful the application of Section 106 of the Town and Country Planning Act of 1990. This allows LAs to generate funds for communal compensation against perceived project externalities. The S106 is considered as an ordinance and it goes pari-passu with the planning permission document, so if a developer doesn't sign the S106, the planning permission is refused. The combination of the planning and S106 documents is seen as an innovative tool for LAs to push for the penetration of CHP-DH schemes by mandating DH connection on CHP-DH zones. However, S106 has been criticised for delaying planning permission as it depends on the negotiation skills of the applicant (TCPA, 2006).

Summarily, LAs could take a strategic role to coordinate interactions of the CHP-DH actors within and outside its jurisdiction by evolving energy policies and adapt planning systems to reflect innovative ways of adopting CHP-DH systems in the UK and mandating DH connections in CHP-DH zones. Such as Birmingham's sustainable energy action plan (BCC, 2011) and Lancashire County Council's revised planning system to signpost developers to CHP-DH systems (CLASP, 2011). The output of such strategies could be energy policy strategies that incorporates CHP-DH as part of its strategy and outlines the roles of LAs in the electricity and heat market with delivery of CHP-DH systems as the outcomes.

9.3.2 LAs as Institutional Bridge

This research has thrown up issues around coordination of national with local energy goals. The CHP-DH industry is undoubtedly one with an array of actors, in part because the system can be deployed at different scales with varying motives, such as electricity generation/sales, heat generation/sales or both. Therefore, it would require an institution to play the role of coordination and bridging. An identified theme from the qualitative data was that the role of the LA is still not visible in the drive for CHP-DH system in their locality. A citation from respondent had this to say:

"You would have to have a body that has the power to bring all of these public sector bodies together. Higher education, further education, the NHS, the local authorities, housing associations in particular…there's no incentive for all of those organizations to come together. I think the local authorities do not have that place."CDHOP4.

Many have postulated different roles LAs can play in this respect so as not to distance themselves from their traditional roles of public administration as “enablers rather than providers” (Barlow and Röber, 1996), “doers rather than enablers” (Peters et al., 2011), “business-like but not like a business” (Worrall et al., 1998). LAs, bearing in mind their steering power as a hierarchy of governance, can take a command and control position to facilitate the process of corporation amongst actors locally through coordination ensuring they are all captured for the collective goal. This coordination of individual institutions which are systems on their own with their governance structures would require a complex (interconnected systems) form of coordination to connect the various systems to forestall governance failure. The coordination of complex actors within the CHP-DH arena locally can be better achieved through systematic coordination. Geels et al. (2004 pg 8) suggest that in addition to systematic coordination the system needs to have directionality to exhibit good governance.

In hierarchy of governance perspective, Worrall et al. (1998) calls it “strategic direction”. Simply put, all institutions or actors will have to participate in an interactive process that will be systematically coordinated if the desired local and national energy targets have to be met. This becomes imperative because institutions like universities and hospitals have unique energy and environmental targets and coordinating these targets to meet national/local objective may be well suited to the LAs (Kelly and Pollitt, 2011). Suggesting that LAs could play the roles of both “enablers” by providing strategic direction through systematic coordination of CHP-DH related activities in their area and also “doers” by developing DH networks to connect individual networks together.

The next two sections will discuss more in detail, LAs role as doers in the electricity and heat markets.

9.3.3 LAs in the Electricity Market

The UK Electricity Industry (EI) has been criticised as being a quasi-monopoly, dominated by a few dominant players which has precipitated resistance to innovation, institutional change and thereby reduced the emergence of new entrants (Mitchell et al., 2014, Woodman and Baker, 2008, Ofgem, 2014, Ofgem, 2008b). The EI is built on the mantra of competition driven by economic regulation. However, the UK energy regulator Ofgem acknowledges that the market still lacks competition, and that there is distrust of the dominant energy suppliers (Ofgem, 2014). The EI market has been captured by the six dominant energy suppliers (“big six”) that are seemly vertically integrated companies, with generating and retail axes and collectively creating a market lock-in. This is reinforced by the characteristics of the regulatory and incentive regimes to make them reduce risk and hold on to (or even increase) market share (Mitchell et al., 2014).

This brings to the fore the route to electricity market participation and what role the LAs can play in instigating institutional changes and participating as formidable electricity providers. This is against the backdrop of LAs being in possession of large and long-term electrical loads and with the ability to intersect social and economic objectives with energy targets through the supply of electricity. In investigating the key routes to instituting a change to the regulatory environment for greater participation by the LAs as electricity providers, two dominant regulatory issues arose; The challenge of registering as a supplier and admission into the Balancing and Settlement Code (BSC). An actor in the electricity market was asked what were the hurdles to overcome to become an electricity supplier in the UK?

“any other country we were able to set up within two, three, six months, in the UK… we made the decision to go into the UK in 2011 and we traded the first MW two years later. It was two years of preparation. So they were four people including myself full time doing nothing else than preparing for the UK market, that is the first cost. The second cost is that you have to get the IT systems up and running, now to give you a range it is a seven digit figure only the IT systems to buy it……that's why I definitely can see why, I would say it is virtually impossible for a UK grown owner of a CHP plant to trade that power themselves,” ELECTSUP

This is consistent with the literature review as to the high transaction cost as a barrier to new entrant to the UK EI, which can inhibit the participation of CHP-DH developers in the electricity market. This could precipitate resistance to institutional change where the incumbents will consider it disruptive because of path dependency and act to oppose this.

Another issue that stifles innovation in the UK’s EI is the complexities that surround the modifications to the Balancing and Settlement Code (BSC) in the electricity market with members of the code holding strong decisive powers on the operation of the market (Mitchell et al., 2014) . BSC is the governance arrangement that oversees electricity market transaction to ensure that the market operates within a threshold and it’s been administered by Elexon. The key point of interest in the activities of BSC is that the process of changes to the market codes known as modification to the code tends to draw concessions from the permanent BSC parties and essentially determining how the electricity market operates (Mitchell, 2014). This highlights the strategic position of the BSC parties in determining changes to the rules of trading of electricity in the UK and invariably making smaller generators and other generators that are not able to sign to the code on a disadvantaged position as suppose to the incumbents. A supplier’s response to being asked why they could not make the rules more open to change is shown below:

“so that means only the guys who already made that very, very difficult progress can then change it to make it easier but once have set up all this huge IT systems why in the world would I want to change them because I just already set them up before. So you are stuck in the system because you can only create a change once you get into the system but once you are in the group of people you don't want to change it anymore because you've finally obliged to all the rules. It’s called inclusion” ELECTSUP

This is tantamount to capturing a territory by network governance for the incumbents. Inferring from Voigt’s (2004 pg. 113) narrative on constitutional change, outsiders can only effect an implicit change to the interpretation of the rules without the formal altering or modification of the rule. However, when the aim of the network and their collective market share is threatened, they will exercise an explicit change that will result in rule modification through their collective bargaining power. Therefore, it can be reasoned that if LAs with CHPs desire an explicit change to the BSC and by extension other codes, rules and incentives, they must transcend the complex and accentuated institutional boundaries within the EI.

However, to be a signature to the BSC you must be a holder of a standard electricity license, which leads the research to possible routes for LAs to being party to the BSC through acquiring an electricity license. In response to the difficulty of entry into the electricity market, Ofgem introduced Licence Lite (LL) to allow potential energy actors without the capability for a standard licence, but LL has struggled to take off due to changes to the industry code as a result of delay in development of workable business models to capture the new process by the working group (Bainbridge and Abrahams, 2011). Nonetheless, LL license does not open the doors to be part of the BSC, but LAs have begun to explore the LL route as a way to afford the opportunity to increase their gains from electricity sales from their generators especially CHPs such as the GLA (2014). Though as earlier noted the LL process is still struggling to take off as we are still waiting to hear from the experience of Greater London Authority (GLA) since no other LA has started off as a LL supplier. Also of importance is the ground breaking news of September 7th 2015 that Nottingham City Council has finally made it as the first council to challenge the status quo of the EI. They are now the first council since nationalization of energy assets in 1948 with a full supply licence to supply residents electricity on a non-profit basis with an estimate potential saving to households of over £200 annually (BBC, 2015, ADE, 2015). A consortium of Scottish housing associations has applied to Ofgem for a similar licence (Bramah, 2014). Other models have been adopted by local authorities to take advantage of their anchor loads to penetrate the electricity market and provide cheaper energy prices to their residents. This includes the formation of a partnership between Plymouth City Council and Ovo Energy to supply electricity on agreed tariff levels (Bramah, 2014).

It's not clear if the LL route or partnership routes of the various councils will be sustainable on price and volume due to the presence of the standard license suppliers. This is against the backdrop of the fact that incumbents drive the price from the wholesale side and not from the supply side, because price follows cost (Helm, 2014a). Therefore, the incumbents who are asset owners of generators (both baseload and now renewables) will still be determining the wholesale cost and perhaps continue the display of institutional rigidity. Thus a possible way will be to challenge the status quo of the incumbent's market share and hold on governance structure, largely because of path dependency arising from large amounts of investment already made, by developing new business models that will trigger a change (Pollitt, 2008). It is also common knowledge that institutional change will be disruptive and therefore resisted, in part because their organisational power, wealth and status will be threatened (Kingston and Caballero, 2009). Hence, the possibility of LAs aggregating their load and resources and participating in the electricity markets with a view to challenge the incumbents, may be an alternative governance route.

9.3.4 LAs in the Heat Market

Heat off-take has been highlighted as one of the risk that is militating against investment in CHP-DH systems in the UK (see Table 26) and the LAs are known to be in possession of anchor loads (domestic and commercial loads) that can provide the necessary heat load to de-risk CHP-DH systems. Furthermore, the argument had been made in chapter 8 for an LA led ESCO to optimally provide and sustain the provision of cost effective heat for its residents and championing the delivery of a citywide network to couple domestic, commercial or industrial loads to converge both the economic and social goals of the LAs are vital to provide a faster penetration of CHP-DH systems. However, the research had taken note of the importance to protect those that provide the heat demand and provide legitimacy to the scheme. Therefore, if the scheme is not socially accepted to create legitimacy by the heat customers, the survival of CHP-DH scheme in a locality may be brought to question as echoed by a developer

"Basically, I think the CHP District heating market will fail at the first hurdle if we don't get the end user on board" CDHDEV1

However, some LAs had expressed their worries about how the heat customers will be treated as some think that these heat customers may not be having a good deal in terms of price and responding to their complaints. Echoes of some of them are seen below.

"we've got powers and the rights to do so, but every offer we've seen has been a terrible deal for the residents"LA4

"We need comfort for the investor. We need comfort for the customer…………and the serving of energy at the right price"LA2

This is consistent with a recent study that highlights that heat customers were not particularly satisfied about the customer service and complaints handling procedure of the DH companies (Which?, 2015). As part of the response to this challenge, the Association for Decentralised Energy (ADE) in conjunction with industry actors have introduced the Heat Trust (HT) scheme which is supposed to provide some protection and an independent ombudsman for heat customers. This HT scheme is a voluntary scheme for CHP-DH operators to sign up to but, however in a recent study of heat suppliers in the UK, a quarter of the respondents from the study say they will not join the scheme because they are already involved with other protection schemes such as Local Government Ombudsman or Housing Ombudsman (CA, 2016). Suggesting that CHP-DH schemes choose which ombudsman to align with and there is little say from the customers, but importantly also is that there are several reasons why voluntary schemes for energy sector had not provided the expected results for energy consumers as anticipated. For instance the voluntary code of practice for gas and electricity billing administered by Energy UK which still did not effectively provide enough information on energy bills for customers until the regulation by Ofgem during retail market review in 2014 (Which?, 2015). Similarly under the same code of practice, Ofgem's probe suggested that 50% of customers were mis-sold tariffs during the door-step sales era of electricity and gas tariffs until a binding license was issued by Ofgem to treat customers fairly and also of note is the cost of administering these schemes are passed back to customers through bills (Which?, 2015). Suggesting that the heat market may require a regulation as indicated by 53.2% of respondents (all groups) in Table 52, to provide a universal protection scheme for heat customers as voluntary schemes may not provide optimal protection for customers as anticipated.

Contrastingly, several reports suggest that energy customers including vulnerable customers in the UK have enormous trust on the LAs as their trusted intermediary for energy services, which it referred to the LAs as the "Trusted Brand" by energy customers (IPPR, 2014). Additionally also in a recent report by the LGA, 77% of respondents trust the local authority to make decisions about how services are provided (LGA, 2014b). Suggesting that the LAs have more "social capital" (Pollitt, 2002) from local residents to engage CHP-DH schemes on their behalf. Hence the LAs may play an intermediary role between the CHP-DH schemes and the residents. An LA had suggested a similar role for LAs to play in the heat market to provide legitimacy for CH-DH schemes.

"The third constraint is around the heat price to the occupants……I think our role in the schemes is often to act as a proxy regulator. There to make sure that any charges are reasonable"LA5

Therefore, a possible route for heat customers to have the desired protection in the absence of a regulation through an effective complaints procedure and feedback mechanism to the heat providers is for LAs to leverage on the trust between them and local residents by playing the role of an ombudsman. In understanding the role of the ombudsman, the research reflects on the definition of an ombudsman as captured in Gadlin (2000) below.

"The Ombudsman system provides a forum which enables citizens to have access to an independent, impartial and inexpensive dispute resolution mechanism which can resolve their grievances, protect their human rights, and restore their dignity and confidence in the democratic process. In this context, it has three essential elements in its favour — independence in operation; flexibility in dispute resolution; and credibility with the public and the organization subject to jurisdiction".

LAs role as an ombudsman can be briefly described as the "advocate" (Rowe, 1995) for the residents and umpire for complaints or disputes. This is with a view to always be seen to protect the yearnings of the residents and escalate systemic concerns of the heat customers with the CHP-DH operators and address them. However, the optimal functionality of this role shall attract acquisition of the requisite skill and knowledge to effectively discharge this function. So, the LAs may have to develop a framework and a skill acquisition programme for those interested in the job or hire an already skilled personal for such one to lead capacity building in the LAs in this knowledge space. Additionally, the effectiveness of this role will also depend on how the ESCOs recognise the LA in this capacity as the ombudsman. It's important that the role of the LAs as the ombudsman is not vague to the ESCOs. In order words the ESCO governance framework is expected to acknowledge that this function resides outside the powers of the ESCO but rather with the LAs. The details of the coordination and interface of the ESCO and the LA as an ombudsman would have been spelt out in possibly the planning permission or any other document from inception that parties have signed up to, such that there is no ambiguity as to the functions of the LA in this capacity.

Secondly, A CHP-DH operator had echoed the need for potential heat customers to be identified and campaigned to, with a view to convince them to connect to the DH network in their locality, which this research suggests LAs could rightly assume as the CHP-DH enablers.

"there is a lot of work to identify the potential customers, to identify the owners to convince them to a change from a standalone heating to district heating" CDHOP12

LAs can play the role of enablers of CHP-DH systems as they are the custodian of the socio-economic indicators that will enable them to identify fuel-poor areas (UNEP, 2015) and the command and control of land development to signpost developers to CHP-DH mapped areas and therefore influence the diffusion of the systems. Furthermore, by reason of their statutory powers, LAs can significantly influence energy production from low carbon sources and energy use in buildings (Hawkey et al., 2014), by playing the role of the local CHP-DH champions. They could be champions by campaigning and educating residents of the socio-economic benefit of CHP-DH systems and how DH heating could be beneficial to their economic status and the environment. Additionally LAs could come up with policies, such as connection polices, or incentives such as tax reduction for companies on DH network with a view to stimulate the growth of CHP-DH systems in their locality (UNEP, 2015).

LAs could also play the role of a quasi-regulator of some sort but it is crucial to highlight that the heat sector may require a national regulator albeit because of the many benefits of what national regulation brings to bear. Such as the need for a national heat customer protection scheme which may require a legislation to be able to investigate and enforce or a uniform pricing model and many more advantages. However, a possible route to create the right environment for the continued acceptance of CHP-DH by local residents in the absence of a national regulation is for LAs to institute governance mechanisms that would govern market transactions, operations and the sustainability of the CHP-DH systems. The advantage is to provide the required governance and accountability pathway of the CHP-DH ESCO to forestall the failure that occurred at Caithness Heat and Power in Scotland (Caithness, 2014), so that the "public pound" can be followed and protected (Audit Scotland, 2011). Other roles could include responsibility for liaising with utility companies and other governance structures with a view to hosting regularly updated planning and energy data. Furthermore, they could also liaise with other tiers of governance to guarantee access to right of way and permits such as environmental, street license and highway.

It is expected that the LAs could suffer challenges as a result of lack of human and financial capital to fully execute the aforementioned roles giving the incessant budget cuts but the innovation to drive through these roles may most likely come from how finance is sought for realisation of the schemes and acquire the requisite knowledge and skills to effectively play these roles. The nest section shall discuss the possible financial options that may suffice.

9.3.5 LAs in financing of CHP-DH systems

Finance has been an obvious barrier to CHP-DH penetration in the UK, as highlighted in the literature review and further vindicated by the research findings in the previous chapter. Two types of risks associated with finance emerged in the risk profile in Table 26; these are availability of finance and cost of finance. Chapter 8 had discussed financing of CHP-DH systems as a high-risk potential in the deployment of CHP-DH systems. However, this section shall seek to discuss the window to mitigate these risks using the LAs as the prime mover in the CHP-DH TIS in the UK.

As discussed in chapter 2, the methodology of finance of CHP-DH systems is usually derived from a discounted cash flow which determines the rate of return. The rate of return is a common theme for investors to access the viability of a CHP-DH scheme. The UK recommends a discount rate of 3.5% for social analysis, with estimates for heat network to be between commercial rates of 10% to 20% (Hawkey and Webb, 2016 pg:122). This is also consistent with a recent meeting of CHP-DH actors with the Government, where it was raised that the low rate of return of many HNDU schemes between 6% -10% as oppose to about 15% which is what is desired by the market could be one of the reasons why many of the HNDU projects have not commenced (King, 2016). This was also further collaborated by many respondents to this research why many CHP-DH projects cannot take off due to low rate of return.

Therefore, many of these schemes cannot access finance on commercial rates except they have access to cheaper finance. Furthermore, in mitigating the initial high capital cost, a report to DECC by Pöyry (2009), suggested two policy levers that government can use to trigger investment in this terrain. Firstly, the provision of initial capital grants to develop the supply chain and catalyse cost reduction. Secondly the provision of cheap finance, which may be more appropriate than the first on the medium and long terms, given the technological and market status of the industry. CHP-DH technology is not a niche or emerging technology but a matured one with some financial barriers to push it through in the UK. So, what may be more appropriate may be policy lever from the treasury on the use of government's funds like the pension which would have a more sustainable effect on the discount rate or liaise with the Green Investment Bank (GIB) to refocus on CHP-DH. Also Johnstone et al. (2010) had suggested that investment incentives such as financial and investment guarantee is more effective to stimulate the diffusion of high initial cost RE technologies. However, the GIB funding principle is tied to commercial terms and not low cost loans that is aimed to stimulate private investment, partly because Governments sees its role as to reduce market barriers by attracting private finance in spite of the socio-economical gains of the project (Webb, 2014). Additionally, government's announcement that it intends to sell some its share in GIB to private bidders dimmed the hope for GIB's intervention in low cost financing in spite of protest from NGOs and low carbon businesses (Hatchwell, 2015). The likely result will be higher cost of capital in investment in low carbon infrastructures. In contrast, the Netherlands introduced a National Investment Bank to militate against high interest rate and limited capital by offering finance at favourable rates without security or any risk assessment to projects like CHP (Blok, 1993, Hekkert et al., 2007a). A citation from a respondent on the limits of GIB below:

"Green Investment Bank are taking a keen interest in these projects, but the Green Investment Bank are required to ... They can't undercut a market offering. They can't offer finance at the same levels that say the PWLB can" CTNT1

Therefore, the GIB is not positioned to provide low interest finance as much as the PWLB can provide.

The discussion will now seek to analyse the role LAs as CHP-DH prime movers can play to alleviate the finance associated risk. The combination of the LAs drawing on their anchor loads and the availability of cheap finance will be key to LAs playing a role to reduce risk profile associated with finance. Pöyry (2009) had previously suggested that the volume of heat uptake has a direct correlation with the cost of the scheme. Volume uptake reflects on the effective heat tariff for the financial model since the fixed cost of the scheme will be spread over the heat load. The study demonstrated that the higher the volume from the heat uptake the lower the cost of the schemes, at least to about 80% of heat uptake before it begins to flatten out. Therefore, the possession of heat anchor loads is critical to de-risking of investment in CHP-DH systems, which places the LAs with heterogeneous types of heat loads from council houses, offices, leisure centres, heritage buildings and schools in a strategic position to seek finance for CHP-DH systems, but the cost of finance may not be right for many.

"The cost of financing…..,you need low-interest loans for district heating to make a return on investments worthwhile. One of the issues are that there's not enough access to low-interest loans" DHP1

Secondly the source of finance is critical to the discount rate as highlighted earlier but currently LAs have few sources of finance, with over 70% of loans coming from the Public Works Loan Board (PWLB) (LGA, 2014a). Other sources include the open markets, pension funds, tax increment financing and municipal bonds even if they're not allowed borrowing over the set threshold by the Prudential Code Regime which is the code that supports LA to borrow for capital investment. (HoC, 2014b). The PWLB is an opportunity for LAs to access loans at a low interest rate from a pool of £95bn, but borrowing from the PWLB has been greeted with mix feelings due to the increased cost of borrowing by the Treasury by 1% in 2010 (HoC, 2014b, LGA, 2013e, UKDMO, 2015). A respondent informed the research that PWLB lends to the LAs for as long as 50 years and the interest rate are set on daily basis. However, the introduction of the infrastructure bill in 2015 includes a provision for abolishing the PWLB and no replacement organ with similar functions has not been announced (UKDMO, 2015).

Another innovative form of borrowing by LAs that is of interest to this research is the municipal bond route. This is sequel to the un-satisfaction of the various governance structures the government had put in place to access finance presumably at a cheap rate such as PWLB and TIF. The LA stakeholders have been keen to institute a governance network that would challenge the governance structure of borrowing for investment by forming a municipal bond body of its own. The result is the inauguration of a municipal bond agency called the Local Capital Finance Company (LCFC) Limited, modelled after similar institutions in other European countries like Sweden's Kommuninvest. It is a financial body to fund, amongst others, infrastructure projects which include CHP-DH technology. It is under the auspices of the LGA with the LAs as investors (LGA, 2014a). The state had in 2010 increased the cost of borrowing by LAs from PWLB by 1%, which had propelled them to come together and share the liabilities (HoC, 2014b, LGA, 2013e). Currently, about 75% of loans by the LAs come from state run PWLB and their model estimates that the municipal bond agency could save the LAs over a £1bn over thirty years. As councils have ownership of the agency they will have the opportunity to refinance debts without penalties, guaranteed lending terms and ultimately ensure competitive pressure on PWLB (LGA, 2014a). An example of bond funded project is the £600m funding for Crossrail by GLA (HoC, 2014b).

In reaction to the emergence of LA led finance model, in 2012 the government introduced a discount of 0.8-1% for LAs borrowing through the PWLB and a further 0.6% if it's an infrastructure nominated by Local Enterprise Partnership (LEP) since November, 2013 (HoC, 2014b). The innovation for access to finance by the LAs had barely started, but it had triggered an incremental change in the governance structure of lending by the state to LAs, and therefore the introduction of LCFC by the LAs is a welcome innovation. However, the size of the portfolio that can be supported by the LCFC remains questionable and it is uncertain as to whether it can be relied upon to stimulate huge capital requirement projects like CHP-DH systems. This is of a concern because as of September, 2014, only 38 LAs had come together to raise just over £4.5m for the municipal bond agency (LGA, 2014a). The foregoing suggests that because of its current low capital base, it may well be more appropriate for other low-cost infrastructure financing other than CHP-DH systems because of the cost and volume of CHP-DH projects that may require funding for example the over a hundred projects that the HNDU had facilitated that has not been executed. Therefore, PWLB may still be the better route to fund CHP-DH systems due to its £95bn funding base but also because LAs borrow against their income stream and they still may not be able to borrow much due to complaints from many LAs on cuts of funding from the state.

The implication of both scenarios from LCFC and PWLB are that it may have an insignificant effect in the penetration of CHP-DH systems due to either low funding available to LCFC bonds or reduced income stream to borrow from PWLB. This will leave the LAs with no option than to seek private finance through ESCOs to fund these projects with the consequence of higher discount rates and energy prices. It is also worth mentioning that the intended reform on the PWLB by the government is still not out, without being too pre-emptive one would expect a reduced bureaucratic process but not the loan criteria after the reform.

However, the seemly unanimous voice on the funding of CHP-DH systems from interviewed actors is that the state has to provide the finance to stimulate the diffusion of CHP-DH systems in the UK, with some calling for DH networks to be treated like public goods.

"I think capital funding from central government kick starts schemes will probably be the key driver in the end" CDHOP15

"If you step back, see district heating as something as providing a heat network for heat for a whole settlement. In the same way that we do utilities"LA2

"What can be done to enhance? The government make money available"LA1

"They have access to finance, certainly competitive interests rates and they're generally seen as a good credit risk, I think, so they can play a role in bringing the financing to the table and reducing the amount of risk in the scheme" LA7

Therefore, the common theme from the research as can be seen from the word tree below in Figure 35 is that CHP-DH systems should be financed from either government guarantees loans to the public authority, pensions funds or loans from public works loan board (PWLB) as the best sources of funds for LAs to finance CHP-DH systems. However, the finance from PWLB is the dominant choice. A citation of one of the interviews is captured below

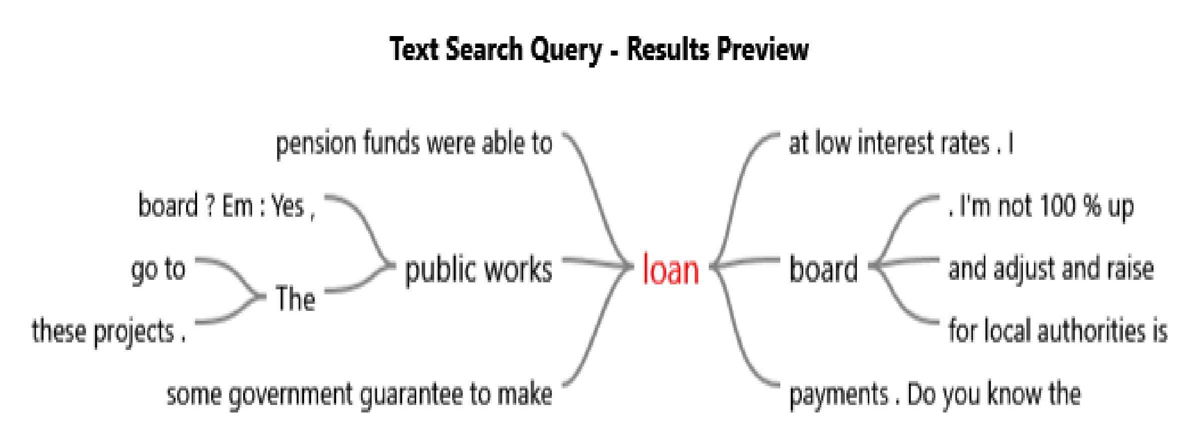

Figure 35: Best sources of funding for CHP-DH systems int eh UK

"The public works loan board for local authorities is very attractive. Because it offers a very low-interest rates and obviously that gives the local authority the opportunity to have ownership and control over the schemes……..they can't offer finance at the same levels that say the PWLB can. So that they can offer flexible financing which is interesting as a blended finance sort of, because that allows you to pay back in a interesting ways that maybe aren't available through other financing sources" CTN1

In order words, it is pertinent that the LAs desires a more innovative route of funding from the state that may offer an alternative and sustainable cheap funding for CHP-DH systems by possibly incorporating assets into the lending principle by PWLB. This is also consistent with the suggestion of Webb (2014), that in the prevailing political economic conditions, for any meaningful penetration of CHP-DH systems in the UK, the dominant form of financing such projects may have to be slightly adjusted. Suggesting that the dominant form of borrowing by the LAs for-capital projects which is from the PWLB could possibly be adjusted. Currently, LAs are not allowed by law to borrow against their asset or breach the overall limits on their borrowing by the prudential code (HoC, 2014b) which limits the volume of loan they can take from PWLB.

Therefore, it may not be out of place to suggest that a possible route for LAs to access cheap finance for the development of CHP-DH systems may be revision of funding principle for LAs to include either LAs asset or the CHP-DH asset in the evaluation criteria of loans from PWLB. A shade of this may make the central government appear to recognise the considerable environmental, societal and economic benefits CHP-DH systems can bring to the LAs and the overall energy goals of the state. The modification of borrowing principles would entail a legislative instrument but as LAs are members of the governance hierarchies that will interact with the state to re-align priorities and agree on accounting principles that will focus on both assets and income generation from the CHP-DH. The negotiated outcome would likely exhibit the potential of reducing the two risks associated to finance mentioned above, which were availability of finance and cost of finance.

The application of these suggestions may evoke other forms of risk for consideration by both the LAs and the state, such as increased national deficit, especially if anticipated revenue is unable to cover the debt (Webber, 2010), but recent ownership restructuring of the Wick DH scheme has shown that CHP-DH schemes can be sold through the secondary market to recover bad debts. This is evident in the acquisition of 100% shares of Wick DH scheme by GIB and Equitex from Ignis Energy, the previous owners (King, 2016). Others have even opined that refinancing of DH networks could be an alternative approach to springboard the development of CHP-DH after the high initial cost outlay using a model known as Pipeco (Manders and Groth, 2016). This was further collaborated by a government respondent to this research that once some of the key initial risk have been taken away. Such as heat off-take risk, development risk, planning risk, the project can access cheaper finance and therefore can be re-financed (GOVT1). Therefore, non-performing schemes can be off-loaded in the secondary market or refinanced, when the state considers the level of performance as unacceptable or considers that the DH market is ripe for exit, thereby offering an escape route for under performing loans or government investment.

However, this may feed into a further research investigation to determine the profile of the risk exposure of hierarchies of governance if asset-based lending is incorporated into the borrowing principles of LAs considering that the state can also attract political capital from financing of CHP-DH systems.

Summarily, if the government reconsiders its current lending criteria of revenue-based lending to lend more funds to the LAs against CHP-DH assets and income generated and considering the anchor loads that the LAs possess, availability of finance and cheap finance may be on the horizon for CHP-DH developers to provide secure low carbon energy with a social outlook. This would also incentivise the LAs to form public led ESCOs and cause the growth of private led ESCO to begin a southward movement.

9.4 Conclusion

This research highlights various significant barriers identified during the descriptive phase of the research and a list of seven risks factors were deduced statistically from the quantitative data in the previous chapter, but the exploratory phase of the research revealed further risks which were discussed with a view to highlight their impact and possible mitigation. For instance, a more integrated information hub and high-level energy data system may be necessary to reduce information asymmetries in the industry and enhance the usefulness of heat map to CHP-DH developers. Others are evolution of innovative ways to address heat debt collection, training schemes to involve more apprenticeships to reduce skill shortages, concern over the impact of the sale of social housing by LAs, and low housing density by new build developers are impacting on the development CHP-DH schemes.

There statistical evidence that industry actors consider a joined-up policy framework to capture and set targets for the development of CHP-DH systems will be helpful in attracting and sustaining investment. Additionally, the actors consider that the heat industry may require a regulation and there is statistical evidence that Ofgem is the favourite organ to take on that function.

Other studies focussing on LAs show that it is not just developing strategies that is the desired outcome but their abilities to innovate ways to navigate through existing systemic challenges to deliver on the expected long term outcomes (Bale et al., 2012). Some of these factors can be overcome by the LAs being innovative in taking a prominent role in providing heat and electricity as well as being an enabler for the CHP-DH technology locally. LAs are the foremost actors with potential to facilitate the growth of CHP-DH systems (UNEP, 2015) , because of the LA's statutory powers to provide social housing, health services, planning and influence energy production and use of energy by buildings, but their role in the CHP-DH arena is being hampered by both endogenous and exogenous factors. Therefore, this research proposes five broad roles that LAs can play to militate against or reduce the impact of these barrier/risk factors with a view to stimulate an incremental diffusion of CHP-DH systems in the UK. These are:

1. LAs could be more strategic by evolving policy frameworks that would encapsulate CHP-DH systems through joined-up policy visions and planning.
2. LAs could act as the bridge between institutions with CHP-DHs systems with a view to coordinate interconnections of DH networks to organically grow the network to a citywide infrastructure.
3. LAs could leverage on their collective electrical generation capacity and load to disrupt the electricity industry status quo by participating in the electricity market.
4. LAs could also leverage on their collective heat load to de-risk CHP-DH investment and the trust they enjoy from residents to play the role of an ombudsman for the local heat sector. As well being a quasi-regulator to institute governance mechanisms that would govern market transactions and provide accountability pathway for the ESCOs operations.
5. Finance supports to CHP-DH systems has been intermittent and unpredictable (Hawkey et al., 2013) suggesting that financing still seems to be a significant risk to the development of CHP-DH systems. This was collaborated by the statistical results that shows that availability of finance and cheap finance are inimical to CHP-DH investment in the UK. In spite of the various routes of finance such as the huge financial chest of the PWLB, GIB, municipal bond agency by LAs and the financial market. These reasons could have been influenced by lack of regulation of the heat sector; low discount rates of many CHP-DH projects, revenue-based borrowing principle of PWLB to LAs. This research suggests LA led CHP-DH systems which are financed on the back of

LAs to develop socially focused CHP-DH systems could contribute to national environmental and energy targets. However, none of the financial routes available to LAs has the combined strength of low or social lending rates and right volume of finance to develop socially focused CHP-DH systems like PWLB with a financial chest of about £95billion (UKDMO, 2015). Nonetheless, PWLB lending principle is revenue based, which effectively limits how much finance many LAs can borrow and LAs are also barred by law to borrow against their asset, as grants may not sustainably develop these systems, neither are other sources but debt finance route. Hence the suggestion from this research of a possible re-thinking of the borrowing principle to include either assets of the LAs or CHP-DH to the lending principle of PWLB to LAs for low carbon energy projects like CHP-DH systems.

The next chapter will discuss the impact of the various governance mechanisms on the diffusion of CHP-DH systems in the UK and possible ways of how they can further instigate an incremental change.

10.0 Discussion – Governance Mechanisms

10.1 Introduction

Several types of governance mechanisms were adopted by the government in the UK with the aim of stimulating investment in the generation of electricity and heat from low carbon sources and securing the integrity of the grid. These instruments could be regulatory, market or public/private partnership driven (Hillman et al., 2011, Nilsson et al., 2012) that has taken heterogeneous designs and scopes. Such as the old traditional forms of grants, loans and taxes or the new forms which are broadly Feed-in-Tariff (FiT), quota (tradable certificates), tendering/auction and capacity mechanisms or a combination of both forms, known as “hybrid regulation” (Hey et al., 2007).

Several authors have discussed the various mechanisms in achieving the UK’s energy goal (Connor et al., 2015, Connor et al., 2013, Helm, 2014c, Wood and Dow, 2011, Newbery and Grubb, 2014, Newbery, 2015, Woodman and Mitchell, 2011) but there is limited work on how these mechanisms impact on the penetration of CHP-DH systems. Therefore, this section shall seek to discuss the various governance mechanisms with specific interest on how it impacts on the penetration of CHP-DH systems in the UK.

10.2 Current governance mechanisms and their impact on CHP-DH systems in the UK

The consultant group were questioned as to what government mechanisms impacted CHP-DH development the most, since they are more involved with developing business case for the systems than the CHP-DH operator and LA groups. The results from Table 72 and Figure 30 shows that 18.5% of respondents consider community energy saving programme, 18.5% considered RHI and 14.8% considered Climate change levy. While another 14.8% considered enhanced capital allowance, with 11.1% of the respondents considering energy company obligation as the most effective government scheme.

The respondents in Table 72 favoured the CESP and RHI as the governance mechanism with the most impact on CHP-DH systems, but the CESP scheme was closed in December 2012 as discussed in chapter 5. It was estimated to have saved about 16.31Mt/CO_2 against a target of 19.25 MTCO2, through 293,922 measures with 48.8% of the scheme on wall insulation, while DH (connection to DH, upgrade of DH and DH meters to house dwellings) was around 8% (Ofgem, 2013h). This suggests that the scheme contributed to the improvement of energy efficiency in social houses, DH billing and the customer base of existing CHP-DH systems but little impact on the development and diffusion of CHP-DH technology. Additionally, the scheme was operational for a short time (3 years) which makes assessment of its long-term impact on CHP-DH difficult. Secondly, because it was targeted downstream with a focus on households within an area, rather than upstream with actual generation of either electricity or heat CHP-DH systems and distribution of heat. Nonetheless, heat customers on social housing from DH networks benefited from the scheme. An early survey of beneficiaries of the scheme suggested respondents were feeling warmer in their homes and about 77% of respondents felt that it had enabled them to pay less for their heating (CAG et al., 2011).

ECO was highlighted in chapter 5 as a governance mechanism that may impact on the penetration of CHP-DH systems. However, a small percentage (11.1%) of respondents consider ECO as effective in driving the penetration the CHP-DH systems. Other measures not strongly considered is the RO with a 3.7% of respondents thinking RO impacts on the penetration of CHP-DH systems in the UK. This also suggests that the respondents do not generally consider RO mechanisms as having significant impact on CHP-DH systems. The discussion of RO operations in chapter five highlighted the associated risk in its early version and the risk after the reform in 2009.

Additionally, the EU-Emission Trading Scheme (ETS) as a multi-level governance EU-led mechanism was also investigated in terms of impact on CHP-DH system penetration in the UK. CHP-DH operators were asked if the EU-ETS was a long-term incentive for CHP-DH systems. The results from Table 73 and Figure 31 shows that 29.5% of the respondents tend to agree and 3.2% strongly agree. While 18.9% tend to disagree, with another 11.6% strongly disagree. This shows that respondents were split on the effect of the EU - ETS scheme, some seeing the scheme as better than paying other carbon taxes like Carbon Price Support (CPS), which is the carbon tax for using fossil fuel for power generation as part of the CCL and it's also considered as a top up on the EU ETS, they both form the Carbon Price Floor (CPF). This is because as the interviewees claim, when you participate in the EU-ETS you pay for the allowances for gas, you are automatically exempted from paying the tax in the CRC. When a CHP operator was asked if the EU-ETS constituted a tax burden to their operations, he came across as if the ETS is a win-win on their overall tax profile.

"Emission trading scheme again it's a cost, but it is not a problem because if the university would have buildings without CHP we would be in EU ETS anyway and our EU ETS, CRC total bill will be higher because would buy more gas and electricity. The saving on EU ETS is part of the business case to reduce the overall tax of the university" CHDOP12

However, the pattern of responses from the respondents suggests that the industrial operators of CHP-DH systems may be more affected by EU ETS on the long term than commercial and domestic (such as housing associations) which thinks EU-ETS is less impactful on their operations. This is consistent with Orchards (2013) that claims the EU ETS is better suited for industrial CHP-DH schemes because of the target of overall emission levels. This is imperative as the scheme targets about 1,000 facilities with more than 20MW thermal output in the UK (DECC, 2015i) and this research suggests that the dominant scale of CHP-DH schemes are around $5MW_{th}$ (see chapter 8), indicating a minimal effect on smaller CHP-DH capacities, but more significant impact on >20MWth capacity sites which contributes about 40% of the total thermal capacity of CHP-DH systems in the UK (see Table 12). Furthermore, the price instability of carbon within the EU-ETS since its introduction may have also influenced operators varying perspective, on the impact of the scheme on CHP-DH systems in the UK especially from industrial schemes, which may likely remain the case until the carbon price stabilises. Therefore, the impact of EU ETS on the growth of CHP-DH systems in the UK may be restricted to the high energy intensive or industrial sectors.

10.2.1 Electricity Market Reform (EMR)

The EMR as a governance mechanism seeks to capture the three prong strategies of attracting investment into low carbon technologies to meet climate change targets, while securing the supply of electricity at a minimal cost to tax payers to meet the overall energy target moving forward to 2050. EMR is mixed bag of both regulatory and economic incentives.

Detailed discussions on the mode of operations of these various mechanisms was undertaken in chapter 5 but the impact of the schemes on the diffusion of CHP-DH systems is being discussed below.

10.2.1.1 Capacity Mechanism (CM)

The CM seeks to provide security of supply of electricity and ensure system stability in view of many plants shutting down. A detailed discussion on CM was undertaken in chapter 5.

Two auction periods had been conducted under the CM scheme, one in each of in 2014 and 2015. In 2014 T-4 auction, out of the total of 49.3 GW procured in the auction, CHP and auto-generators accounted for 8.6% of the capacity (NG, 2015d) . While in 2015 T-4 auction, out of the 46.35GW procured, CHP and auto-generators accounted for 4.21GW (9%) of the contracted volume (NG, 2015a). Since CHPs were eligible to participate in the CM processes, the research sought the view of actors of the mechanism with a view to investigate the impact on the diffusion of CHP-DH systems in the UK. An actor's response on the CM mechanism summarises a general notion of the scheme by CH-DH actors.

"Yeah, capacity markets I think ... it's nice for CHP because it's an extra income, but the biggest winners in the whole capacity market where the very big, very old power stations" ELECTSUP 1

The response is consistent with Newbery and Grubb's (2014) prediction that the design of the UK's CM is questionable due to its poor attention to political economy, because the design may favour coal plants which may be unprofitable without CM due to taxes from carbon price floor and have less risk as against the gas plants that are struggling with rising and volatile gas prices. Therefore, the research sought to investigate the features of the UK CM mechanism that may have locked out the participation of CHPs in the auction process.

Firstly, CHPs are commonly installed based on heat to power ratio. The quantitative data presented in chapter 8 indicates that they are often heat-led (see Table 13). This is as a result of meeting local heat load and consuming generated electricity on site while any additional electrical needs are met from the grid. Since heat consumption will be the primary concern and CM requires electrical availability, implying the need for possible heat dumping. The second possible reason is that the CM scheme does not admit CHPs with STOR contracts and many are already involved in providing ancillary services as indicated by the research data presented in Table 74. Thirdly, CHPs that benefit from any low carbon subsidy such as RHI, RO, CfD or FiT are not entitled to participate in the CM unless they can show that such funding routes have been revoked or dissociated from. This is largely to discourage developers from engaging in double incentive schemes. However CHPs with balancing service contracts can participate in the CM as an alternative revenue stream, but when both services are in demand the balancing services supersedes the CM demand (DECC, 2014k) .

Lastly, new plants (capacity and unproven DSR) will have to post collateral equivalent to a 100% termination fee of £500/MW to be held by the settlement company before qualification. This poses an additional transaction cost to small and new entrants. Compounding this is the failure for any new plant or unproven DSR to show evidence of a connection agreement offer to NG for at least 18 months before the start of the delivery year, else the site will pay a termination fee drawn from the collateral (DECC, 2014k). The interesting part about this clause is electricity projects still suffer connection bottlenecks with the severity depending on the regions. For example delays may be as much as seven years on Teesside (PX, 2010) with a respondent in Scotland to this research suggesting they have suffered a ten year delay to CHP grid connection and seeing NG electrical infrastructure as part of a jigsaw to get connected. A CHP-DH operator had this to say:

“Over the last 10 years we have tried to connect a CHP up and routinely we've been told no…..it’s effectively been a game changer for us. It's effectively stopped us.” CDHOP7

The grid regulator acknowledges that the grid requires as much as £32bn of investment to ensure grid security by 2020 (Ofgem, 2010a). The congested grid results in a restricted power flow of about 2.2GWe from Scotland to England (Hammond and Pearson, 2013), and other areas of the UK as well as indicated by an interviewee and all these contribute to a grid infrastructure barrier to CHP developers. The severity of this barrier can also be appreciated with smaller generators now have to obtain statement of works (SoW) from NG before the DNO or NG can grant the connection agreement offer. SoW is usually obtained from NG if the generation will impact on the transmission grid and usually above 50MW but a DNO informed this research that a SoW can now be requested for as low as 250kW of generation in some locations, such as Lincolnshire.

“if you've got an area which is particularly constrained sometimes national grid requests you do statements of work for smaller generators as well. In Lincolnshire they've asked for generators over two hundred and fifty kilowatts to go through statements of work because they are really constrained” DNO2

The implicit message from government to the new build here is that for you to participate in the CM auction you should have started the process to get a connection offer many years before the auction year. The experience of some respondents suggests that even with significant forward planning it may not be possible to get an agreement with any reliability in more congested network areas. This evokes concerns that there is a governance issue with NG playing the role as the delivery body of the CM yet also a participant in the process (HoC, 2015). Simply put, NG stands as the "defendant" of not letting generators connects to the grid due to congestion and low investment by determining when to grant connection agreement through statement of works. Yet NG is also the "judge" receiving a request for a connection agreement offer from new generators at least 18 months before delivery. Additionally, in the recent review of the rules of the CM mechanism, any generator that seeks to connect through the transmission grid will have to demonstrate they have secured a Transmission Exit Capacity (TEC) before qualification for the auction (DECC, 2016c). The combination of postage of collateral to the same organ that will determine if the collateral will be called for or not, and the grid infrastructure barrier to new plant, appears to indicate a system failure of the CM design. This is a system failure borne out of infrastructural failure resulting from limited investment in grid infrastructural provision and therefore may seek policy intervention (Foxon, 2007 pg 133-134). This may have also resulted in the non-procurement of any new CHP plants in favour of existing plants.

A possible solution may be since NG is responsible for grid availability, they may apply locational marginal pricing factors for new generations in different regions of the country (Cramton and Ockenfels, 2011) as was done in the Italian CM scheme to encourage CHP generators at less congested part of the grid to be part of the CM process (Eurelectric, 2015).

10.2.1.2 Contract for Difference (CfD)

CfD is one of the pillars of the government's EMR programme with emphasis on incentivising cost effective development of renewable electricity projects with a view to ensure confidence of revenue to investors through a tariff mechanism with more focus on >5MW plants (Grant Thornton and Pöyry, 2015b). A more detailed discussion was done in chapter five.

In respect to CHPs, only energy from waste (EfW) was listed in the established category, while in the less established technologies, there are four routes for CHPs such as advanced conversion technologies, anaerobic digestion, geothermal and dedicated biomass but only two EfW CHP projects, totalling 95MW of new capacity, were successful in being allocated contracts (Grant Thornton and Pöyry, 2015b). The technology winner of the day were the wind energy developers with over 90% of the capacity procured, as shown in Figure 36.

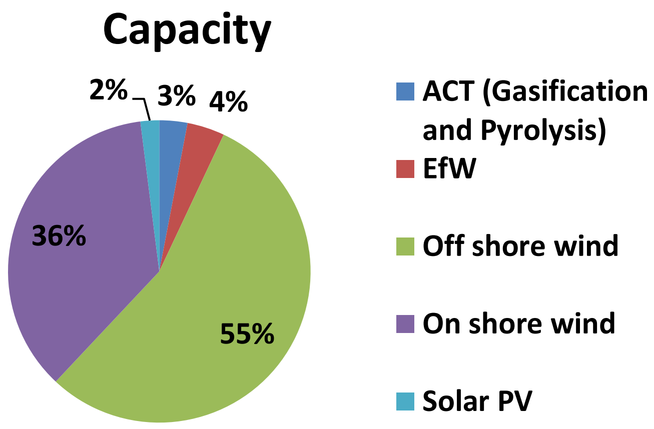

Figure 36: Capacity Distribution in the first CfD round allocation

Source: (Grant Thornton and Pöyry, 2015b)

The beneficiaries received varying years of contract with the first delivery date by 2016/17 (LCP/FRONTIER, 2015) with utilities winning the greatest share of the contracts at 41%, while large independent developers received 31% (Grant Thornton and Pöyry, 2015b). In reviewing the CfD auction process, this research sought to investigate the poor performance of CHP developers with a view to highlighting the factors that impacted on their performance and the CHP-DH systems on the whole.

In an attempt not to be drawn to the performance and profile of fuel sources for CHP-DH systems as its dimmed not part of the research but to take a more critical look at the impact of the CfD round on CHPs, the research looked at the contribution of various renewables sources to CHPs to better understand their performance. The digest of UK energy statistics suggests that RES-E increased by 19% from 2013 to 2014, mostly solar PV which increased by 104% and biomass by 45%, with plant biomass also being second largest contributor to renewable heat after industrial wood in 2014 (DECC, 2015c).

In 2014, bioenergy contributed 72.2% to renewable electricity generation with biomass contributing 58% and landfill gas accounting for 22% of the bioenergy contribution. The dominant fuels for renewable CHP in the UK are biomass and sewage gas (DECC, 2015c). Drawing upon the contribution and growth of biomass to both renewable electricity and heat generation in the UK and its poor performance at the CfD first round auction throws up a complex (interconnected) system concern. In the course of the research, CHP developers were engaged, and a renewable CHP developer in particular came across this way

"if your heat user goes bust during the plant life time, you will lose your CHP status, your CHPQA accreditation and therefore you will lose all of your support. Again, if you're doing this on a project finance basis, banks simply will not take that risk. If there is a significant cut off that suddenly your heat user goes bust which is a risk in itself because you're reliant for a lot of your revenues on heat sales. Suddenly, you lose your heat sales, you lose any incentive you might get through any renewable heat

incentive and you lose your contract for difference to the government, so you're left only with your electricity revenue" CDHDEV 3

The performance of CHPs at the CfD was as a result of a network of system failures that had culminated in many developers to shy away from the bidding arena. Key amongst them as narrated by the developer above and consistent with the finding of an independent government report to review the process (Grant Thornton and Pöyry, 2015b) was the effect of heat off-taker risk to secure investor buy-in. The report also confirms that biomass CHPs had a grace period of five years if they lose their heat customers or else they face termination of their CfD contract, losing all support from government.

The starting point of this governance failure is not with the CfD. It starts at the good quality CHP status accreditation by the CHPQA, an agent of government. All CHP must be certified with good quality status from CHPQA before it can get any government support. When CHPQA are satisfied that a CHP installation meets the quality index and power efficiency criteria, they are issued a certificate which is then submitted to DECC. DECC will then issue a Secretary of State (SoS) certificate to the CHP developer before they can now enjoy any government support. This certification becomes invalid the moment you lose your heat customer because it is deemed that you are now dumping your heat and therefore the generating plant becomes inefficient and environmentally unfriendly. The process is reviewed annually so the process of certification is a regular annual ritual for CHP operators.

Chapter 8's analysis of the risk profile experienced by the CHP-DH sector highlighted that heat off-take and cost of finance were major risk consideration and one of the reasons why cost of finance was highlighted because of the consideration of the high-risk attribute of the heat off-taker. Hence lenders would often consider long term heat contracts as the security for the loan rather than the asset (Chao et al., 2008 pg:45). These risks were echoed by a supplier

"that to an investor is of course not that easy and because they don't see two income streams they see two risks of income" ELECTSUP

Other times even with a heat purchase agreement, investors still place a premium on the heat off-take risk because they assume that companies can go bust or relocate and shareholders are not liable for payment as long as they don't consume the heat. A developer below affirms the difficulty that even with a heat purchase agreement, investors can remain sceptical in cases where the heat consumer is not an institution, and that relocation is not in the foreseeable future as with LAs, universities, hospitals or housing associations. The developer states that even with well-known manufacturer with 170 years of experience, investors were still seeing the heat as a risk in developing a biomass CHP and not revenue:

"which is an enormous brand, has billions of pounds worth of whisky in storage and is an enormous business that's been there for 170 years, it's still seen as a credit risk…The banks assume that your heat user is not going to be there…They can't take the risk that the third party is going to be there for the term of the debt" CDHDEV 3

Considering that CHP developers have to show evidence of project financial viability, some CHP developers may have struggled to cross the financial bridge without a concrete heat agreement. Thus, CHP developers may have been locked out of the CfD auction due to a cascade of barriers from impact of heat off-take risk to the necessity to stay within the regulatory ambit of CHPQA.

In addition to the issues raised above, there are a few legacy concerns which had been highlighted but still impact on CHP developers attempting to participate in the CfD auction. One is the entry route into the electricity market for independent generators such as guaranteed power purchase agreements. This is key because CfD contract beneficiaries have to earn revenue from the market, topped up via the LCCC. The implication of this is that renewable generators would have to enter into PPAs to earn guaranteed price indexed to the reference price of the CfD minus a discount from suppliers. Furthermore, suppliers have a better negotiating position and skills as they have the capacity to hire the best expertise. This discount, which is made up of the cost of trading, balancing cost, administrative cost, long-term risk and profit margin for the PPA provider, usually means a 10-20% reduction on the wholesale electricity market price to the generators (Handley, 2013). Therefore this risk is significant for the development of the market in the long term which was even acknowledged by government (DECC, 2013i).

However, to mitigate the challenge of entry to the market by CfD beneficiaries, BEIS (formerly DECC) had developed an alternative route to the market known as off-taker of last resort (OLR). Where necessary the OLR mandates suppliers to enter into short-term (one year back stop) PPAs with generators that hold a CfD contract on a fixed and pre-set discount to the market reference price until they can find a commercial PPA. However OLR will only be available for RE generators from April 2016 through applications started in October, 2015 (DECC, 2014b), so the weight of the merits and demerits of the OLR are unknown at the time of writing.

The second legacy issue is grid connection for independent generators. This barrier was discussed in section 2.3, concerning CM, but also has a bearing on the performance of CfD auctions as its part of the qualification risk. This resulted in the disqualification of three applicants in the CfD allocation round for not submitting a validly signed connection agreement (Grant Thornton and Pöyry, 2015b) though it's not clear if any of the three disqualified CfD beneficiaries intend to use CHP but nonetheless grid connection has been identified as barrier to CHPs.

10.2.1.3 Carbon price floor/CCL/CRC

The UK has an array of energy taxes on electricity, gas, LPG and other solid fuel used by businesses and the public sector with the motive of incentivising reduction of decarbonisation of energy consumption. Furthermore, 14.8% of respondents in Table 72 considers CCL as an effective government scheme to drive the penetration for CHP-DH system. The Climate Change Levy (CCL) was introduced in 2001 on fuel and electricity supplied to non-domestic energy consumers (HMRC, 2016a) excluding renewables. The CCL is typically made up of two tax routes, namely, the main rates and the Carbon Price Support (CPS) rates. The main rates mandates businesses and public sector to pay taxes on consumption of electricity and other fuel used for lighting, heat and power to their suppliers, who then pay it to the revenue and customs. The CPS rate is a tax on energy products such as oil, coal and gas used for electricity generation by the non-domestic sector. In effect the main rate is a downstream tax on energy products and the CPS an upstream energy tax. Additionally, the CPS is the also considered as the top-up tax on the EU ETS to form part of the Carbon Price Floor, which seeks to attach a floor price to carbon from both the EU ETS and CPS with a view to incentivise the non-domestic sector to monitor and reduce their emission through renewable energy sources such as biomass.

Other related governance mechanisms are the Carbon Reduction Commitment (CRC) and the Climate Change Agreement (CCA). The CRC is both a regulatory and market mechanism which targets companies and institutions with over 6000MWh annual electricity consumption and who are not part of the EU ETS and the CCA. These have to report and publish their annual energy (electricity and gas) consumption and buy allowances from the Government or secondary market for every tonne of carbon emitted or face a penalty (Carbon Trust, 2016) with heat having a zero allowance (CCC/DECC/DEFRA, 2015b). While the CCA is a voluntary agreement between networks or actors in the energy intensive sector like paper or chemical sectors and the Government to monitor and reduce their carbon emission to an agreed target and which is being administered by the Environment Agency. CCAs are captured through two major sets of agreement, namely the umbrella agreement between networks or association and the Government, while the second is the underlying agreement between Government and the actors. The significance of the CCA is that organisations that sign up to the CCA attract a 90% discount on their CCL main rates on electricity and a 65% discount on CCL main rates on other fuels (EA, 2014).

However, the complexities and reporting burden of these interrelated mechanisms on the non-domestic energy actors have spurred the Government to announce the abolishment of the CRC scheme after the 2018-2019 compliance year and integrate it with the main rates of the CCL (HMRC, 2016a). This is with a view to smoothing the energy consumption reporting landscape and to incentivise energy efficiency and renewable energy sources. The implication of the abolishment of the CRC scheme is that the band of organisations under the CRC scheme will focus on the paying the main rates of the CCL only but with the CCL main rates now increasing with inflation.

Nonetheless, the CRC scheme has been seen by CHP operators as another example of policy change as a result of political change. This scheme was intended to be revenue neutral when it was announced in 2007, with operators getting their money back if emissions were reduced to agreed limits at the end of the compliance year (DTI, 2007 pg 54. para 2.23). However, on the arrival of the Coalition government in 2010, the return side of the policy was abolished, and it literally became a carbon tax. This constituted a distortion in their financial flow with a knock-on effect on payback time.

Additionally in 2010 through its consultative proposal, the treasury initiated a reform of the CCL regime to remove the previously enjoyed levy exemption certificate (LECs) on electricity exported from CHPs with effectiveness from the 1st of April, 2013, but still retained the LECs for site-only electricity consumption (HMRC, 2010). Therefore, since April 2013 if the CHP is certified by the CHPQA, it will attract an exemption from CPS on fuel used for heat generation and from April 2015 CHPs are also exempted from fuel used for electricity generation that was consumed not exported (DECC, 2015c). Indicating that from April 2015 CHPQA certified CHPs are now exempted from both main rates of CCL and CPS on fuel used for electricity generated that is consumed but not exported including CPS on fuel used for heat generated. The findings from this research suggest that the industry's impression about CPS is mixed on the impact on CHP. Some think it makes gas fired CHPs more expensive to develop since some of electricity generated will have to be exported to gain revenue from the electricity market, while others think its impact is negligible considering the low and unstable price of carbon and for any serious impact on CHP economics the price of carbon will have to be many folds more as suggested by a CHP-DH developer below.

"*I think the carbon price floor the CPS, that is a tax, so it makes CHP more expensive, so it's not good. If you have a gas CHP, it's obviously making business more difficult" CDHOP 12*

"I think carbon price floor ... this is where it becomes quite interesting because I've looked into this a little bit. Actually, for CHP not to be economic, I'm purely speaking from a financial perspective, I've done some exercises looking at it. In reality carbon would have to increase by about ten-fold, the cost of carbon… The quick sums that I did, I reckoned it had to be over 100 before it would have any impact" CDHDEV 5

However the Government has reviewed the CPS policy by pegging the CPS to £18 from 2016 to 2020 due to uncertainty of carbon price at the EU ETS partly due to the excessive supply of permits at the continental level (HMRC, 2014), but as highlighted in chapter 5 the increased and continuous levy on the UK industries through the CPS without a corresponding levy on their counterparts in Europe may precipitate the risk of carbon leakage (the relocation of production to less taxed areas). The negative effect of the CPS will continue to impact on the finances of CHP operators who participate in the EU ETS. For instance the British companies under the EU ETS pay an additional £18t/CO_2 compared to their European counterparts, which has led to some politicians calling for the scrapping of the CPS scheme (Carbonnel, 2016). Therefore, until the EU evolves a policy lever to have stable price for carbon through the management of the supply of emission allowance, the CPS cost to business will continue to destabilise the policy framework in the long term. Secondly, the UK CPF policy may be integrated into an EU-wide policy so as to create a level playing field for the CHP operators in the UK else it may begin to show signs of unpopularity.

Nonetheless, CHPQA certified CHP-DH systems in the UK appears not to be significantly worried with the various reviews of CPS and CRC schemes but more concerned with the exclusion of CHP from export of electricity from CCL main rates. This suggests that the overall objective of the schemes which is to incentivise investors in low carbon technology by exploring gains from both electricity and heat production may not reach its full potential through these governance instruments.

10.2.1.4 Emissions Performance Standard (EPS)

EPS is a regulatory mechanism under the EMR framework which seeks to limit emission from new fossil fuel plants but is elaborated further in Section 5.1.3.4.

However, CHPs (including gas fired) plants that have been certified by CHPQA as good quality are usually EPS compliant so are not affected by this policy. Therefore, the EPS shall not receive further consideration in this analysis because of its insignificance to the CHP-DH sector.

10.2.2 Renewable Heat Incentive (RHI)

The RHI is a tariff-based governance mechanism introduced in law in 2008 and intended to support the diffusion of renewable heat sources in the UK. Its adoption was partitioned into two phases, the first phase covering non-domestic use of RES-H in 2011 and the second, a domestic phase, introduced in 2014 (Connor et al, 2015).

The concern of this research lies with the non-domestic RHI, in part because the focus is on CHP-DH technology which entails heating more than one building which the domestic RHI does not support while the non-domestic RHI supports both CHPs and district heating.

There are four renewable heat sources that are relevant to CHP which are eligible for non-domestic RHI. These are biogas, solid biomass, waste and geothermal. There is also a separate tariff level for solid biomass CHP. Despite solid biomass CHP being eligible to RHI, there are caveats for CHPs to be eligible for RHIs, for example, solid biomass CHPs must show evidence of CHPQA certification. Effectively saying any solid biomass CHP that loses or is unable to renew their CHPQA certificates will only receive the solid biomass tariff for that period, which is smaller than the solid biomass CHP tariff (Ofgem, 2015b). This is because of the combustion component involved in solid biomass CHPs in the process of heat generation. Secondly, biogas CHP below 200kwth that has converted from electricity to heat must have been installed on or after July 2009 (on or after December 2013 if it's over 200kW_{th}). In accessing the payments for RHI under the non-domestic regime, CHPs installed before July 2009 have been exempted from the mandatory class 2 meters, if they have a pre-installed class 3 meter (Ofgem, 2015b)

In addition to CHPQA certification, solid biomass CHPs with capacities of 45kW_{th} or below are required to obtain a Microgeneration Certification Scheme (MCS) accreditation. However, there are technologies that are 45kW_{th} and below that don't require MCS certification such as biogas, geothermal and solid biomass in waste heat sources. What this essentially means is that under the non-domestic RHI scheme there was no obligation for compliance regarding design standards and sizing of equipment that was required for capacities over 45kW. Connor et al. (2013) had argued that lack of standard may undermine public confidence and the value for money of tax payer's money spent on such schemes. Therefore, absence of a standard for over 45kW may erode legitimacy of the scheme. However, in 2014, three years after the non-domestic scheme had started; CIBSE unveiled a guidance manual on applying for biomass systems known as AM15 Biomass heating. It sought to inject some form of standardisation on biomass heating systems by outlining design, installation and commissioning standards. This application manual only covers biomass systems between 50kW and 5MW (CIBSE, 2014) leaving an overall standardization of the schemes still in doubt, especially for schemes between 45 - 50kW. Also, of note is the insufficient monitoring and feedback mechanism embedded in the scheme. A CHP developer had this to say on the lack of standardization of the scheme.

"The kind of thing that we could have probably in a few years ago, be like the biomass technically guide of CIBSE that came out a few months ago, it would have been handy if we would have had that before the RHI started so that a lot of the biomass projects that went in would have been designed more efficient" CTNT3

Ofgem, as administrators of the scheme, released a guidance document on non-domestic RHI but didn't make mention of CIBSE AM15 standardization document but rather only referred to CIBSE's heat loss calculation document for heat metering purposes (Ofgem, 2015b). Indicating that the adoption of the CIBSE AM15 standardisation manual is not obligatory to applicants by Ofgem. However, applicants who are members of CIBSE which is a governance network of heating professionals are bound to adhere to the instructions from the CIBSE AM15 document. The concern remains that the efficiency of larger systems outside the regulatory reach of MCS may not be guaranteed to actually reduce the emissions as expected or justify the value for money as there will be no uniform standard of installation. Another implication could be the heating landscape becomes proliferated with different installation standards which may constitute a barrier to learning lessons from large-scale systems.

To investigate the role and impact of RHI on the diffusion of CHP-DH systems in the UK amongst the respondents of the research, CHP operators and consultants were asked whether the RHI scheme should stimulate the required growth of CHP-DH in the UK. The results from Table 76 shows that about 42.5% of the CHP operators and 37.0% of the consultants tend to agree that the renewable heat incentive (RHI) should stimulate the required growth of CHP – DH in the UK. However, the support is weak due to the non-significant result as the p value was 0.182 (0.182>0.05), therefore the data are inconclusive. Hence there is no statistical evidence that the respondents think that RHI should stimulate the diffusion of CHP-DH in the UK.

Summarily, since there was no significant in the statistical results, a further research with a view to achieve significance may necessary to reinforce the qualitative data which some consider RHI as an instrument that should stimulate CHP-DH penetration but it's not.

10.3 Conclusion

The UK has deployed several governance mechanisms for RE systems, including tendering/auction, tariff, quota mechanisms and tax instruments, which might have had the potential to facilitate the penetration of CHP-DH systems if applied to them. A number of these mechanisms have been home or domestic focused to improve energy efficiency of homes such as CESP, ECO, and GD with little impact on the development of CHP-DH systems.

Secondly the taxation regime to drive the penetration of low carbon generation of electricity such as EU-ETS, CPS, CCL, CRC and ECA have not driven penetration due to the prolonged uncertainty of the price of carbon, removal of tax rebate on electricity exported from CHP-DH systems on CCL and the removal of ECA rebate for

CHPs if they are enjoying other mechanisms like RHI. Other mechanisms that seek to incentivise the generation of electricity include the RO, CM, and CfD. The RO was reformed but still presents risk; the CfD sought to reduce unit energy costs by addressing these with a view to guaranteeing investor revenue and market access through OLR. However, in respect to development of CHP-DH systems, problems with grid access was still prevalent in both CfD and CM schemes which was further encapsulated in qualification risk and reinforced by the non-convergence of cost and revenue risk of CHP-DH systems which may have systematically locked out the penetration of CHP-DH system in the UK. The literature suggests a possible alternative for the adoption of locational pricing in the procurement of fixed payment capacities to achieve a middle ground response to the connection risk as employed in the CM scheme of Italy (Eurelectric, 2015).

As other mechanisms were focused on electricity generation, RHI is focused on RES-H, but there was no significance on the results to reinforce the claim that RHI should stimulate the penetration of CH-DH or not.

11.0 Conclusion Chapter

11.1 Introduction

The outline of this conclusion chapter starts with a definitive introduction that captures the broad status of CHP-DH systems in UK and the research objectives underpinning this research. This is followed with a synthesis of the empirical findings presented in the statistical results in chapter 7 and the discussion in chapters 8, 9 & 10. The next section seeks to discuss the theoretical and policy implications of the findings in the context of adopted concepts, which may offer insights to alternative governance pathways to address the findings. Thereafter, the strength, weakness and contribution to TIS was discussed. This chapter also highlighted the original contribution of this research to knowledge, how recommendations would be quantified and accessed and the recommendations for further research.

Despite the benefits and the technological maturity of CHP-DH, it is still commercially immature in the UK as evident from its low penetration (about 6% of UK electrical production, while ~2% of total heat consumption is supplied via DH networks). This may be largely due to an array of failures that extend beyond the traditional market failure, such as high entry cost. However, Government's usual focus of reducing market barriers by providing seed money to crowd in private investment may not be optimal. Since in a market economy like the UK, the market failure approach does not capture externalities. Such as free riders or knowledge generation which are not reflected in market transactions that is driven by competitive prices. Furthermore the persistent focus of regulatory paradigms driven by techno-economic factors but with little recognition of socio-economic factors (Webb, 2014) does not internalise the externalities associated with the growth of CHP-DH systems and this choice of regulatory route may also have resulted in resistance to new entrants, lock-in by incumbent actors and selection environment of heating technology.

The investigation of the failures that may have contributed to the low penetration of CHP-DH systems in the UK is broadly captured in three research objectives. Firstly, to investigate the dominant operational and marketing landscapes and governance structures that permeate the UK CHP-DH industry. This includes consideration of the underlying characteristics such as economic and management models, with a view to improving the impacts of these models on technology diffusion and also providing illumination on the dominant risks that militates against the development of the system from the CHP-DH actor's perspective. Secondly, building on the barriers thrown up by this research and the dominant risk profile, the research seeks to pose alternative governance pathways to reduce or eliminate these barriers. Alternative roles of local authorities (LAs) as governance hierarchies and TIS prime movers are also explored to address these barriers given the potential roles they can play to promote social, economic and environmental wellbeing of their community and being CHP-DH champions globally (UNEP, 2015)**.** Thirdly, the research explores the impact of current governance instruments in the UK electricity and heat sectors on the diffusion of CHP-

DH systems, with a view to propose pathways to influence the penetration of CHP-DH system.

In achieving these objectives, this research has adopted a TIS functional analytical approach system to diagnose and explain how the socio-technical system work and performs in relation to the structure rather than how the system is composed (Markard and Truffer, 2008b). This is as suppose to a system failure framework which only captures the structural element of the system (actors, networks and institutions) and not paying enough attention to the system dynamics that determine the performance of the system (Bergek et al., 2008b, Bergek et al., 2010, Hekkert et al., 2007b).

Since infrastructures are socio-technical systems with complexities arising from the interaction of technical, economic, political and social actors to ensure their diffusion and utilization. The modes of governance of the interactions of these actors are vital for the technology to meet set targets and goals (Carlsson et al., 2002, Hillman et al., 2011). Therefore, governance mechanisms were adopted in mapping of a TIS functional pattern to advance alternative governance routes.

This research does not suggest any form or type of governance mechanism that is the silver bullet to influence the greater penetration of CHP-DH systems in the UK because of the complex array of actors in the CHP-DH industry but suggest a targeted combination of governance mechanisms or “hybrid regulation” (Hey et al., 2007) that may influence and coordinate the nested nature of decision-making. Nonetheless, key to note is the role of the hierarchies of governance (state and LA) in enabling or blocking the diffusion of the technology. Primarily, with the state evolving a joined-up policy portfolio to stimulate investment in CHP-DH systems and the LAs taking up “doers and enablers” roles as prime movers in the penetration of the technology.

11.2 Empirical Findings

The empirical findings of this research were discussed in chapters 8, 9 and 10. These chapters sought to investigate the research objectives using results from both the quantitative (statistical) and qualitative (thematic and citation) data analysis. Below is the synopsis of these findings.

Chapter eight sought to offer an insight into the prevailing technological, economical and management landscape of the UK CHP-DH industry. Technologically, the industry is dominated by small sized CHP-DH systems that are predominantly heat-led silo systems with little interconnectivity with other systems. While the electricity from CHPs is mainly consumed locally through private wire arrangements with little patronage of the electricity grid. Economically, the industry is commonly driven by techno-economic and commercial objectives suggesting that socio-economically motivated systems are not prevalent, with the dominant management approach favouring more emphasis on vertically integrated ESCOs that are predominantly privately led as supposed to public led. Suggesting that ESCOs are more structured as shared savings with the ESCOs bearing both technical and credit risk due to the inability of LAs to bear the credit risk of the development of CHP-DH systems. Results also suggest that 35.3% of LAs think they disagree and another 14% strongly disagree (see Table 32) that they possess the capacity to engage ESCOs for their services. Suggesting that LAs lack the capacity to engage with ESCOs.

Furthermore, the results suggest minimal participation of LAs in the CHP-DH industry, which may be inimical to its diffusion considering that LAs are custodians of large anchor loads and can locate and coordinate other potential customers. Results in this chapter also shows that there is statistical evidence that the CHP-DH industry in the UK is at an infancy but growing stage with $p = 0.000$ ($0.000 < 0.05$) (see Table 16). Also, the descriptive results show that 63% of respondents thinks the industry is at infancy but growing (see Table 15). Suggesting that UK CHP-DH industry is in a nursing market phase of development due to its limited penetration.

Chapter eight also investigated the prevalent risk factors that militate against investment in CHP-DH system in the UK and the results show that there is statistical evidence of seven risk factors which militates against the development of CHP-DH systems in the UK with p value less than 0.05. They are heat off-take, availability of finance, cost of finance, delay in planning permission, planning permission risk, land acquisition and compensation and LAs experience in PPP (see Table 26). Furthermore, when CHP operators were asked the dominant challenge to their operations, 28.44% of respondents consider regulatory, while 23% considers the market and another 18.9% thinks its taxation (see Table 30). Similarly, consultants were asked the dominant challenge before construction. Results show that 44% of respondents also consider heat load as the most, with 24% considering lack of capital (see Table 29).

Chapter nine discussed the significant barriers identified during the research that are militating against the growth of the industry and possible pathways from actors on ways to ameliorate these risks. Key areas of discussion as highlighted by respondents included:

- The impact of information asymmetries in the industry as a barrier where all actors don't access information equally due to high transaction cost in getting information for CHP-DH development resulting from lack of registered database on CHP-DH systems and accessible energy data. Results show that many LAs have developed and are developing heat maps for their area, but how the content can be populated with updated building level energy data to enhance planning and development as the current national heat map is insufficient and yet to be clear. Also, importantly the privacy rights of dwellers will be key to the success including the coordination of the roles of both the regulators and energy suppliers as critical factors.

- There was qualitative and statistical evidence that the absence of nationally integrated CHP-DH strategy is hampering the growth of the industry and therefore a joined-up national framework for CHP-DH systems be put in place to curtail incessant policy changes and provide certainty to investors with respondents suggesting more roles for the LAs. Furthermore, there was also statistical evidence that Ofgem is the preferred body to host any regulation for heat infrastructure.

- The sale of social housing by LAs is a concern to the industry as these anchor loads impact on the ability of LAs to lead the development of CHP-DH projects. While Scotland and Wales seem to have back pedalled on this, LAs in England are more concerned with adjusting to financial cuts by selling off these social housing schemes than keeping them. Suggesting that the state may be driving the selloff due to cuts to LAs. Thus, this research suggests the state to mandate the LAs to insert in sale/lease agreement of such housing stock that it should be connected to DH networks when it's made available or such housing areas should be designated as DH zones, whenever DH is made available. This would provide the avenue for the LAs to still make money from the sales but still ensure that such housing stock will still be considered for DH in future energy plans.

- This research also investigated skill deficiency in UK CHP-DH industry by firstly, determining if there is a skill gap in the UK's CHP-DH industry. Quantitative results show that about 55.2% of the CHP operators and 40.7% of the consultants tend to agree (51.8% total group) that there is a skill gap in the CHP and DH industry in the UK (see Table 58). However, the support is weak due to the non-significant result as seen in Table 59, which shows a p value of 0.340 (0.340 > .05) therefore the data are inconclusive. Furthermore, CHP-DH operators and consultants were asked that if they agree that there is a skill gap then they should grade the deficiency of skills according to the enumerated skill sets. Statistical results show that the p value corresponding to the t-test in all skill set – Design and manufacture of DH pipes, Manufacture of CHP systems, Business development, construction of DH systems, installation of CHP systems and operations and maintenance are all more than 0.05 ($p>0.05$). Hence, we can conclude that, there is no significant difference in the skill set between CHP operators and consultants. Therefore, the data are inconclusive. However, in a view to further distinguish the proportion of variability of the various skill set and considering the profound effect of sample size on statistical significance and the independence of effect size from sample size (Fritz et al., 2012, Gail M. Sullivan and Richard Feinn, 2012). A further consideration of the effect size (Cohen's d) was noted, as only Business development and Operations and Maintenance skill set had positive effect sizes of 0.077 and 0.32 respectively (see mean differences in Table 62). According to Cohen (1992), business development with a 0.1 effect size equivalent shows a small effect but not trivial, while operations and maintenance have 0.32 effect size, which shows a near medium effect on the variability of the mean values. Therefore, this provides an opportunity for further research to increase the sample size with a view to achieve statistical significance and arrive at a more concrete theoretical and practical conclusion even though there was strong qualitative evidence.

- Finally, the qualitative data suggest that scale of housing could also influence the influence the selection environment of CHP-DH systems as it becomes appropriate to use CHP-DH between 500 – 1000 housing units/site. However, the current new build scale of about 54 houses per site is too low to attract CHP-DH systems. In understanding the role of housing density. This research also sought to find out what is the development growth path of CHP-DH systems in the UK with a view to ascertain if respondents consider new builds as one of the areas that could be critical to the diffusion of CHP-DH systems. Statistical results from Table 64 show that the p value corresponding to the t-test in new builds, urban centres, sub-urban, industrial areas and remote areas are all more than 0.05 ($p>0.05$). Hence, we can conclude that, there is no significant difference in the various growth pathways between CHP operators and consultants. However, in a view to further distinguish the proportion of variability of the various growth pathways and considering the profound effect of sample size on statistical significance and the independence of effect size from sample size (Fritz et al., 2012, Gail M. Sullivan and Richard Feinn, 2012). A further consideration of the effect size (Cohen's d) was noted, as only new builds and industrial areas had positive effect sizes of 0.1 and 0.12 respectively. According to Cohen (1992), new builds with a 0.1 and industrial areas with a 0.12 effect sizes, both shows a small effect but not trivial, on the variability of the mean values. Therefore, this provides an opportunity for further research to increase the sample size with a view to achieve statistical significance and arrive at a more concrete conclusion.

Chapter 9 also captured the roles LAs can play as prime movers in the CHP-DH TIS in mitigating the identified risks and barriers. Considering that LAs as part of the hierarchies of governance, they are the foremost actors with the potential to facilitate the growth of CHP-DH systems (UNEP, 2015). This is in part because of their statutory powers to provide social housing, health services, planning and influence energy production and use of energy by buildings. Five major roles were outlined which were drawn from results of this research, these include:

- Strategic role of LAs to evolve local policy frameworks that would encapsulate CHP-DH systems through joined-up policy visions and planning.
- LAs playing the role as the institutional bridge between institutions with CHP-DHs systems with a view to coordinate interconnections of DH networks to organically grow the network to a citywide infrastructure. This is in view of respondents suggesting LAs as the link between various heat off-takers.
- LAs could leverage their collective electrical generation capacity and load by obtaining a full electricity standard license so as to disrupt the electricity industry status quo by participating in electricity market governance.
- LAs can leverage on anchor loads to de-risk CHP-DH investment to ameliorate the heat off-take risk. LAs can also leverage on the trust they enjoy from residents to play the role of an ombudsman for the local heat sector and a quasi-regulator to institute governance mechanisms that would govern market transactions and provide accountability for the ESCOs operations. However, there may arise skill challenges that may reflect financial constraints.

- There was statistical evidence that availability of finance and cost of finance are risk factors that militate against the penetration of CHP-DH systems in the UK. Furthermore, there was also strong qualitative data to support this as many interviewees suggest that the finance must be provided by the state to capture these two risk factors. Therefore, data from the qualitative research suggests a government guarantee to loans, loans from pensions fund or loans from PWLB, as more innovative and sustainable route to financing CHP-DH systems, that captures LAs as prime mover. However, the dominant choice was getting loans from PWLB to deliver LA led systems as the alternative pathway. However, PWLB lends to LAs based-on revenue, so many LAs are locked out due to low earnings and severe cuts on statutory grants from the state over time. Hence, the alternative governance for LAs to have access to sustained high volume of low cost finance. Therefore, the lending criteria of the PWLB to the LAs may be reconsidered by the state to reflect the CHP-DH asset or revenue. This would effectively consider the potential for LA led CHP-DH systems to contribute to national environmental and energy targets.

Chapter 10 discussed the prevailing governance mechanisms that permeate the CHP-DH landscape in the UK. Quantitative results from respondents favoured Community Energy Savings Programme (CESP) which is an obligatory scheme and Renewable Heat Incentive (RHI – a form of FiT) schemes as the governance mechanisms that influenced the diffusion of CHP-DH systems in the UK the most. However, the CESP scheme was before the commencement of this research, which leaves the RHI for further investigation and only the non-domestic RHI supports biomass CHPs but not DH, which suggest that RHI supports decentralised heat system rather than centralised heating system like DH network.

To investigate the role and impact of RHI on the diffusion of CHP-DH systems in the UK. CHP operators and consultants were asked whether the RHI scheme should stimulate the required growth of CHP-DH in the UK. Quantitative results from Table 76 shows that 41.2% of respondents tend to agree and another 15.8% strongly agree that the renewable heat incentive (RHI) should stimulate the required growth of CHP – DH in the UK. However, the support is weak due to the non-significant result as the p value was 0.182 (0.182>0.05) (see Table 77), therefore the data are inconclusive. Hence there is no statistical evidence that the respondents think that RHI should stimulate the diffusion of CHP-DH in the UK.

Chapter 10 also investigated the impact of the EU-ETS on CHP-DH diffusion but results from this research shows that respondents were almost evenly split as to the extent of the influence on the diffusion of CHP-DH in the UK. This is largely depending on the scale of the CHP-DH system, if it's larger than 20MW or less. Domestic and commercial CHP-DH operators do not see the EU-ETS as impacting on their operations as they are often below 20MW thermal output. A further investigation of the impact of government's electricity market reform schemes on the CHP-DH industry was also examined. These mechanisms are seen to have minimal impact on CHP-DH system, largely because they were not targeted by the EMR mechanisms, and thus they have weak interaction with CHP-DH systems. According to respondents of this research, infrastructural failure resulting from CHPs being unable to access connection offers due to grid bottlenecks, may also contribute to why CHP investors may consider the qualification risk as a significant hurdle. These may all have combined to result in CHP-DH system being systematically locked out from EMR governance mechanisms (CM and CfD).

11.3 Applying Technological Innovation Systems Framework to CHP-DH

11.3.1 Functional Analytical Pattern – CHPDH development phase

Results from quantitative analysis shows that there is statistical evidence that the CHP-DH industry in UK is in an infancy but growing stage. Therefore, this section shall seek to diagnose and explain the development stages in the diffusion of CH-DH systems in the UK using the TIS functional pattern with the aim of analysing the performance of the CH-DH innovation system which would give special attention to the governance measures that influenced the functioning of the innovation system. Such as regulations, tax exemptions and so on. Also, in the focus shall be the actors and institutional structures that permeates the CHP-DH innovation system considering their various roles in influencing the rate of diffusion of CH-DH system in the UK.

In diagnosing and explaining the development of CHP-DH innovation system using the functional approach, there are two distinct phases that defines the technological transformation of the system. They are the formative and growth/market expansion phases (Jacobsson and Bergek, 2004). The description of the formative phase was undertaken in chapter 3.7.2. While this section shall describe the growth phase. The growth phase is determined by when the market is formed and up to when its self-sustaining. This phase is also known as the market formation phase, which is further divided into three categories, namely: (a) nursing market – when market begins to evolve and with limited size, (b) bridging market – enlargement of actors and increased market size, (c) mass market – when market is fully evolved and self-sustaining. Therefore, drawing from the quantitative results that shows that the CHP-DH industry is in infancy, but growing stage suggests that the growth/market formation phase of the UK CHP-DH industry is a nursing market.

The seven amalgamated categories of functions of a TIS as discussed by various authors (Hekkert et al., 2007b, Hekkert and Negro, 2009, Bergek et al., 2008b, Bergek et al., 2008a) are F1 – Entrepreneurial Activities, F2 – Knowledge Development and Diffusion, F3 – Influence on the Direction of Search, F4 – Market Formation, F5 – Resource Mobilization, F6 – Creation of Legitimacy, F7 – Development of Positive Externalities.

The description of each function of the structure is discussed below, highlighting the significant contributors to its performance as well as capturing the complex interaction of the element within the structure. Suggesting that one contributor may have the potential to impact on several functions.

Influence of the direction of search

These are factors that can stimulate network and institutional interaction with a view to signposting new firms to enter the CHP-DH arena. These include regulatory mechanisms, Government targets and policies, incentives, visions, actors assessment and elimination of technical bottlenecks (Bergek et al., 2008b). Scarcity or non-alignment of these factors may be detrimental to the performance of CHP-DH systems. The UK has evolved several sorts of mechanisms that may stimulate the penetration of CHP-DH systems through electricity and heat policies, such as tax rebates & exemptions, price and quantity determinant schemes. The first UK national assessment of the CHP-DH potential was in 1977 by the Marshall report, which gave rise to the Atkins report that led to the Lead city scheme, which provided a grant of £750,000 from DOE to three LAs (Belfast, Edinburgh, Leicester) in 1985 (Babus'Haq and Probert, 1996). Subsequently, there has been several stop-and-go grants schemes to facilitate the penetration of CHP-DH systems and the recent being the £320m under the HNIP.

There have also been four major national strategy statement/documents with implications for CHP-DH systems. These are (1) The Climate Change – UK programme in 2000 (DETR, 2000), (2) The Future of Heating: A Strategic Framework for low carbon heat in the UK (DECC, 2012), (3) The Community Energy Strategy (DECC, 2014) and (4) Next steps to heat policy (CCC, 2016). The first (Climate Change – UK programme), set a target of 10,000MWe of CHP by 2010 while the fourth one (Next steps for heat policy) sets a target of connecting 250,000 homes to DH by 2020. However, none had a joined-up target for CHP-DH system. One of the key ways to assess the performance of a TIS is to identify the factors that will influence the direction of growth through set targets (Bergek et al., 2008b pg. 94). The absence of CHP targets in three out of the four strategy statements and the absence of DH targets in three of the four documents suggests a disconnect between these strategy documents and expectations. Furthermore, the results from the quantitative analysis also reinforces that there is evidence that the absence of a joined-up strategy may have militated against the penetration of CHP-DH systems in the UK.

Also importantly, since the first target of 10GW of electricity generation from CHP by 2010 (DETR, 2000), the UK has not set any further target from CHPs or heat generation from DH. An exception is the recent adoption of a Scotland specific target of 1.5TWh of heat demand through DH by 2020 by the Scottish Government (GIB, 2015).These policy expectations not only influence direction of growth of CHP-DH but also impact on other functions of TIS in the CHP-DH arena such as actor behaviour.

Furthermore, there is no regulation for heat supply in the UK and there is statistical evidence from this research that the CHP-DH actors would refer Ofgem to be the regulator. The results of this research also note the difficulty of CHP connection to the grid, with a respondent suggesting up to 10 years delay in obtaining connection approval, which was collaborated by a distribution network operator, that conditions meant for 100MW CHPs are now being implemented for small CHP plants as small as 250KW in some areas in the UK due to grid bottlenecks.

Since elimination of technical bottlenecks is one of the factors that can influence direction of search, CHP grid connection barriers further reinforces a system failure, since CHPs cannot effectively connect to the electricity grid due to grid infrastructural failures (Foxon, 2007 pg:131-133).

Entrepreneurial Experimentation

Entrepreneurial experimentation within the functional pattern of system innovation framework attempts to capture the entrance of new actors in the CHP-DH arena as they seek to take a position in the market or the entrance of incumbents that change their business strategies with a view to capturing business opportunities that the CHP-DH may offer. LAs have been central to the development of CHP-DH systems in the UK. However, this research has shown that many CHP-DH schemes are private led due to their dept of resources (human and capital) and ability to carry on both technical and credit risk. Such as Veolia, Thameswey, Cofely, Vital Energi and so on. Furthermore, the recent trend in the entrance of energy utilities known as super-ESCOs into the CHP-DH industry to explore the business opportunities that CHP-DH industry offers may potentially alter the landscape of CHP-DH market. One example is the entrance of E-ON with the delivery of a CHP-DH scheme at Cranbrook in Devon in 2009 (Hawkey and Webb, 2016 pg:131). The concern around the entrance of incumbent large-scale vertically integrated energy companies is that it will further perpetuate their lock-in of the energy sector. Some 72% of UK total electricity generation in 2014 was from the six biggest electricity generators - EDF, Uniper (formerly E-On), RWE npower, British Gas (owned by Centrica), Drax, SSE, and Scottish Power- (Ofgem, 2016b).

The expansion in gas infrastructure alongside rising demand for gas and other governance activities such as the privatization of the gas industry in 1986, which triggered the “dash for gas” in 1990s that resulted in about 20GW capacity of gas plants at an average growth of 2.1GW/year between 1991 and 2001 (McGlade et al., 2016). These growths of gas capacity has also contributed to the significant displacement of coal by natural gas as the major primary energy source in the UK. This positions the gas actors to take opportunity of the North Sea gas and demand for gas to further exhibit stability and lock-in attributes of the gas grid as an infrastructure, contributing to gas being the dominant fuel for CHP-DH systems.

According to the results reported in section 8.2.1, the UK CHP-DH industry has also recently seen the entrance of several new DH pipe suppliers. Hitherto there had been four major suppliers servicing the UK market, with the UK seeing its first local DH pipe manufacturer in 2012. However, lack of information on CHP-DH systems in the UK, lack of a joined-up strategy for CHP-DH system and the frequency at which policies are changed over short periods may have deterred more new entrants to the CHP-DH arena. Additionally, this research has shown evidence that seven risk factors, namely: heat off-take, availability of finance, cost of finance, delay in planning, planning permission, land acquisition and compensation, and lack of LAs experience in PPP militates against investment in CHP-DH systems in the UK.

Knowledge Development and Diffusion

This function is determined by the learning activities which are considered to be at the heart of the innovation process. The common forms of learning processes, as highlighted in chapter 3, are “learning-by-doing” which arises from market growth that leads to reduction in the cost of production (Smith, 2000) , learning-by-using” which is as a result of increased use of CHP-DH systems by demand actors to influence increase in development and diffusion (McWilliams and Zilbermanfr, 1996), “learning-by-research” which is typically as a result of knowledge resulting from research and development and while “learning-by-interaction” is the knowledge acquired through interaction of demand and supply actors to influence the diffusion of CHP-DH systems (Edquist, 2005 pg:16). However due to the limited time of this research and the maturity of CHP-DH technology learning-by-research has been under-emphasised in this research work. The opportunity for learning-by-using activities are likely to be weak due to increased sale of LA housing stock, especially in England, which limits the economic viability and opportunity to lead the development and learning from CHP-DH projects. Other factors that may have affected CHP-DH systems from being accepted and deployed that will see the increase in learning activities are for instance, the common perception that DH is not considered an integral part of the energy system in UK but rather an appendage (Russell, 1993, Hawkey, 2014) and widespread gas network may also have affected the low selection rate of CHP-DH systems for heating. Nonetheless, the Heat Networks Code of Practice (HNCP), jointly developed by ADE and CIBSE, and which seeks to regulate the development of CHP-DH system may trigger some form of regulation of best practice amongst signed-up members in the interim, though yet to be seen, but a sustainable pathway may be national regulatory code of practice and not voluntary for the CHP-DH industry.

This research also suggests that the weak learning-by-interaction activities, due to lack of interaction of demand and supply actors may have been influenced by the absence of a national/local ombudsman and institutional infrastructures for heat. However, the learning-by-interaction activities has been strengthened by the Heat Customer Protection Scheme (HCPS) by ADE resulting in the Heat Trust, which has provided the channel for registered heat suppliers to further interact with their customers by providing a channel of feedback on complains and grievances. This is further strengthened by learning networks, which facilitates learning through interaction of CHP-DH actors such as ADE (formerly CHPA), CIBSE, Heat and the City, and UKDEA.

The process of learning-by-doing which influences the cost reduction of development activities within CHP-DH systems is also weak due to high transaction cost resulting from information asymmetries such as lack of harmonised information concerning CHP-DH systems, lack of skills and unavailability of building level heat maps. However, DBEIS and its Scottish equivalent, Business, Industry and Energy of Scottish Government (BIE) through governance structures like HNDU and HNP respectively are acting to improve learning-by-doing activities through several measures. These include assisting in the development of knowledge and diffusion of CHP-DH systems by supporting feasibility studies, development of heat maps and through skill acquisition in many LAs. HNDU has supported over a hundred LAs in developing CHP-DH systems, energy maps and council staff skills across England and Wales (DECC, 2016b). However, results from this research suggests that many LAs remain concerned about whether they have sufficiently skilled personnel to manage these schemes to delivery, with many suggesting they are not sufficiently equipped to deliver them without external help. Suggesting that the low learning activities is also because of the current low penetration of CHP-DH systems in the UK with other contributing factors. Such as, low scale of new builds, lack of standards of energy contracts or ESCO, lack of recognised apprenticeship schemes and lack of institutional infrastructures for heat.

In response to skill acquisition, many LAs with universities within their jurisdiction have developed working teams to enable knowledge transfer from universities to the LAs while other LAs are seeking help from external consultants. Additionally, there has been several steps by governance hierarchies to increase learning activities by improving penetration of CHP-DH systems. Such as the Scottish Government which sought to provide a total of £8million from 2014-2016 to registered social landlords, LAs, small and medium sized enterprises and energy services companies (ESCOs) with fewer than 250 employees to develop DH systems (Ricardo-E&E, 2015) through the District Heating Loan Fund. Another £320m has been provided by DBEIS to develop DH systems under the HNIP funding. These governance hierarchies have also stimulated the markets with several other mechanisms with a view to increasing the diffusion of CHP-DH systems including tax rebates such as Enhanced Capital Allowance or exemptions like CHP-DH exemption from CPS. However various scholars have regarded these mechanisms as ineffective due to their unpredictable and intermittent approach, and therefore cannot sustain the desired growth of CHP-DH systems in the UK (Hawkey, 2016 pg:101, Winskel, 2016 pg:70, Tingey et al., 2016 pg:174).

Therefore, the stop-and-go policy approach by governance hierarchies, may have contributed to the low learning processes for the CHP-DH industry in the UK and thus may require alternative pathways to increase knowledge diffusion through seeking ways to improve learning curves by reducing barriers that may impact on the sustainable penetration of the systems. Such as the introduction of a national system of joined-up regulation for CHP-DH systems by the state that will be overseen by a national regulator for heat. Furthermore, for the LAs to take up more strategic and leadership roles in the development of CHP-DH systems locally, by being enablers and doers in the CHP-DH industry through participation in the electricity and heat sectors. Such as leading the development of DH networks through LA-Led ESCOs and being a local ombudsman for heat.

Market formation

CHP contributed about 5.9% to UK electricity generation in 2015 (DBEIS, 2016a) with DH providing about 2% of heat demand (DECC, 2013a). Suggesting the limited contribution of CHP-DH to UK's energy market and this collaborates with the findings of this research that the CHP-DH industry is at infancy meaning it's a nursing market. Markets are created by policies and regulatory mechanisms and the stability of these mechanisms in the long-term determines how investors react to the market (Foxon et al., 2005). This research suggests that there are seven risk factors that militate against the investment in CH-DH systems in chapter 8. Namely: heat off-take, availability of finance, cost of finance, delay in planning, planning permission risk, LAs experience in PPP, and land acquisition and compensation. Furthermore, the CHP-DH industry is at an infancy stage according to the findings of this research. This is consistent with various Government data that suggests the relatively small contribution of CHP-DH to UK's electricity and heat sectors. Since the first national assessment potential of CHP-DH systems by the Marshall report which advocated Government support for the diffusion of CHP-DH systems in the UK (Marshall, 1977). There has been several supports schemes such as the DOE £750,000 grant under the Lead City Scheme for Belfast, Edinburgh and Leicester (Babus'Haq and Probert, 1996). However these mechanisms have been considered unpredictable and intermittent and therefore likened to a "stop and go" policy (Praetorius et al., 2008 pg:157) with little impact to migrate the CHP-DH industry from a nursing market to a bridging market to enable it compete with the incumbents (Andersson and Jacobsson, 2000). Furthermore, the increased sale of LA housing stock, especially in England, reduces the de-risking capacity of LAs to economically justify the deployment of schemes and the low scale of housing development per site of new builds have also been highlighted in this research as contributing to blocking the formation of market for CHP-DH systems. Also the lack of information on CHP-DH systems in the UK may contribute to the low adoption of the technology (Jaffe and Stavins, 1994). Also, importantly is the matured gas grid network which has dominated the provision of heat in the UK.

However, despite the slower than expected growth, the increased awareness and acceptability of CHP-DH technology, arising from amongst other reasons. The interaction of increased energy demand, bills and the environment have precipitated gains in the supply chain. For instance, in 2012 the first UK based DH pipe manufacturing plant was built in 2012. While some other DH pipe manufacturers still think the volume of UK CHP-DH industry is not yet big enough to attract the development of a manufacturing plan to the UK.

However, the respondents to this research agree that there is a growth in the industry, with a Denmark-based DH pipe supplier to the UK market claiming an annual growth of ~20% from 2013 - 2014 and the DH pipe supplier market broadening from the previously dominant four companies (LOGSTOR, Isoplus, Power-Pipe, and Brugg) to around ten in 2015. Respondents also reported gains in the CHP supplier market such as increased in sale of CHPs to the UK market.

Additionally, this research suggests that there is growing optimism in the CHP-DH industry that the successful take-off of over 200 HNDU supported projects (DECC, 2016b) and the recent £320m HNIP funding announcement (DECC, 2016a) could lead to further growth. Furthermore the potential increase of the CHP-DH market by the delivery of over 100 potential heat network projects to be supported by the Scottish Government's Heat Network Partnership (HNP) (GIB, 2015) offers the opportunity for potentially significant market growth in the CHP-DH industry leading to bridge the CHP-DH market in the UK.

It is important to note that the delivery of many potential LA CHP-DH projects that are currently on the shelf and in feasibility stages would require the removal of several barriers that are militating against the penetration of CHP-DH systems in the UK. Such as finance, grid connection for CHPs, joined-up policy/regulation and many more as highlighted in chapter eight would be critical to the market growth of the industry.

Legitimation

In innovation system, legitimisation is the process of overcoming the "liability of newness" (Bergek et al., 2008b) for the technology to be socially acceptable as incumbents seek to de-legitimise the technology by unit performance, growth potential or cost (Negro et al., 2012). The seemly poor historical performance of CHP-DH systems in the UK resulting from the failure of a few earlier CHP-DH systems. Such as the failure of the Gorton scheme in Manchester in 1919 due to pipe corrosion and the failure of Duddeston scheme in Birmingham in the fifties due to poor costing of the pipelines (Diamant and McGarry, 1968 pg 171-172). These and in addition with unsure position of government on the technical and economic viability of the technology (Russell, 1993) may all have contributed to weak selection environment and acceptability of CHP-DH systems in the UK.

Therefore, the growth of CHP-DH systems in the UK would require for it to overcome its baggage of social acceptance and this process has been driven by several actors advocating the benefits of deploying CHP-DH systems. These advocacy groups/actors engage the Government, parliament, media, the energy industry, consumers, LAs and other actors with a view to creating social acceptance of the technology. Actors such as ADE, CIBSE, Heat and the City (A joint university collaboration energy research programme between universities of Edinburgh and Strathclyde), universities, UKDEA and many more are playing different roles in advocating for the deployment of CHP-DH systems in the UK. These lobby groups, which also draw from the research community and non-governmental organisations, have continued to exert pressure on the hierarchies of governance, to promote the benefit of CHP-DH systems on the environment and energy targets. They advocate for appropriate accommodation of CHP-DH systems in energy policies and for Government and regulators to evolve favourable governance mechanisms to eliminate barriers militating against the CHP-DH industry through various stakeholders' workshops and meetings.

This increased national awareness and acceptance of CHP-DH systems has led many LAs to evolve energy policies and adapt planning systems to reflect innovative ways of adopting CHP-DH systems in the UK. Such as Birmingham's sustainable energy action plan (BCC, 2011) and Lancashire County Council's revised planning system to signpost developers to CHP-DH systems (CLASP, 2011). Furthermore, the increased acceptance and legitimisation of CHP-DH systems has also attracted media coverage to advocate for the benefits of the technology (Johnson, 2014) and provide input to the energy sustainability debate in the UK.

However, several other factors may also have negatively impacted on the legitimisation of CHP-DH systems in the UK. These include the increased sale of LA housing stock (especially in England), the centralised energy policy, the lack of governance structures for heat suppliers and customers to build consumer confidence and strengthen social acceptance may all have impacted in reduced legitimacy for CHP-DH systems. Despite the seemingly increasing buy-in by national and local Government. The results of this research suggest the need for a national integrated strategy. The state has remained slow in presenting a joined-up policy and regulations for CHP-DH systems to influence its acceptance. In part because the Government considers district heating as still not widespread and therefore considers that regulatory mechanisms will impede its growth (DECC, 2013a). Furthermore, other factors against the legitimisation of CHP-DH systems could be attributed to the strong and organised incumbent advocates of centralised energy system which influence policy making and often oppose moves to strengthen support to a more distributed energy system (Bergek et al., 2008b). Nevertheless, several CHP-DH actors under the auspices of ADE and CIBSE have come together to evolve self-regulating mechanisms such as the Heat Customer Protection Scheme (HCPS) and Heat Networks Code of Practice (HNCP) with a view to instilling increased confidence and enhanced legitimacy, at least in the interim while the industry awaits a national regulatory system.

Resource Mobilisation

The results from this research suggest that availability of finance and cost of finance are some of the risk factors that are militating against investment in CHP-DH systems in the UK. Since after the lead city scheme of £750,000 in 1983 that offered grants to LAs for the development of CH-DH schemes. There have been several other grants and loan schemes with irregular timelines to facilitate the penetration of CHP-DH systems in the UK. Such as the Community Energy Programme (CEP) established in 2001 was a £50m scheme by government that offered grants to develop CHP-DH projects. Such as in Aberdeen and Birmingham but closed in 2007 (Webb, 2016a pg:139). £26m Low Carbon Infrastructure Fund (LCIF) established in 2009 as a one-off grant to LAs to develop CHP-DH schemes (Hawkey, 2016b pg:94).

Furthermore, Private Finance Initiative Scheme was another government scheme that was introduced in 1992 to encourage the private sector to invest in infrastructural projects in partnership with the public sector, which includes CHP-DH systems. Such as the 1.4MW combined cooling/heating and power (CCHP) project with 250W absorption chillers at St. Bartholomew's Hospital (GIB, 2014a). The UK Green Investment Bank (GIB) was also launched in November, 2012 to provide finance with a view to stimulate the development of green infrastructure and creation of the expertise to impact on the economy with a £3.8Billion take off fund that has focus on a number of green technologies which includes CHP-DH systems (GIB, 2014a). A case in hand of a GIB sponsored scheme was the Edinburgh and Glasgow city council CHP-DH project and Cambridge University Hospitals CHP based energy centre project, where GIB is committing £18m (GIB, 2013). However, it does not provide capital on public borrowing term but rather on commercial terms with the aim to crowd in private sector capital. Renewable Energy Investment Fund (REIF) is also a similar scheme like the GIB by the Scottish government through Scottish Investment Bank with renewable generation of electricity and heat including DH networks as priority (Hawkey, 2016b pg:95).

Recently also CHP-DH schemes have been drawing upon various funding routes to facilitate its penetration in the UK. Such as the UK Government £11m grants since 2013, under the HNDU to support DH networks across 118 LAs (DECC, 2016b). The HNDU has also provided guidance support through the feasibility exercise by attaching a “critical friend” during the process with a view to enhancing human capital (DECC, 2015b). Others are the Scottish Government’s £20m funding under the Local Energy Challenge Fund (LECF) since 2014 -2016 to support the feasibility and development of low carbon technology including CHP-DH systems like the DH scheme at Highland Council. Others are the Scottish District Heating Loan Fund that provides currently about £8m loan supports to DH schemes in Scotland, such as the Aberdeen Heat and Power (DECC, 2015p). Similarly is the Rural Community Energy Fund (RCEF) since 2012 of about £15m that is jointly funded by DBEIS and Department for Environment, Food and Rural Affairs (DEFRA) for rural communities to access loan for the feasibility to develop low carbon technologies such as CHP-DH systems in England (WRAP, 2016). The European Union is one source of funding of CHP-DH systems in the UK through provision of grants and part funding such as the Islington CHP-DH system in London. It could get sponsorship from European Social Funds and European Regional Development Fund (ERDF) as 20% of ERDF are targeted towards low carbon infrastructures (DECC, 2014).

In addition, another £320m under the Heat Network Investment Project (HNIP) is expected to be spent to aid the delivery of the supported HNDU projects from 2016 to 2021 with a view to attract additional £2b capital investment (DECC, 2016a). While the Green Investment Bank (GIB) is projected to make available another £3.6b to DH networks in the UK by 2016 (GIB, 2013) but it’s not clear if this finance was made available. This all suggest to the litany of finance routes outside the commercial market that is expected to be explored to support the CHP-DH industry.

The GIB has estimated that the UK district heating market may offer an investment opportunity of over £500m by 2020 (GIB, 2015), suggesting that the CHP-DH industry may require huge financial mobilisation and this is most likely to be sourced from outside the loans and grants routes from both the UK Government and Scottish devolved Government. However, this research has suggested that availability of finance and cost of finance are significant barriers to the penetration of CHP-DH systems in the UK. This suggests that the industry may require a more reliable and sustained source of finance outside the Government’s intermittent loans and grants routes such as the open market. However, the contrasting tension of the evaluation criteria’s and strategies of many CHP-DH schemes between if the scheme is driven by socio-economic (fuel poverty) or techno-economic (capital accumulation) objectives determines the financial routes to pursue (Webb, 2014). Put simply the implication is that most LA led schemes tend to be on the back of socio-economic models are stifled out of the open market finance routes due to the low rate of returns of their schemes. This illustrates the reason why many HNDU schemes that have the potential to provide the bridging market for the CHP-DH industry according to this research are not in the construction phase. This indicates a system failure, as many LAs are not able to transit their CHP-DH schemes from feasibility stage to delivery stage due to low rate of return of their projects.

This tension of low rate of returns of many HNDU projects is what the HNIP funding of £320m tends to address but this route may still be an unsustainable route considering the volume of projects to be considered and future schemes. However, this research has pointed to PWLB that has a financial chest of over £90b as a more sustainable source of cheap funding. Drawing on the fact that the almost 70% of LA borrowing comes from PWLB (LGA, 2014a), but the LAs are constrained by the prudential code, which determines the volume to be borrowed depending on revenue. This research suggests a possible consideration of a change of borrowing principles to the LAs to capture CHP-DH projects as they provide public goods like heat and electricity, so that they can have a sustained access to cheap finance, that would capture their socio-economic objectives.

Development of positive externalities

The emergence of a DH pipe manufacturer in the UK in 2012 and many more CHP-DH developers outside the hitherto four big ESCOs, suggests successful entry of new actors and increase of the supply chain in the CHP-DH arena, which may impact on the penetration of CHP-DH systems in the UK.

CHP-DH actors may have increased in political power as the Government has supported several industry-led mechanisms such as the HNCP and Heat Customer Protection scheme being introduced by both the ADE and CIBSE bodies with a view to providing ad-hoc regulation for the industry. These bodies, as well as other bodies such as UKDEA, have grown in recognition in the CHP-DH arena stimulating interaction of actors and knowledge diffusion through seminars, workshops and training programmes, such as the training on the Heat Network Code of Practice conducted by CIBSE.

However the absence of an institutional infrastructure for heat, and lack of a joined-up policy framework for CHP-DH system may hinder the development of positive externalities to firms due to the non-existence of a heat market (Bergek et al., 2008d). Additionally, these barriers may also have impacted on knowledge spill over due to low penetration of CHP-DH systems.

11.3.2 Mapping of TIS

The process of innovation of the CHP-DH system inherently involves the complex interaction of variety of activities, such that outlining the elements of change alone will not be enough to capture an appropriate interpretation of the dynamics within the innovation system (Hekkert et al., 2007b). Therefore, to enable a clearer understanding of the system dynamics after the analysis of the various functions mentioned above, a mapping approach was adopted to show the interaction of the factors that strengthen or limit the performance of the functions within the innovation process. The mapping of these functionalities of the CHP-DH system in the UK was carried out with a view to present a pictorial view to access the performance of the systems by linking the blocking and inducing mechanisms that impact on innovative activities within the system (Johnson, 2001). Secondly, it makes more visible the differences in institutional infrastructures when comparing different innovation systems and thirdly it offers the potential to provide clarity of governance mechanisms to achieve set targets (Hekkert et al., 2007b).

However, the complexity of activities in the innovation process makes it impossible to effectively map all the factors that influence CHP-DH system, but this research endeavoured to map the most relevant factors that has been evident from both quantitative and qualitative results which significantly impacts on the penetration of CHP-DH systems in the UK. Nonetheless, the functional mapping will seek to provide insights in to possible key governance pathways which may seek to reduce the strength of the blocking mechanisms. Figure 37 below shows the mapping of the functional pattern aligned with possible alternative governance pathways to influence the diffusion of CHP-DH system in the UK.

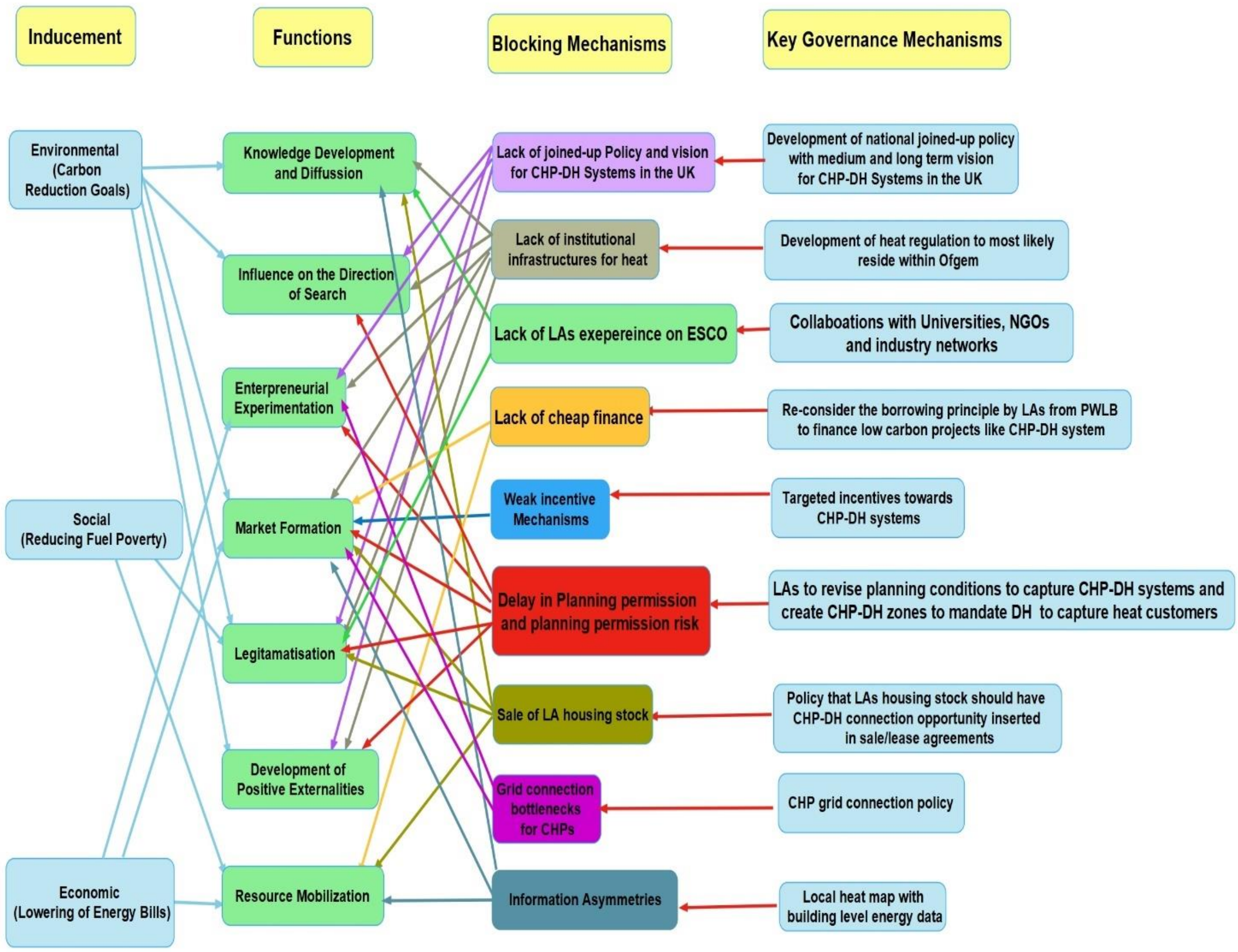

Figure 37: TIS mapping of CHP-DH system

This research captured three key drivers for the growth of CHP-DH systems in the UK as primarily economic (lower energy bills), environmental (carbon reduction) or social (reducing fuel poverty) which is depicted as the inducement mechanisms, though not necessarily all at once for a scheme. For instance, many universities deploy CHP-DH systems to reduce energy bills, while some LAs like Aberdeen have the social motivation of reducing fuel poverty and others like hospitals use CHP-DH systems to meet their carbon reduction targets at the least cost as required by the NHS England which has a target of 34% emission reduction by 2020 (NHS, 2010)**.** These inducement mechanisms interrelate with many functions in the CHP-DH technological system in the UK, which seeks to strengthen the diffusion of the system. However, nine significant blocking mechanisms have been identified as significant factors that limit the diffusion of CHP-DH system in the UK. The interactions of these mechanisms are also interconnected with many other functions as they impact on the performance of CHP-DH systems negatively in the UK. For instance, the absence of a joined-up policy towards CHP-DH affects the legitimatisation function of the CHP-DH in becoming socially accepted and also impacts on other functions like entrepreneur experimentation that would allow firms to seek business opportunities that the CHP-DH industry may present.

The TIS mapping diagram also captured several key governance mechanisms that may be introduced with a view to reducing the scope of the blocking mechanisms within the CHP-DH TIS and increasing the strength of the inducing mechanism so as to increase the diffusion of CHP-DH to a self-reinforcing stage (Bergek et al., 2008b). These mechanisms could take various shapes to target the identified blocking mechanism, with some governance mechanisms possessing the potential to target several blocking mechanisms. For instance, developing a national joined-up policy with medium and long-term vision for CHP-DH systems in the UK may have the potential to reduce the effect of both policy uncertainty and lack of direction of growth of the CHP-DH industry.

11.4 Strength and Weakness of TIS from research findings

11.4.1 Strength of TIS

TIS has been deployed severally as a diagnostic tool to investigate the performance of a socio-technical system and derive policy recommendations that would target specific technological penetration for economic growth (Hawkey, 2012, Hendry et al., 2008 , Praetorius et al., 2008). This investigative characteristic of TIS through the functional pattern has been beneficial to achieving the overall objective of this research, which seeks to investigate the performance of CHP-DH system in the UK with a view to have insights into the barriers and drivers to its diffusion and utilization and contribute to economic growth. Therefore, I shall enumerate some strong insights to the understanding of the UK CHP-DH system that TIS concept had facilitated.

Firstly, the diagnostic feature of the TIS (Kern, 2015) using its functional pattern offered the opportunity to determine and capture the blocking or inducing innovative activities within the system and map these functions with a view to provide a picture of the system performance as seen in Figure 37.

Secondly, the incremental innovation and competency enhancement characteristics of TIS (Alkemade et al., 2011) was a critical consideration of this analysis. Considering that CHP-DH as a matured network-based infrastructure only has negligible contribution to UK's electricity and heat generation profile and since, infrastructures slowly transit, but rather they have tendencies for incremental change (Frantzeskaki and Loorbach, 2008). Furthermore, Ofgem as part of the matured governance infrastructures for electricity and gas in the UK, regulates the electricity and gas sectors. Therefore, the opportunity of strengthening of an existing regime like Ofgem in the governance structure of heat was helpful rather than a regime shift. For instance, the research results showed that there is statistical evidence that CHP-DH actors would prefer heat regulation to reside with Ofgem.

Thirdly, TIS captures the role of actors in networks knowledge generation by collectively supporting the actors, learning activities, building support structures and building the CHP-DH system that would legitimize and stabilize CHP-DH systems in the UK (Markard et al., 2011, Musiolik et al., 2012). This is evident in the role of ADE and CIBSE in building support structures. Such as the development of the Heat Networks Code of Practice (HNCP) which seeks to regulate the development of CHP-DH system amongst actors and the role of ADE in the development of the Heat Customer Protection Scheme (HCPS) resulting in the Heat Trust, which has provided the channel for registered heat suppliers to further interaction with their customers by providing a channel of feedback on complains and grievances. This also captured learning networks such as Heat and the City, UKDEA, e.t.c, which facilitates learning through interaction of CHP-DH actors.

Fourthly, TIS acknowledges the role of social acceptance in the transformation change of a network infrastructure, given the interplay of the heterogeneous actors in the diffusion of a CHP-DH system. This feature of TIS offered the opportunity to capture the impact of failed CHP-DH systems on its diffusion and importance of buy-in by heat customers and other social actors.

Fifthly, the role of an actor with unique features that can facilitate the diffusion of CHP-DH has been acknowledged by TIS as the prime mover. This feature offered me the opportunity to designate LAs in the CHP-DH TIS as a prime mover. Considering their position of champions of local energy targets and custodians of the social and economic fabric locally. Furthermore, TIS also presents the opportunity to capture the heterogenous actors (vertical and horizontal) that permeates the CHP-DH industry which has the capacity to influence the building of the system. Such a hospitals, universities and auto-producers.

Lastly, the emphasis of TIS on the importance of directionality through targets, strategies and resource mobilization is critical for actors to experiment on entrepreneurial activities. Like the building of the first DH pipe manufacturing factory on the back on the potential of so many HNDU supported projects amongst others to come to fusion.

11.4.2 Weaknesses of TIS

TIS is generally formed through three key structural processes. Namely: formation of networks, entry of firms and institutional alignments (Bergek et al., 2008b). The formation of networks of actors can been captured in the light of learning networks and “political networks” advocacy coalitions (Bergek et al., 2008b). However, TIS is less clear on the political processes that ensue between hierarchical political actors and the role they play in shaping the technological growth, but rather it captures more emphasis on political processes like lobbying or advocacy, which was captured under the legitimization function (Bergek et al., 2015, Markard et al., 2015) . This is given against the back drop of LAs as the prime mover of the TIS and part of the hierarchies of governance depend on the state for financial survival to sufficiently play their role. TIS appears to capture horizontal political processes and interactions but less on vertical political processes across hierarchies of governance. For instance, as evident in this research financial resource mobilization from the state is critical to the legitimization and stabilization of CH-DH in the UK. In part because financial resources are considered a vital input to the development of a TIS but the processes to acquire various sources of finance is not given much attention outside public grants or collective network resources, as the LAs in the UK depends on the state for its financial survival. Therefore, the impact of hierarchical political processes on resource (such as financial) mobilization is under theorized.

This weakness is particularly important to CHP-DH systems because of its features as a network infrastructure. Such as asset specificity, exhibition of stability and lock-in due to huge sunk cost, increasing returns, network externalities, and the economic, social and political impact as a large-scale capital goods producer/service delivery with multiusers that often requires public intervention. Furthermore, this research suggest that the public intervention is expected from the state due to a centrally resource allocation in the UK. However, LAs are the prime movers of the CHP-DH TIS considering that they are in the best position to champion the diffusion of DH systems (UNEP, 2015) due to their social capital -trust, norms and networks (Pollitt, 2002), geographical proximity to CHP-DH actors (Boschma and Frenken, 2010 pp:123) and frontline role to promote social, economic and environmental wellbeing of their community. Therefore, the political interaction between the hierarchies of governance in resource mobilization is hugely critical to attract more emphasis in the TIS concept

Another weakness of the TIS with respect to CHP-DH in the UK is the role of the incumbent centralized energy paradigm that has a seemly vertical integration of actors and the role of a matured gas grid which is the main source of energy for individual heating and electricity generation as well as being the main source of fuel for CHP-DH system in the UK. This can be seen as the “paradox of embedded agency” captured by Battilana et al. (2009) and Farla et al. (2012). This captures the inadvertent role of institutional actors in the CHP-DH TIS to reinforce the incumbents. Such as the role of super- ESCOs in the vertical chain of the energy sector and the lock-in of the gas grid system that challenges the adoption of CHP-DH system which they seek to promote that may precipitate internal conflict and competition. This is against the backdrop of the UK energy system where in 2016, 81% of gas and 82% of electricity retail market share belong to the big six energy providers and they have strong presence in both energy whole sale (Ofgem, 2017b) and in deployment of CHP-DH systems. Such as E-ON in the Cranbrook CHP-DH system in Exeter and as well as being part of the big six. Indicating that these actors (big six) have presence in the governance structures, such as in Elexon in the electricity market and have the potential to influence the directionality of the CHP-DH TIS. However, TIS considers that in directing the influence of search, actors of competing technologies are not controlled by one organisation apart from regulation (Bergek et al., 2008d). Rather TIS recognises the role of advocacy coalitions to build-up momentum which would lead to a process of creative destruction within the incumbent system (Hekkert et al., 2007a). Though TIS scholars have also admitted that the framework pays little attention to the interaction of multiple technologies and the decline of incumbents (Markard et al., 2015). Therefore this suggest that TIS has paid more emphasis on the creative destruction – destabilization of incumbent in a specific technological space by political networks to achieve legitimacy without similar consideration to “destructive creation” (Calvano, 2006) - which is the monopolistic role of an actor to introduce a new improved product simultaneously with an old product at a price gain with a view to destabilize the incumbent. This also suggest that TIS is silent on the role of actors in institutional determinism to reduce conflict and competition within the TIS and therefore insufficient for a broader energy sector transformation.

Also, TIS concept mainly focuses on the meso-level of the system with little attention on the micro-level and therefore it’s not intended to capture all the activities at the micro level (Markard et al., 2015, Bergek et al., 2008b, Kukk et al., 2015). Suggesting that its primary unit of analysis is the system level even though it recognises actors as its strong focus, cumulative effects and couple dynamics within the system. This emphasis of the TIS system on the system level may not fully capture the dynamics that permeates a CHP-DH TIS. In part because CHP-DH systems are not nationally interconnected but delineated by regions or localities and as such actors may possess distinct social and environmental characteristics that would inform their role at the micro level in the TIS. For instance, results from this research suggest that Scotland and Wales have proscribed the sale of social houses, while England still engages in the sale of social houses. Considering that social houses are critical for de-risking CHP-DH systems as it guarantees heat off-take, thereby militating against a significant risk to the development of CHP-DH systems according to the results from this research that showed heat off-take is a significant risk to the formation of CHP-DH market. This suggest that actors or LAs in Scotland and Wales may exhibit varying characteristics from other actors in England that would inform their interaction, action and entrance of new actors to the UK CHP-DH TIS. Nonetheless, TIS scholars are open to support more micro-level analysis in a view to enrich their understanding at the meso-level (Markard et al., 2015).

Lastly, TIS captures the importance of directionality as earlier discussed, but without emphasis on coordination at both the system level and micro levels. Rather, coordination in TIS is concentrated on R&D activities, which makes it insufficient for a mature technology like CHP-DH system with several local actors that have independent governance systems. Such as hospital, universities, auto-producers and so on that would require strategic coordination by the prime mover (LAs) to achieve a mutual goal. This is critical because the DH network can be a service provider to many actors who want to use the DH infrastructure to sell their heat to their independent customers. Therefore, this can be considered another weakness of the TIS concept

11.5 Contributions to TIS Concept

I would hereby make a few contributions to the conceptual framework of TIS which would offer more understanding and application to low carbon energy resources and network infrastructures. This is in the light of the role of incumbent actors and the hierarchies of governance in contributing to environmental innovation through generation of positive externalities. Such as knowledge spill overs, waste and emission reduction from established technologies.

Firstly, resource mobilization as a function in TIS has been categorized into four distinct areas: tangible resources – finance, human resource – expert, skill; structural resources – governance structures like rules and culture; and lastly relational resources – power and reputation (Musiolik et al., 2012). These resources emerge and can be accessed at the firm, network and system levels to influence the building of the TIS (Markard et al., 2011). However, mobilization of certain resources (such as finance) are beyond the capability of some actors and networks and more so in the UK context of the position of LAs as prime movers of the CHP-DH TIS with severe dependency on the state. Therefore, considering the argument that the transformation of network based infrastructures like CHP-DH systems with huge investment and sunk cost would require strategic intervention of a particular actor (Farla et al., 2012) like the state. Suggesting that the capturing of the processes and interaction of the current steering and rowing (top-down) power of an actor like the state and LAs as the prime mover in building of a TIS. Given that the prime mover like the LAs possess unique and relevant characteristics but would still require accessing finance from the state to enable them to effectively build the system. This consideration would be useful in further enhancing the application of TIS in a network-based infrastructure.

Secondly, the role of actors in the creative destruction of the incumbent was captured in TIS under the legitimization function but further analysis on the roles of actors with multiple and competing technologies may offer greater understanding to how actor strategies could perpetuate destructive creation and institutional embeddedness.

11.6 Recommendations arising from this research

This section shall synthesize the various results from both the quantitative and qualitative analysis as discussed in the empirical findings section in this chapter in a view to highlight the recommendations that arose from the findings. These recommendations depict several governance options that seeks to contribute to the policy debate to influence the diffusion of CHP-DH systems in the UK and this section shall also seek to discuss how these recommendations shall be tested to quantify their impact on the penetration of CHP-DH system in the UK. Furthermore, this research generated other serendipitous findings which were not statistically significant but offers useful contribution to understanding the barriers that may be militating against CHP-DH in the UK. Therefore, these findings will also be highlighted for further research.

There are four commonly known research methods to measure the impact of a policy and gather evidence on the efficacy of a policy in overcoming the identified barriers/risk. They are namely: Randomised Controlled Trials (RCT)- locate respondents at random to assess policy, Difference-in Difference (DID) – Compares change in outcome over time amongst respondents using pre-policy and post-policy data, Regression Discontinuity Design (RDD) – Measures effect of policy on respondents close to eligible thresholds and not the entire population and finally, Statistical Matching (SM) – matching data from different sources (EC, 2014b). However, desired outcomes such as the penetration of a networked infrastructure like

CHP-DH system that draws on the interaction of several actors from the technical, economic, social and political sphere of the society would require both research and participatory processes to effectively measure the impact of the identified governance mechanisms that are suggested to reduce the blocking effect of the barriers/risk to the penetration of CHP-DH systems in the UK. The participatory processes shall be a parallel and simultaneous process along with the research process in a view to provide feedback and implications of the policies and secure buy-in from the diverse range of actors (EC, 2014b). The participatory process entails the development of learning processes and network management through series of seminars, conferences, consultations, works shops and public debates (Geels et al., 2004 pg:9).

Hence, I shall discuss further the recommendations advanced from the empirical findings and shall also attempt to assign ways to quantify the impact of the advanced the governance mechanisms on the penetration of CHP-DH systems in the UK.

- According to the empirical findings there was statistical evidence that the UK CHP-DH industry requires a national joined-up strategy to facilitate the penetration of CHP-DH systems (See Table 50). Suggesting a joined-up governance mechanism that would couple both CHP and DH systems is desired. Therefore, the assessment of the impact of this mechanism may require a participatory process since evidence had been gathered from a randomised control trial process and significance had been achieved. In a view to secure buy-in by the multiple social bodies that permeate the CHP-DH industry, conferences and works shops driven by the state should be held to capture the myriad of views to access its impact.
- There was statistical evidence that the lack of LAs experience on PPP is a significant risk to the development of CHP-DH systems in the UK (See Table 26). Furthermore, many respondents from the qualitative data suggests that collaboration with universities within their localities was used to improve skills in setting up ESCOs and negotiating PPPs, while others without such institutions used consultants and paid huge cost for the services. Additionally, 49% of LAs don’t think they have the skills to engage ESCOs, while 28.4% thinks they do (see Table 32). Suggesting that LAs may require an innovative way to acquire skill, especially LAs without academic institutions. Results from qualitative research had proposed collaborations with NGOs and industry networks as possible ways for LAs to improve such skills. Therefore, a participatory process of using conferences involving actors from institutions, NGOs, industry networks and LAs may be required to access the impact of this governance mechanism.
- The results from this research shows that there is statistical evidence that the CHP-DH industry in the UK is at an infancy but growing state with a strong thematic pattern from the qualitative data suggesting that the industry requires a regulation to facilitate its growth. Furthermore, the quantitative results suggest that about 73% of respondents (See Table 52), thinks that the industry requires heat governance infrastructures and CHP-DH operators considers regulation as their biggest barrier (See Table 30 and Figure 19). However, the support is

weak as there was no statistical significance between respondents that the industry requires a regulation. Therefore, this may be further subjected to a larger sample size with a view to achieve significance. Hence, I recommend that a further research using the RCT method be conducted to validate the descriptive results before proceeding to a participatory process.

- There was statistical evidence that if a regulation is required for the industry that the body to administer the heat regulation be Ofgem, since it's already administering the gas and electricity sectors, which is similar to the model adopted by the Netherlands and Norway. Nonetheless, a further participatory process may be conducted through conferences to covey the merits of this development to other actors and secure buy-in.

- The qualitative data from the interviewees captured a theme of lack of cheap finance. Which many expressed in various ways such as abandoned projects due to low rate of return to access private finance, difficulties of borrowing due to cuts from central government, high cost of borrowing to achieve social objectives, premium cost on heat off-take risk and absence of public support capital to provide total control by LAs. The theme was captured by the quantitative results in both availability of finance and cost of finance risk factors, as both risk factors were statistically significant risk to CHP-DH development in the UK (See Table 26) and the dominant choice from interviewees was that this can only be provided by the government with PWLB as the most likely source of cheap finance. However, LAs borrow from PWLB based on their revenue, which limits how much that can be borrowed and not on their assets, therefore a policy shift is proposed from revenue financing to asset financing which would capture the value of the CHP-DH assets in borrowing. This would however require a further participatory process amongst the policy echelon of government agencies and political actors using conferences to capture the views of actors that are close to decision making.

- Qualitative data suggest that there is a theme amongst interviewees identified as lack of information on CHP-DH systems in the UK. This was captured in various aspects by the interviewees such as, lack of where to go and ask questions about CHP-DH system, not enough knowledge available outside, lack of energy usage and CHP-DH systems data, lack of communication amongst CHP-DH practitioners, lack of CHP-DH systems knowledge amongst developers and consultants. Furthermore, the quantitative results in Table 45, shows that 44.4% of respondents (39.3% of the CHP operators, 44.4% of the consultants and 48.6% of the LAs) tend to agree and another 28.7% strongly agree that there should be a one stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network. However, the support is weak due to the non-significance of the result. Therefore, a further research would be required to be conducted with a larger sample size in a view to achieve significance before embarking on a participatory process. Nonetheless, the consensus amongst interviewees was that the national heat map is insufficient in terms of building level energy data and since LAs have developed and are developing heats maps, more building level energy data is required to better inform investment decisions. However, currently, building level energy data is being harvested through the smart meters programme and administered by Smart Data Communications Company Limited (DCC), the licensee from the Government, but LAs are not part of governance structure. Therefore, LAs have limited access to the data, which may also have data privacy implication and may require legislation. Hence, a further quantitative research is required to conduct its usefulness to investors/developers and ways for LAs to access the data in a bid to influence the penetration of CHP-DH in the UK. This would be followed by a participatory process, such as consultations, public debate, that shall capture the impact of dwellers and views from CHP-DH actors.

- Skills have been shown to be essential to the expansion of numerous energy technologies and precipitate incremental change (North, 1990). Shortage of skills in the CHP-DH industry was captured by the qualitative data with legal and CHP-DH O&M skills as more pronounced. This was further validated by the quantitative results as seen in Table 58. This shows that about 55.2% of the CHP operators and 40.7% of the consultants tend to agree (51.8% total group) and another 18.4% of the total respondents strongly agree that there is a skill gap in the CHP and DH industry in the UK. However, the support is weak due to the non-significant result as seen in Table 59. This suggest a recommendation for further research with a larger sample size be conducted to investigate skill shortage in the industry, what type of skill is more deficient in the industry and the best way to bridge the skill gap if any. Then a participatory process may follow afterwards.

- Responses from interviewees suggests that for the development of CHP-DH systems to be economically viable, it may require between 500 – 1000 houses per site. However, available UK house development data suggest that the average range of new house development per site in the UK is about 54, which indicates that the UK has a low scale of viable new build development. To further understand the growth pathway of CHP-DH systems in the UK. CHP operators and Consultants were asked the growth pathway for CHP-DH systems in the UK. The quantitative results did show any significance for the pathways (see Table 64). However, only new builds and industrial area had a positive effect size. Suggesting that a further research with a larger sample size would be required to achieve statistical significance and validate the strength of effect of industrial areas and new builds on CHP-DH development in the UK.

- The results of this research also suggest that CHP-DH systems in the UK requires an injection of innovation to the energy policy arena to create the desired diffusion of the technology. For instance, the various governance mechanisms introduced by the UK has not targeted CHP-DH systems as a technology that can contribute to its energy targets and considering that it contributes to two energy vectors (electricity and heat) of the UK energy spectrum. This is evident from the systemic lock out of many CHP-DH systems from the key mechanisms, such as the EMR (CfD and CM) due to qualification risk resulting from grid access barrier and non-convergence of cost and revenue risk since electricity and heat are two separate risk factors. Results from interviewees suggest a more targeted response towards CHP-DH system with a view to capture both electricity and heat risk factors and a grid connection policy to assure developers of secured CHP connections as obtained in the Netherlands. Therefore, a further participatory process of conferences and consultations may be required to seek buy-in from actors including policy makers and grid operators to access this policy.

- There was statistical evidence in this research that delay in planning and planning permission are risk factors that are militating against the development of CHP-DH systems in the UK (see Table 26). However, results from the qualitative data suggest that some LAs have revised their planning conditions to influence the development of CHP-DH systems by capturing CHP-DH systems for new builds and designate such areas as CHP-DH zones using planning conditions. This is with a view to mandate DH networks to capture heat customers and facilitate planning permissions for CHP-DH systems. Such as in Leicester, Croydon. Furthermore, other LAs such as in Exeter, where planning conditions were used to mandate developers to adopt CHP-DH system and were successful with the litigation in court are all ways of how planning conditions have been adopted by LAs to influence the penetration of CHP-DH systems. Therefore, this research presents a useful mechanism to reduce planning related risk from LAs by revising planning conditions to capture CHP-DH systems and create CHP-DH zones to mandate heat connection to DH systems. For other LAs to gain from the lessons of LAs which have successfully used planning conditions to reduce planning risk. A participatory process such as, through workshops and conferences would be required for LAs and developers to share their experiences on how planning was used as an inducement tool rather than a blocking tool.
- The sale of LA housing stock was a prominent feature in the qualitative data, which many LAs consider as not beneficial to the development of CHP-DH systems. In part because these housing stock helps de-risk CHP-DH system by guaranteeing some level of heat load. However, Scotland and Wales have stopped the sale of these buildings, while it's still prevalent in England. Therefore, an alternative pathway may entail LAs inserting mandatory connection to DH system but not obliged to consume the heat in housing sale/lease agreements as obtained in Norway or designated CHP-DH zones as already done in some LAs. Such as Leicester. However, this policy would require a buy-in from the hierarchies of governance in UK and other actors. Therefore, a participatory process through conferences would be required to access its impact.

Furthermore, this research suggests that CHP-DH systems mostly supply their electricity through private networks by consuming their electricity on site rather than exporting it to the grid (see Table 18 and Table 19). In part because of the conditions in the electricity license regime, which limits the capacity to export electricity to the grid without a standard license. This suggest that innovation in electricity market participation is required to trigger the penetration of CHP-DH systems, since the hierarchies of governance (state and local authorities) have the capacity to play new roles and address or mitigate the barriers that have impacted on the penetration of CHP-DH systems (Foxon et al., 2005, Edquist, 1999). In part because LAs as part of hierarchies of governance are custodians of social fabrics and the political institutions to coordinate the production of public goods. Consequently, a possible model for the LAs is proposed here. Its adoption may offer a route to instigating an institutional change and thus the development of an alternative governance structure to challenge the status quo and make explicit changes to the governance arrangements that govern daily transactions in the electricity industry. The proposed model is shown in Figure 38 below, and comprises an interactive governance model (Teisman and Edelenbos, 2004) that puts the LAs at its core. The model aims to leverage on the collective load of the LAs as regards their CHP assets and resources with a view to obtaining a standard electricity supply licence. It would allow them to jointly buy and sell electricity to themselves. The governance structure of the model would look like the newly created Local Capital Finance Company (LCFC) to finance infrastructural projects which was discussed in chapter eight. It was suggested that the Local Government Association (LGA) could be the centre championing this role of electricity trading for the LAs. However, respondents agreed to the necessity of having a common front to enter the electricity market, but a point of variation amongst respondents was the level of scale this would take, whether national or regional level. Some favoured such a role residing within the LGA as echoed below from an LA respondent.

"So I think it certainly makes sense for us as a local government sort of family, to have something within the LGA and look at how we, it gives us more interest in terms of how it makes it simpler for us as local authorities to access the market and enter it, and get to be able to get to the point when we can offer really good quality power products to our residents, to our businesses" LA9

The LGA was suggested because it is a cross-party umbrella organisation with presently 414 registered LA members out of 418 UK LAs. The LGA also has other registered members, including 21 Parish/Town councils, 31 fire authorities and 10 national parks (LGA, 2015). The LGA exhibit the potential to deploy this model faster than regional networks at reduced administrative cost due to economy of scale so as to free up more fund to source for required experts to commence the operation. However, the dominant choice amongst respondents was for the model to be operational at the regional level so as not to lose the benefits from LAs negotiating local rates due to proximity to generation with a view to reduce transmission and distribution charges. Therefore, some respondents argued that a regional approach may be more beneficial and attractive as echoed below.

"Many councils now enter into Power Purchase Agreements (PPAs) locally but some of the benefits of this approach could be lost if the model were to be extended to provide national coverage. For example, would there still be the ability to negotiate local rates or would a national or regional rate have to be accepted? Thinking about distribution and transmission costs, would a national arrangement be as attractive to a council in an urban area close to a power generator compared to a council for

example at the tip of Cornwall many miles from a generation source? Councils may feel they are able to negotiate more advantageous rates with local generators where distribution and transmission costs are lower" CDHOP 18

"good idea but why be attached to London? I am sure a number of authorities would like it starting by the Northern Powerhouse LA's around Manchester" CDHOP12

Thus, the electricity trading role could reasonably reside within a regional body, most likely shaped after the structure of the defunct regional development agencies that will be formed by LAs with geographical proximity. These regional networks will be responsible for marketing and development of the business model. The role of the regional electricity trading body will include operating an electricity clearing house for its members. It will advise LAs on-electricity market dynamics, analysis and forecasting of demands, scheduling and to let them know when it's best to bring up their CHPs. It will also act as an off-taker of all CHP generation and trade power on their behalf either on the market or to other LAs that require it. It can also position itself to buy cheaper and greener electricity from other international exchanges, LAs and countries in Europe. It can act as the intermediary between the LAs, other local institutional actors and the electricity market. It would also represent the actors to the balancing and settlement company Elexon, and to the regulator. A graphical description of the model is seen in Figure 38.

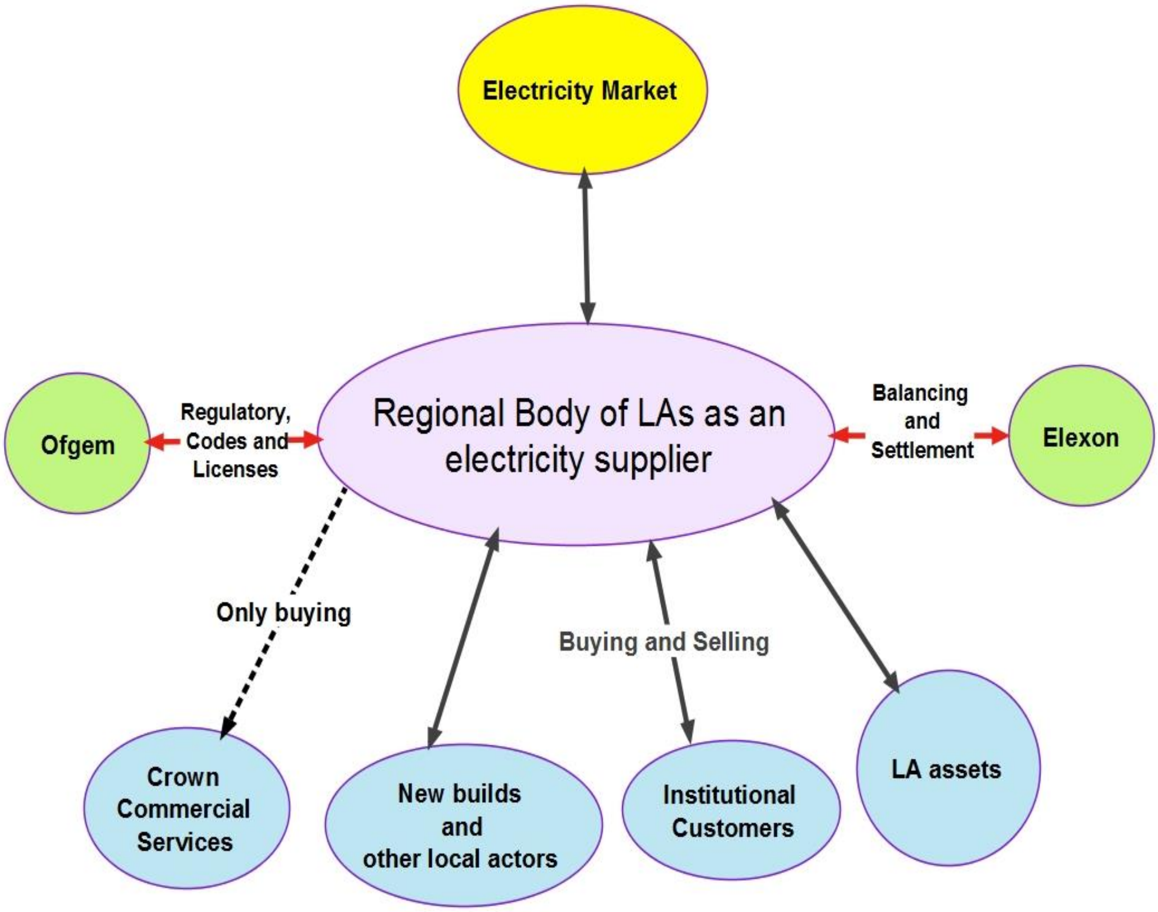

Figure 38: Electricity Governance Structure for LAs

The illustrated electricity trading model above depicts an integrated business case where the LAs will form a regional body, which can target local institutional bodies like, universities, hospitals and other potential clients with a view to incorporating actors with CHP-DH systems to sell or buy excess electrical capacity. Though hospitals usually source procured electricity via the Crown Commercial Service (CCS), which procures electricity for public institutions, such as courts, police offices and other state buildings. However, hospitals are not under obligation to buy from CCS, so they could be offered the option to partner with the LAs if it makes business sense. The link to the CCS has been incorporated to open the opportunity for electricity trading since CCS presents a potentially useful partner to invite into the model because of their buying (not selling) capacity. Engaging with these third parties is really a pivotal part of the whole model as these parties (hospitals and universities as institutional customers) are very concerned with the economics of the deployment of CHP-DH systems such as energy bill reduction as a vital part of their energy strategy. If a good business case is presented with a good off-take tariff, many may well buy into it. However, the LAs also possess large electrical load such as housing stock or leisure centres that can provide the initial take off to de-risk the model without other institutional participation.

The model portends many advantages which can be harnessed by all parties given the share size of the potential aggregated CHP assets from these actors. The key benefits that may convince actors of the business case include:

- All regional electricity trading bodies of the LAs that obtains an electricity supply licence and can now sign up to be part of the BSC and therefore have a right to vote and trigger an explicit change on the electricity market governance from inside and not outside.

- An important component in complementing market activities is the development of trust, norms and networks (Pollitt, 2002). A recent report by the LGA showed 77% of respondents trusted the LA to make decisions about service provision (LGA, 2014b). LAs may thus be able to leverage on their social capital to generate and supply electricity to citizens through coordinated actions to solve market failures (Pollitt, 2002). For instance, LAs can use CHP-DH systems to internalise the benefits of low carbon and efficient generation of electricity and reduce fuel poverty and can also self-supply local domestic load above 2.5MW with their self-generation, which currently, generators are inhibited without a standard licence.

- The retail margin amongst the incumbent electricity retailers is about 5% and one of the reasons why it could be this high is the ability of customer switching and increased volume risk (Helm, 2014b); but the LAs can leverage on the aggregated customer base from the local generation to gain economy of scale and customer stability to reduce volume risk which will translate into reduced margin. This may also translate in to cheaper energy.

- The combined collective gains of contracting bulk power from institutions with private wire such as universities and hospitals for a long-term can impact on energy prices by internalizing the discounts earlier paid out to suppliers. Further gains can also be derived from reduced network charges as more local generation will be supplying local demand at minimal Transmission Use of System charges (TUoS).

- As a result of the stable revenue for the CHP operators from electricity, heat prices can be reduced, which would reinforce the reduction of fuel poverty in the locality and increase energy access for the poor and vulnerable.

- The LAs would be able to implement and monitor key performance indicators of their local energy strategies as they would be better placed to contribute to their social, energy and environmental targets from the supply side through investment in CHPs.

- LAs would have the opportunity to evolve tariff and payment schemes for low-income/vulnerable residents in a bid to target fuel poverty in their locality.

- The cost for the procurement of a standard electricity license and cost of electricity trading infrastructure shall be jointly borne by LAs in the same body. However, the richer and bigger LAs will be more likely to carrier greater implementation cost and smaller LAs to contribute smaller amounts, while allowing all members to jointly benefit from the gains of the scheme, irrespective of the size of the contribution. This band wagon effect would afford smaller LAs who ordinarily wouldn't have been able to obtain such license to enjoy the benefits of a full electricity license.

However, this model, which seeks to effect radical change to the current electricity governance structure by challenging the status quo will no doubt be open to resistance by the system in which change is sought, due to the path dependency by the incumbents (Mitchell, 2008 pg. 85). Secondly, lessons from institutional theory suggest that there are substantial challenges in building partnerships (Teisman and Klijn, 2002). Possible institutional barriers which may emerge from this model include:

- Long negotiation and conceptual period to actualise the project due to various councils requiring approval from their individual local governance institutions. In part because this is due to the varying degree of political affiliations and different hierarchal system of governance since it is the politicians that will determine the success and not the residents.

- As an owner of a full electricity licence, the associated operational risk and market risk will be internalised by the LAs (IPPR, 2014). Indicating that the responsibility of bearing the complexities and scheduling of electrical transactions amongst councils shall be borne locally by the regional licence body which may exhibit the potential of going burst.

- The process leading to acquisition and operation of a full licence is expensive and knowledge based, therefore the start-up cost may constitute a challenge

- Coordinating and linking of actors/institutions with a single governance structure may be difficult in terms of achieving a common solution. This is in part because of their dedication to their own internal hierarchical method of governance (Teisman and Edelenbos, 2004 pg. 183). For instance, universities and hospitals have their governance structures and energy strategies, which may not intersect. Furthermore, it may be a challenge to elicit cooperation from LAs in the same region that have already entered the electricity market. Examples include Nottingham City Council which already has a full supply licence or the GLA which is about to commence the operation of their Licence Lite (LL) provision. This parallel process brings a new mode of discussion as to how what they've already obtained can be integrated in to the new objective if desired.

- Decision making lies with the administrative (technocrats) and political (politicians) actors; they may not always buy in to the outcome of interactive processes, partly due to path dependency. Also, because the process of interaction and feedback may not be properly coordinated that may lead to disassociation from either the administrative or political processes (Teisman and Edelenbos, 2004 pg. 179). Hence precipitating likely tension between the administrative and the political process of each LA.

- There may be reluctance from LAs, universities, hospitals and private actors to share their CHP-DH assets and resources with other private or societal actors, though this might be mitigated by the economic opportunities.

This model could trigger an explicit institutional change by the LAs instigating a change from inside as a member of the BSC thereby exhibiting the potential to cause a radical disruption to the electricity market system. Since LAs participation in the electricity market may alter market share of the incumbents and expose energy customers to new economic, social and environmental benefits, especially when compared with other type of energy market participants in the UK.

The possible antidote to the several misgivings highlighted above is to engineer a careful and robust coordination mechanism, through efficient marketing and negotiation. The success of this model seems likely to be dependent on the quality of interaction amongst the actors within the LA subsystem (Markard and Truffer, 2008b). The marketing strategy of the trading model should also emphasise the social benefits to the local area such as job creation and fuel poverty reduction. In a recent survey from a YouGov poll in 2014 concerning the support LAs can get as energy suppliers, it showed that 32% of respondents believed that the LAs are more likely to provide a better energy tariff than incumbent energy providers, with only 11% favouring the incumbents, while 25% indicates that they don't know with another 25% favouring smaller energy suppliers (IPPR, 2014) . In the same survey 37% of respondents would prefer to buy their energy from a community energy company than the large retailers, if both present the same price and service (IPPR, 2014). The future of the electricity industry is going to be greatly determined by the continued growth of distributed energy, including CHP-DH systems. This will create more space and emphasis for the role of the LAs to participate in the electricity market.

However, the impact of this role of LAs would require series of conferences by LAs and the LGA to access the overall implications on their traditional roles and with a view to secure buy-in from other stakeholders.

Concluding, the UK has shown the will to meet its environmental target of emission reduction compared to 1990 base levels and 2020 energy targets from renewable energy by introducing several governance mechanisms. Such as EMR and many others, but it's evident by the low penetration of CHP-DH systems that these mechanisms have not fully capture the full potential of these systems in the range of technological options available in the energy spectrum to achieve these targets. Secondly, it is also not clear if the UK have adequately considered heat energy as a critical aspect of the energy vector to meet its energy target, based upon the limited governance infrastructures to facilitate the efficient generation and distribution of heat. Therefore, this research seeks to highlight the roles the hierarchies of governance (state and LA) can play in influencing the diffusion of the technology, with the state evolving a joined-up policy portfolio to stimulate investment in CHP-DH systems and the LAs taking up “doers and enablers” roles in the penetration of the technology. Thereby contributing to the energy policy debate by persuading the hierarchies of governance to consider the vital potentials CHP-DH systems may bring to the energy mix and meeting energy, social and environmental targets. These potentials can be better harnessed by considering alternative governance mechanisms that may enhance the selection environment of CHP-DH systems and ultimately progress the present nursing market of these systems to a bridging market.

11.6 Recommendation for further work

One recommendation of this research is for LAs to play a more significant role in the UK electricity market. Action in this direction might result in the disruption of the market share of the incumbents; this suggests a further investigation as to the potential impact of LA participation in the electricity market and on wholesale electricity prices.

Energy utilities in the UK have made inroads in to the CHP-DH industry; they are commonly known as super-ESCOs (Vine et al., 1999) and have unique advantages in deploying CHP-DH system. This includes their ability to provide integrated energy services, their ability to bear risk due to deep capital and human resources and greater likelihood of having access to consumer energy data than other ESCOs. The emergence of these super-ESCOs with strong presence in large scale electricity generation and supplier chain of the electricity market, may usher in a potential question regarding their role in the CHP-DH landscape. The question will be, what the electricity regulatory landscape will portend, regarding the low liquidity ratio of the UK electricity market (Ofgem, 2014f) as these super-ESCOs will further reinforce their hold on the energy market and suffocate new entrants. This might draw on the lessons of the electricity and gas sectors where network ownership is outside the portfolio of the energy companies.

This research proposes that Government should re-evaluate the criteria for LAs to access PWLB loans from the current revenue-based approach to one based on the assets of the CHP-DH developer. A further research might consider the possible risk profile exposure of hierarchies of governance if assets of the CHP-DH systems can be incorporated into the borrowing principles to LAs for CHP-DH projects, considering that the Government shall also gain political capital from financing CHP-DH systems.

This research results also suggest that the current UK energy paradigm exhibits a missing link in nesting the ambitions of its energy security, environmental and social targets together, considering that the dominant electricity and heat governance mechanisms that ought to impact on CHP-DH systems do not. In part, because CHP-DH systems are not targeted and are therefore not internalising the low carbon and social benefits. Therefore, this research proposes further work as to the appropriate governance model to adopt biomass and energy from waste CHP-DH systems for capacity adequacy provision in the UK, considering its potential to provide base load capacity and renewable energy generation and its long-term role in the Government’s decarbonisation programme.

Regarding financial support for decarbonising heat in the RHI scheme, this research also suggests a possible consideration of RHI to support distribution of heat through CHP-DH systems. Further work might usefully consider the impact of possible roles of the RHI scheme in the penetration of RES-H using CHP-DH systems in an off-gas system.

11.7 Conclusion

The work in this thesis seeks to contribute to the debate on the role of governance on CHP-DH system in the UK and opportunities to improve its penetration, considering its potential contribution to the economic, environmental and social fabric of the society.

The underlying driver of this thesis is the current approach of the government and policy makers to CHP-DH as another energy technology, which they seek to trigger technological diffusion by eliminating market barriers. Such as the HNIP £320m funding to attract about £2b private investment to ameliorate the tension of low rate of returns of many HNDU projects (DECC, 2016a). This can be considered as another government stop-and-go approach to CHP-DH system, even though government thinks that after this programme the industry would have been self-sustaining not to require such interventions. This still suggests that government is still losing sight of the fact that CHP-DH system is a network-based heat distribution infrastructure that market failure approach may be not a sustainable path to address its failures.

Market failure is considered blind to several externalities. Such as knowledge generation, which is often not reflected in market transaction that is underpinned by competition or free riders that may benefit from the infrastructure without payment as well as the constant demand for expansion due to increase in demand (Finger et al., 2005). This suggest that market actors will not allocate the right resources to steer technological change. This is not going to be different to CHP-DH systems, considering that it is network-based infrastructure with huge investment cost, high sunk cost, long duration, with path dependency and network externalities features. Therefore, a system failure that would warrant government's intervention that is different from grants or stop-and-go intervention, considering the political, economic, social and environmental impacts of CHP-DH systems may be more sustainable.

This brings the issue of the current political economy of technological neutral policy position to the fore. Most often energy policy makers use one brush to paint all energy technologies without considering the differences between network-based and non-network-based infrastructure, especially as it relates to CHP-DH systems. The point of departure to my mind is the distinction between product and service. A product is an output of a service. For instance, wind and solar farms produce electricity and use the services of the electricity grid to deliver or sell their produce, but these technologies (wind and solar) are not used to produce electricity by non-owners except you would have to install your wind turbines or solar panels yourself. This is the key reason why government embarked on high pressure natural gas transmission network known as NTS in 1977 and the low pressure gas network replacement programme known as the Iron Main Replacement Programme to be completed by 2032 in a view to provide wholesalers and retailers safe and secured access to gas (HoP, 2017). In a similar vein, the 2016 national grid's Network Options Assessment (NOA) recommends an expenditure of £83m on network reinforcements in 2017 to provide secured transmission services to electricity customers such as offshore wind farms (NG, 2017b). The implications of the services provided by these network-based infrastructures is key to why investments made by these sectors are guaranteed under the RIIO regulatory framework, which is indexed to RPI that is tied to government and corporate bonds. This regulatory framework incentivises electricity and gas network companies to seek finance for investment for the development of networks at a reasonable cost (Ofgem, 2010c). These investment assurances are captured through governance infrastructures such as regulation.

However, CHP-DH infrastructure which not only provides electricity and heat as product but services to other heat production customers (though not nationally but geographically limited to local or regional areas) are not regulated in the UK and as such investments are not guaranteed by any regulation. This may be because of CHP-DH systems are being considered as delivering a product and not services. This research exposed me to auto-producers whose business strategy was to sell heat and not to transport heat. For instance, an interviewee lamented that he had excess heat to sell to a hospital that requires his heat but neither of them had the capacity to build the heat distribution infrastructure. This is a classic case of one seeking to use the services of a DH infrastructure, but it was not available. Therefore, the argument of technological neutrality or picking winners as often advanced may not apply to CHP-DH systems as a network-based infrastructure with its peculiarities.

Rather. government should provide the steering "coordination and control" (Barlow and Röber, 1996) role of policy strategies to influence direction, create regulation, and make available cheap sustainable finance considering the infancy phase of the CHP-DH industry as shown statistically in this research. This is not an uncommon approach to other network-based infrastructures. As the electricity and gas infrastructures benefited from states governance interventions after nationalisation in the late 1940s through the Gas Act and Electricity Acts of 1948 (Arapostathis et al., 2014, Winskel, 2002), before privatisation in the late eighties, guiding these infrastructures through the bridging phase before the current mass market phase of guaranteeing investment through regulation as we see today. While the LAs and other actors in the CHP-DH arena would engage in rowing "delivering and implementation "role. This is contrary to the traditional top-down "state-led" approach where the state does the steering and rowing, but rather a governance approach which captures the role of the state concentrating on steering powers (e.g. making ground rules) while leaving rowing (e.g. services provision) to other segments of the system or actor such as LAs (Jessop, 2001).

This form of governance is not new to other countries like the Netherlands with higher penetration of CHP-DH system than the UK and with similar energy market conditions with huge gas reserves. For instance, in 1982 Netherlands established National Investment Bank to militate against high interest rate and limited capital by offering finance at favourable rates without security or any risk assessment to projects like CHP (Blok, 1993, Hekkert et al., 2007). Furthermore, they've established a Heat Act to mandate a negotiated access to DH grids as oppose to regulated third party access and provide clarity and protection with regards tenancy roles in a heat supply contract (CMS, 2017).

Therefore, in the light of the discussion above, energy policy makers should not bunch CHP-DH systems with other energy technologies in the application/discussion of the current political economy of technological neutral policies, if CHP-DH systems are seen through the lenses of a network-based infrastructure that provides heat distribution services. Hence, I support the role of the state to advance targeted CHP-DH policies and national heat governance infrastructures if the government is seriously considering meeting its to 80% emission reduction by 2050 compared to 1990 levels.

References

AANENSEN, T. & FEDORYSHYN, N. 2014. District heating and cooling in Norway - Development in key sizes. *Statistics Norway,* https://www.ssb.no/en/energi-og-industri/artikler-og-publikasjoner/_attachment/184839?_ts=1475e7199a8.

ADE 2015. First council-owned energy supply company launched in Nottingham. *Association for Decentralised Energy,* http://www.theade.co.uk/first-council-owned-energy-supply-company-launched-in-nottingham_3455.html.

ALKEMADE, F., HEKKERT, M. P. & NEGRO, S. O. 2011. Transition policy and innovation policy: Friends or foes? *Environmental Innovation and Societal Transitions,* 1**,** 125-129.

ANDERSON, D., SWEENEY, D. & WILLIAMS, T. 1993. Statistics for Business and Economics. *Fifth Edition,* West Publishing Company, USA.

ANDERSSON, B. A. & JACOBSSON, S. 2000. Monitoring and assessing technology choice: the case of solar cells. *Energy Policy,* 28**,** 1037-1049.

APBENSON 2011. Investigation of the options available for setting up an Energy Services Company (ESCO). *http://www.apbenson.com/assets/Uploads/ESCO2.pdf*.

ARAPOSTATHIS, S., CARLSSON-HYSLOP, A., PEARSON, P. J. G., THORNTON, J., GRADILLAS, M., LACZAY, S. & WALLIS, S. 2013. Governing transitions: Cases and insights from two periods in the history of the UK gas industry. *Energy policy,* 52**,** 25-44.

ARAPOSTATHIS, S., PEARSON, P. J. G. & FOXON, T. J. 2014. UK natural gas system integration in the making, 1960–2010: Complexity, transitional uncertainties and uncertain transitions. *Environmental Innovation and Societal Transitions,* 11**,** 87-102.

ARES, E. 2013. Carbon Price floor. *www.parliament.uk/briefing-papers/sn05927.pdf,* House of commons library.

ARONSSON, B. & HELLMER, S. 2009. An International comparIson of dIstrIct heating markets. *Svensk Fjärrvärme AB,* ISBN 978-91-7381-042-5.

ARUP 2011b. Decentralised Energy Masterplanning - A manual for local authorities.

ATKINS, W. S. 1982. Combined Heat and Power District Heating Feasibility Programme: Stage 1. *Energy Paper Number 53*.

AUDIT SCOTLAND 2011. How councils work: an improvement series for councillors and officers -Arm's-length external organisations (ALEOs): are you getting it right? . *http://www.audit-scotland.gov.uk/docs/local/2011/nr_110616_aleos.pdf*.

BABUS'HAQ, R. F. & PROBERT, S. D. 1996. Combined heat-and-power implementation in the UK: Past, present and prospective developments. *Applied Energy,* 53**,** 47-76.

BAINBRIDGE, T. & ABRAHAMS, S. 2011. Developing "Licence Lite" How can local authorities become licensed suppliers of electricity? http://www.localgovernmentlawyer.co.uk/index.php?option=com_content&view=article&id=6582:developing-qlicence-liteq&catid=58:property-articles.

BALCOMBE, P., RIGBY, D. & AZAPAGIC, A. 2013. Motivations and barriers associated with adopting microgeneration energy technologies in the UK. *Renewable and Sustainable Energy Reviews,* 22**,** 655-666.

BALE, C., BUSH, R., HAWKEY, D. & WEBB, J. 2014. Valuation of passive provision for heat network investments. *Chapter 5,* Economic evaluation of systems of infrastructure provision: concepts, approaches, methods, iBUILD/Leeds Report.

BALE, C. S. E., FOXON, T. J., HANNON, M. J. & GALE, W. F. 2012. Strategic energy planning within local authorities in the UK: A study of the city of Leeds. *Energy Policy,* 48**,** 242-251.

BALZAT, M. & HANUSCH, H. 2004. Recent trends in the research on national innovation systems. *Journal of evolutionary economics,* 14**,** 197-210.

BARLOW, J. & RÖBER, M. 1996. Steering not rowing: Co-ordination and control in the management of public services in Britain and Germany. *International Journal of Public Sector Management,* 9**,** 73-89.

BARUCH, Y. & HOLTOM, B. C. 2008. Survey response rate levels and trends in organizational research. *Human Relations,* 61**,** 1139-1160.

BATTILANA, J., LECA, B. & BOXENBAUM, E. 2009. How actors change institutions: towards a theory of institutional entrepreneurship. *Academy of Management annals,* 3**,** 65-107.

BBC 2015. Nottingham City Council energy company claims UK first. *http://www.bbc.co.uk/news/uk-england-nottinghamshire-34171736*, British Broadcasting Corporation.

BCC 2011. Birmingham Sustainable Energy Action Plan. *http://www.bebirmingham.org.uk/uploads/Birmingham%20Sustainable%20Energy%20Action%20Plan%20SUBMITTED.pdf*, Birmingham City Council.

BECH, M. & KRISTENSEN, M. B. 2009. Differential response rates in postal and Web-based surveys in older respondents. *2009,* 3**,** 6.

BERG, B. L. 2009. Qualitative Research Methods for the social sciences. Seventh Edition.

BERGEK, A., HEKKERT, M. & JACOBSSON, S. 2008b. Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policy makers. *Innovation for a low carbon economy: economic, institutional and management approaches,* 79**,** pp. 79-112

BERGEK, A., HEKKERT, M., JACOBSSON, S., MARKARD, J., SANDÉN, B. & TRUFFER, B. 2015. Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. *Environmental Innovation and Societal Transitions,* 16**,** 51-64.

BERGEK, A., JACOBSSON, S., CARLSSON, B., LINDMARK, S. & RICKNE, A. 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research policy,* 37**,** 407-429.

BERGEK, A., JACOBSSON, S., CARLSSON, B., LINDMARK, S. & RICKNE, A. 2008d. Analyzing the Dynamics and Functionality of Technological Systems: A Manual.

BERGEK, A., JACOBSSON, S., HEKKERT, M. & SMITH, K. 2010. Functionality of innovation systems as a rationale for and guide to innovation policy. *The Theory and Practice of Innovation Policy. Edward Elgar, Cheltenham***,** 117-146.

BERKHOUT, F., SMITH, A. & STIRLING, A. 2004. Socio-technological regimes and transition contexts. *System innovation and the transition to sustainability: theory, evidence and policy. Edward Elgar, Cheltenham*, 48-75.

BERNARD, H. R. 2006. Research methods in antropology: Qualitative and Quantitative approaches. *Book,* 4th Edition, 1-821.

BERTOLDI, P., REZESSY, S. & VINE, E. 2006. Energy service companies in European countries: Current status and a strategy to foster their development. *Energy Policy,* 34, 1818-1832.

BEST, M. 2001. The new competitive advantage: the renewal of American industry. *OUP Catalogue*.

BEVIR, M. 2011. Governance as Theory, Practice and Dilemma. *Chapter 1,* The Sage Handbook of Governance, Pg. 1-16.

BIS/DECC 2009. The UK Low Carbon Industrial Strategy. http://www.berr.gov.uk/files/file52002.pdf.

BLACK, R. T. 2005. Doing Quantitaive Research in the Social Sciences - An integrated approach to research design, measurement and statistics. *Book,* Third Edition.

BLOK, K. 1993. The development of industrial CHP in the Netherlands. *Energy Policy,* 21, 158-175.

BOAIT, P. 2009. Energy Services and ESCos – their benefits and implications for regulation and the consumer *https://www.ofgem.gov.uk/ofgem-publications/52028/ofgem-rpi-x20-esco-paper-final.pdf*.

BOARDMAN, B., SARAH DARBY, KILLIP, G., HINNELLS, M., JARDINE, N. C., PALMER, J. & SINDEN, G. 2005. Chapter 5: Building fabric and housing stock. *40% House,* Environmental Change Institute, University of Oxford.

BOLTON, R. & FOXON, T. J. 2015. Infrastructure transformation as a socio-technical process — Implications for the governance of energy distribution networks in the UK. *Technological Forecasting and Social Change*.

BONILLA, D. 2006. *Energy Prices, Production and the Adoption of Cogeneration in the UK and the Netherlands*, University of Cambridge, Electricity Policy Research Group.

BOOTH, R. 2016. Tory bill could cost UK nearly 200,000 council houses, warns Labour. *http://www.theguardian.com/society/2016/jan/12/tory-bill-council-houses-labour*.

BOOTH, R. & CLARK, T. 2015. Council houses have been sold at 70% under their market value. *theguadian,* http://www.theguardian.com/society/2015/sep/11/council-houses-have-been-sold-at-70-under-their-market-value.

BÖRZEL, T. A. & RISSE, T. 2010. Governance without a state: Can it work? *Regulation & Governance,* 4, 113-134.

BOSCHMA, R. & FRENKEN, K. 2010. The spatial evolution of innovation networks. A proximity perspective. *The handbook of evolutionary economic geography,* Chapter 5, 120-135.

BOTTINI, N., COELHO, M. & KAO, J. 2013. Infrastructure and Growth. *LSE Growth Commission*.

BRAMAH, M. 2014. Can local authorities be energy utilities? *APSE Scotland Renewables and Energy Efficiency Advisory Group, 26 November 2014,* http://apse.org.uk/.

BRAND, M. & SVENDSEN, S. 2013. Renewable-based low-temperature district heating for existing buildings in various stages of refurbishment. *Energy,* 62**,** 311-319.

BRANNEN, J. 2005. Mixing methods: The entry of qualitative and quantitative approaches into the research process. *International Journal of Social Research Methodology,* 8**,** 173-184.

BRE 2003. The UK Potential for Community Heating with Combined Heat & Power. *http://www.chpa.co.uk/medialibrary/2011/05/18/7c424ada/BRE%20EST%20Potential%20Study%20-%202003.pdf*, Building Research Establishment Ltd.

BREEZE, P. 2005. Power Generation Technologies. *Newnes Publication*.

BREEZE, P. 2018. Piston Engine Based Power Plants. *Academic Press*.

BRESCHI, S. & MALERBA, F. 2005. Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries. *Book,* Systems of Innovation Technologies, Institutions and Organizations**,** 130 - 156.

BROUSSEAU, E. & RAYNAUD, E. 2006. The Economics of Private Institutions: an introduction to the dynamics of institutional frameworks and to the analysis of multilevel multi-type governance. *Available at SSRN 920225*.

BROWN, M. A. 2001. Market failures and barriers as a basis for clean energy policies. *Energy policy,* 29**,** 1197-1207.

BROWN, M. A. & CHANDLER, S. 2008. Governing confusion: how statutes, fiscal policy, and regulations impede clean energy technologies. *Stan. L. & Pol'y Rev.,* 19**,** 472.

BRYMAN, A. & CRAMER, D. 2011. Quantitative Data Analysis with IBM SPSS 17, 18 &19: A guide for social scientist. *1st Edition,* Routledge Taylor & Francis Group.

BUDDEN, R. J. R. CHP and the 1983 Energy Act. Electricity in the Paper and Board Industry, IEE Colloquium on, 28 Jan 1988 1988. 5/1-5/5.

BULKELEY, H., BROTO CASTÁN, V., HODSON, M. & MARVIN, S. 2011. Cities and the Low Carbon Transition. *http://www.salford.ac.uk/__data/assets/pdf_file/0011/318719/TEFR-Aug-Sep-2011-Cities-and-the-low-carbon-transition.pdf*.

BULKELEY, H., BROTO, V. C. & MAASSEN, A. 2014. Low-carbon Transitions and the Reconfiguration of Urban Infrastructure. *Urban Studies,* 51**,** 1471-1486.

BULKELEY, H. & KERN, K. 2006. Local government and the governing of climate change in Germany and the UK. *Urban Studies,* 43**,** 2237-2259.

CA 2016. District heating networks: Analysis of information request, January 2016. *https://www.citizensadvice.org.uk/Global/CitizensAdvice/Energy/District%20Heating%20Information%20Request%20-%20January%202016.pdf*, Citizens Advice, UK.

CAG, IPSOS MORI & BER 2011. Evaluation of the Community Energy Saving Programme: A report on the findings from the process and householder experience research streams.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48210/3342-evaluation-of-the-community-energy-saving-programm.pdf, Building Research Establishment.

CAITHNESS 2014. The Highland Council: Caithness Heat and Power Follow-up statutory report. http://www.audit-scotland.gov.uk/docs/local/2014/sr_140109_chap.pdf.

CALVANO, E. 2006. Destructive creation. SSE/EFI Working Paper Series in Economics and Finance.

CARBON TRUST 2010. Introducing combined heat and power. https://www.carbontrust.com/media/19529/ctv044_introducing_combined_heat_and_power.pdf.

CARBON TRUST 2012b. Local authorities - Saving energy in local authority buildings. http://www.carbontrust.com/media/196392/ctv028-local-authorities.pdf.

CARBON TRUST 2015. The Enhanced Capital Allowance scheme for energy-saving technologies. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/421006/ECA272_Capital_Allowance_v7_April_2015.pdf, Accessed on the 9th of September 2016.

CARBON TRUST 2016. CRC Energy Efficiency Scheme. https://www.carbontrust.com/resources/guides/carbon-footprinting-and-reporting/crc-carbon-reduction-commitment, Accessed on the 18th of August 2016.

CARBONNEL, A. D. 2016. Lead EU carbon policymaker calls for end to UK price floor to help steel. http://uk.reuters.com/article/us-eu-carbon-idUKKCN0X21MW.

CARLSSON, B. 1997. *Technological systems and industrial dynamics*, Springer Science & Business Media.

CARLSSON, B. 2006. Internationalization of innovation systems: A survey of the literature. *Research policy,* 35**,** 56-67.

CARLSSON, B. & JACOBSSON, S. 1994. Technological systems and economic policy: the diffusion of factory automation in Sweden. *Research Policy,* 23**,** 235-248.

CARLSSON, B., JACOBSSON, S., HOLMÉN, M. & RICKNE, A. 2002. Innovation systems: analytical and methodological issues. *Research policy,* 31**,** 233-245.

CARLSSON, B. & STANKIEWICZ, R. 1991. On the nature, function and composition of technological systems. *Journal of evolutionary economics,* 1**,** 93-118.

CCC 2016. Next steps for UK heat policy. *Committee on Climate Change,* https://www.theccc.org.uk/wp-content/uploads/2016/10/Next-steps-for-UK-heat-policy-Committee-on-Climate-Change-October-2016.pdf.

CCC/DECC/DEFRA 2015b. Policy paper: 2010 to 2015 government policy: energy demand reduction in industry, business and the public sector. https://www.gov.uk/government/publications/2010-to-2015-government-policy-energy-demand-reduction-in-industry-business-and-the-public-sector/2010-to-2015-government-policy-energy-demand-reduction-in-industry-business-and-the-public-sector#appendix-3-crc-energy-efficiency-scheme, Committee on Climate Change, Department for Energy and Climate Change, Department for Environment Food & Rural Affairs.

CHAO, H.-P., OREN, S. & WILSON, R. 2008. Chapter 1 - Reevaluation of Vertical Integration and Unbundling in Restructured Electricity Markets. *In:* SIOSHANSI, F. P. (ed.) *Competitive Electricity Markets.* Oxford: Elsevier.

CIBSE 2014. AM15 Biomass heating 2014. *Chartered Institution of Building Services Engineers, London*.

CLARKE, L., WEYANT, J. & BIRKY, A. 2006. On the sources of technological change: Assessing the evidence. *Energy Economics,* 28**,** 579-595.

CLASP 2011. Planning guidance for renewable energy: Produced for Lancashire County Council. *Climate Change Local Area Support Programme*.

CODE 2010. European Summary Report on CHP support schemes a comparison of 27 national support mechanisms. *http://www.code-project.eu/wp-content/uploads/2011/02/231210-European-Summary-Report-on-CHP-support-schemes.pdf*, Cogeneration Observatory and Dissemination Europe

COFELY 2016. Olympic Park & Stratford City District Energy. *http://www.cofely-gdfsuez.co.uk/solutions/district-energy/district-energy-schemes/olympic-park-stratford-city/*, Accessed on the 11th of May, 2016.

COGEN EUROPE 2013. What is cogeneration? *http://www.cogeneurope.eu/what-is-cogeneration_19.html*, The European Association for the Promotion of Cogeneration.

COHEN, J. 1992. A power primer. *Psychological bulletin,* 112**,** 155.

COHENDET, P. & UERENA, P. 2005. Learning, Technical Change, and Public Policy: How to Create and Exploit Diversity. *Book,* Systems of Innovation Technologies, Institutions and Organizations**,** 223-241.

COLE, S. T. 2005. Comparing Mail and Web-Based Survey Distribution Methods: Results of Surveys to Leisure Travel Retailers. *Journal of Travel Research,* 43**,** 422-430.

CONNOLLY, D., LUND, H., MATHIESEN, B. V., WERNER, S., MÖLLER, B., PERSSON, U., BOERMANS, T., TRIER, D., ØSTERGAARD, P. A. & NIELSEN, S. 2014. Heat Roadmap Europe: Combining district heating with heat savings to decarbonise the EU energy system. *Energy policy,* 65**,** 475-489.

CONNOR, P., BÜRGER, V., BEURSKENS, L., ERICSSON, K. & EGGER, C. 2013. Devising renewable heat policy: Overview of support options. *Energy policy,* 59**,** 3-16.

CONNOR, P. M., LEI, X. & THOMAS, R. 2015. The development of renewable heating policy in the United Kingdom. *Renewable Energy,* 75**,** 733-744.

COOK, C., HEATH, F. & THOMPSON, R. L. 2000. A meta-analysis of response rates in web-or internet-based surveys. *Educational and psychological measurement,* 60**,** 821-836.

COOKE, P., URANGA, M. G. & ETXEBARRIA, G. 1998. Regional systems of innovation: an evolutionary perspective *Environment and Planning* 30**,** 1563-1584.

CORNWALL, N. & LITTLECHILD, S. 2008. Offtake arrangements and market access for small-scale distributed energy generators. *A Report for Ofgem*.

CR 2017. Homes fit for ageing. *Care & Repair England is an independent charitable organisation*

CRAMTON, P. & OCKENFELS, A. 2011. Economics and design of capacity markets for the power sector. http://www.cramton.umd.edu/papers2010-2014/cramton-ockenfels-economics-and-design-of-capacity-markets.pdf.

CRES & ZREU 1999. Training Guide on Combined Heat and Power Systems. CRES - Centre for Renewable Energy Sources

ZREU - Zentrum fur ratioelle Energieanwendug undUmwelt GmbH.

CREWE, T. 2016. The strange death of municipal England. *London Review of Books,* Vol. 38**,** 6-10.

DALEY, E. M., MCDERMOTT, R. J., MCCORMACK BROWN, K. R. & KITTLESON, M. J. 2003. Conducting web-based survey research: a lesson in internet designs. *American Journal of Health Behavior,* 27**,** 116-124.

DARROW, K., TIDBALL, R., WANG, J. & HAMPSON, A. 2015. Catalog of CHP Technology - Section 4. Technology Characterization – Steam Turbines *U.S. Environmental Protection Agency - Combined Heat and Power Partnership* ICF International.

DARROW, K., TIDBALL, R., WANG, J. & HAMPSON, A. 2017. Catalog of CHP Technology. *U.S. Environmental Protection Agency - Combined Heat and Power Partnership* ICF International.

DAVIES, A. 1996. Innovation in large technical systems: the case of telecommunications. *Industrial and Corporate Change,* 5**,** 1143-1180.

DAVIES, E. 2013. Information Guide:-Trans-European Networks. *http://www.cardiff.ac.uk/insrv/resources/edc/Trans-European%20Networks.pdf,* Accessed on 30th August, 2016.

DAVIES, H. 2010. THE CHALLENGE OF REFURBISHING OUR EXISTING BUILDING STOCK. *Chartered Institution of Building Services Engineers, London*.

DBEIS 2016a. DIGEST OF UNITED KINGDOM ENERGY STATISTICS 2016. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/552060/DUKES_2016_FINAL.pdf,* Departmant of Business, Energy and Industrial Strategy, London.

DBEIS 2016b. Government Response to the Consultation on Amendment to the Contracts for Difference (CFD) (Allocation) Regulations (2014). *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/550415/CfD_Government_Response.pdf,* Department for Business, Energy & Industrial Strategy.

DCLG 2015a. Table 101: Dwelling stock: by tenure1, United Kingdom (historical series). *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/423173/LT_101.xls,* Department for Communities and Local Government.

DCLG 2015c. Historic Housing and Planning Bill will transform generation rent into generation buy. *press release,* https://www.gov.uk/government/news/historic-housing-and-planning-bill-will-transform-generation-rent-into-generation-buy**,** Departmant for Communities and Local Government.

DDD 2012. UK Bioenergy strategy. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48337/5142-*

bioenergy-strategy-.pdf, DEFRA/DECC/DoT, Department for Environment, Food and Rural Affairs/Department of Energy and Climate Change/Department of Transport.

DECC 2003. The U.K. Government Response to the Royal Commission on Environmental Pollution's Twenty-Second Report - Energy — The Changing Climate. *http://webarchive.nationalarchives.gov.uk/20110322143804/http://www.rcep.org.uk/reports/22-energy/2003-22response-UK.pdf*, Department of Energy and Climate Change.

DECC 2005. Digest of United Kingdom Energy Statistics. *Departmant of Energy and Climate Change, London*.

DECC 2006. Digest of United Kingdom Energy Statistics. *Departmant of Energy and Climate Change, London*.

DECC 2007. Digest of United Kingdom Energy Statistics. *Departmant of Energy and Climate Change, London*.

DECC 2009. National Renewable Energy Action Plan for the United Kingdom. *Departmant for Energy and Climate Change*.

DECC 2009b. Feed-in Tariffs Government's Response to the Summer 2009 Consultation. *http://webarchive.nationalarchives.gov.uk/20121217150421/http://decc.gov.uk/assets/decc/consultations/renewable%20electricity%20financial%20incentives/1_20100204120204_e_@@_fitsconsultationresponseandgovdecisions.pdf*, Department of Energy and Climate Change, London**,** 14.

DECC 2010a. Government response: Consultation on local authority power to sell electricity from renewables. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42525/361-gov-resp-local-auth-elec-cons.pdf*, Department of Energy and Climate Change, London.

DECC 2010d. Digest of United Kingdom Energy Statistics. *Departmant of Energy and Climate Change, London*.

DECC 2011. UK Renewable Energy Roadmap. *Departmant of Energy and Climate Change, London*.

DECC 2011a. Memorandum of Understanding: DECC and LG Group. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48040/1380-mou-lggroup-decc.pdf*, Department of Energy and Climate Change, London.

DECC 2011c. Planning our electric future:a White Paper for secure, affordable and low carbon electricity. *Departmant of Energy and Climate Change, London***,** Pg 27.

DECC 2011f. Renewable Heat Incentive Scheme: Q&A Index. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48237/1393-rhi-faqs.pdf*, Department of Energy and Climate Change, London.

DECC 2012. The Future of Heating: A strategic framework for low carbon heat in the UK. *Department of Energy and Climate Change,* Department of Energy and Climate Change, London.

DECC 2012c. Digest of United Kingdom Energy Statistics. *https://www.gov.uk/government/.../5949-dukes-2012-exc-cover.pdf*, Department of Energy and Climate Change, London.

DECC 2012d. Electricity market reform: policy overview. *Department of Energy and Climate Change, London*.

DECC 2012f. Government response to the consultation on proposals for the levels of banded support under the Renewables Obligation for the period 2013-17 and the Renewables Obligation Order 2012 *Departmant of Energy and Climate Change, London*.

DECC 2013a. The Future of Heating: Meeting the challenges. *Department of Energy and Climate Change, London*.

DECC 2013b. 60th Aniversary, DIGEST OF UNITED KINGDOM ENERGY STATISTICS, . *Departmant of Energy and Climate Change, London*.

DECC 2013i. Electricity Market Reform Delivery Plan. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/267668/EMR_Delivery_Plan_FINAL_FOR_PUBLICATION.pdf*, Department of Energy and Climate Change, London.

DECC 2013k. Digest of United Kingdom Energy Statistics. *Departmant of Energy and Climate Change, London*.

DECC 2013l. Domestic Renewable Heating Incentive: The first step to transforming the way we heat our homes. *Department of Energy and Climate Change,* Department of Energy and Climate Change, London.

DECC 2013m. TECHNICAL ANNEX TO SUPPORT THE CONSULTATION ON THE NON-DOMESTIC RHI EARLY TARIFF REVIEW. *Departmant of Energy and Climate Change, London*.

DECC 2014. Community Energy Strategy: Full Report. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/275169/20140126Community_Energy_Strategy.pdf*, Departmant of Energy and Climate Change, London.

DECC 2014b. Implementing the Offtaker of Last Resort. *Department of Energy and Climate Change, London*.

DECC 2014d. Gas and electricity prices in the non-domestic sector. *https://www.gov.uk/government/statistical-data-sets/gas-and-electricity-prices-in-the-non-domestic-sector*, Department of Energy and Climate Change, London.

DECC 2014e. DIGEST OF UNITED KINGDOM ENERGY STATISTICS. *Departmant of Energy and Climate Change, London*.

DECC 2014i. Infrastructure Bill: The Community Electricity Right - Policy Brief. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/381677/infrastructure_bill_policy_brief.pdf*, Department of Energy and Climate Change, London.

DECC 2014k. Implementing Electricity Market Reform (EMR) - Finalised policy positions for implementation of EMR. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/324176/Implementing_Electricity_Market_Reform.pdf*, Department of Energy and Climate Change, London.

DECC 2015b. Heat Networks Delivery Unit: - Round 5 : Overview. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/466130/HNDU_Round_5_-_Overview__Oct_2015.pdf*, Departmant of Energy and Climate Change, London.

DECC 2015c. DIGEST OF UNITED KINGDOM ENERGY STATISTICS 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/450302/DUKES_2015.pdf, Departmant of Energy and Climate Change, London.

DECC 2015g. DIGEST OF UNITED KINGDOM ENERGY STATISTICS 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/450302/DUKES_2015.pdf, Departmant of Energy and Climate Change, London.

DECC 2015i. Guidance: Participating in the EU ETS. https://www.gov.uk/guidance/participating-in-the-eu-ets, Accessed on the 14th of December, 2015.

DECC 2015k. Annual Fuel Poverty Statistics Report, 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/468011/Fuel_Poverty_Report_2015.pdf, Department of Energy and Climate Change.

DECC 2015n. How the UK supports the use of combined heat and power (CHP) or 'cogeneration', which avoids network losses and reduces emissions. https://www.gov.uk/guidance/combined-heat-and-power, Department of Energy and Climate Change, London.

DECC 2015p. Investing in the UK's heat infrastructure: Heat Networks. *Departmant of Energy and Climate Change, London*.

DECC 2015r. CFD Auction Allocation Round One - a breakdown of the outcome by technology, year and clearing price. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/407465/Breakdown_information_on_CFD_auctions.pdf, Department of Energy and Climate Change.

DECC 2015t. Smart Meters, Smart Data, Smart Growth. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/397291/2903086_DECC_cad_leaflet.pdf, Department of Energy and Climate Change.

DECC 2015u. Cutting the cost of keeping warm – a fuel poverty strategy for England. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/408644/cutting_the_cost_of_keeping_warm.pdf, Departmant for Energy and Climate Change.

DECC 2015v. CHP Outreach Workshops: Programme: Reducing Energy Costs with Combined Heat & Power. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/413032/Energy_Efficiency_Directive_Update.pdf, Department of Energy and Climate Change, London.

DECC 2016a. HEAT NETWORKS INVESTMENT PROJECT CONSULTATION: Capital funding for building heat networks. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/532483/HNIP_consultation_vFINAL.pdf, Department of Energy and Climate Change.

DECC 2016b. HNDU Round 6: Overview. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/513884/HNDU_overview_round6_April2016.pdf, Department of Energy and Climate Change.

DECC 2016c. Government Response to the March 2016 consultation on further reforms to the Capacity Market. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/521301/Govt_response_to_March_2016_consultation_FINAL.pdf, Department of Energy and Climate Change.

DEFRA 2004. The Government's Strategy for Combined Heat and Power to 2010. *Department for Environment, Food and Rural Affairs*.

DELOITTE 2015. European energy market reform. Country profile: Netherlands. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/gx-er-market-reform-netherlands.pdf.

DETR 2000. Climate Change: The UK Programme. http://www.cne-siar.gov.uk/emergencyplanning/documents/Climate%20Change%20-%20UK%20Programme.pdf, Department of the Environment, Transport and the Regions, UK.

DEVINE-WRIGHT, P., FLEMING, P. & CHADWICK, H. 2001. Role of social capital in advancing regional sustainable development. *Impact Assessment and Project Appraisal,* 19**,** 161-167.

DIAMANT, R. M. E. & MCGARRY, J. 1968. Space and District Heating. London Iliffe Books Limited.

DIEHL, P. & GAY, L. 1992. Research methods for business and management. *New York: McMillan*.

DODDS, P. E. & MCDOWALL, W. 2013. The future of the UK gas network. *Energy Policy,* 60**,** 305-316.

DOSI, G. & NELSON, R. R. 1994. An introduction to evolutionary theories in economics *Energy policy,* 4**,** 153-172.

DTI 2001. NEW & RENEWABLE ENERGY: Prospects for the 21st Century. http://www.uea.ac.uk/~e680/energy/energy_links/renewables_Obligation/Renew_OBligation.pdf, Department of trade and Industry, London.

DTI 2005. A Guide: Sale of power oppotunities for distributed generators PART B. http://webarchive.nationalarchives.gov.uk/20100919181607/http://www.ensg.gov.uk/assets/kel000620000partb.pdf, Department of Trade and Industry.

DTI 2007. A White Paper on Energy : MEETING THE ENERGY CHALLENGE. *Department of Trade and Industry, London*.

DTI/OFGEM 2007. Review of Distributed Generation. https://www.ofgem.gov.uk/ofgem.../review-distributed-generation.pdf, Department of Trade and Industry, Office of Gas and Electricity Markets

DUTTON, J. 2015. EU Energy Policy and the Third Package. *University of Exeter Energy Policy Group: EPG Working Paper: 1505*.

EA 2014. Guidance - Climate change agreements. https://www.gov.uk/guidance/climate-change-agreements--2, Environment Agency.

EC 2014b. Testing Social Policy Innovation. *Employment, Social Affairs and Inclusion,* European Commission.

EDELENBOS, J. 2005. Institutional implications of interactive governance: insights from Dutch practice. *Governance,* 18**,** 111-134.

EDF 2018. Value Added Tax and Climate Change Levy explained. https://www.edfenergy.com/sites/default/files/sme_vat_guide_1212.pdf.

EDQUIST, C. 1999. *Innovation policy: A systemic approach*, Tema, University.

EDQUIST, C. 2005. Systems of Innovation Approaches - Their Emergence and Characteristic. *Book,* Systems of Innovation Technologies, Institutions and Organizations**,** 1-35.

EDQUIST, C. & JOHNSON, B. 2005. Institutions and Organizations in Systems of Innovation. *Book,* Systems of Innovation Technologies, Institutions and Organizations**,** 41-85.

EDWARDS, P. J. & BOWEN, P. A. 1998. Risk and risk management in construction: a review and future directions for research. *Engineering, Construction and Architectural Management,* Vol. 5**,** pp. 339 - 349.

EEA 2008. Technology Characterisation: Reciprocal Engines. www.epa.gov/chp/documents/catalog_chptech_reciprocating_engines.pdf, Energy and Environmental Analysis.

EHRNBERG, E. & JACOBSSON, S. 2005. Technological Discontinuities and Incumbents' Performance: An Analytical Framework. *Book,* Systems of Innovation Technologies, Institutions and Organizations**,** 318-341.

ELM 2015. Removal of Climate Change Levy - Drax Power ltd V HM Treasury. *Environmental Law & Management,* 27.

ELZEN, B., GEELS, F. & GREEN, K. 2004a. Conclusion: Transitions to sustainable lessons learned and remaining challenges. *Book,* System Innovation and the Transition to Sustainability, Theory, Evidence and Policy.

ELZEN, B., GEELS, F. & GREEN, K. 2004b. System Innovation and the Transition to sustainability: Theory, Evidence and Policy. *Edward Elgar Publishing* Book.

EST 2004. Community heating – a guide. *Energy Saving Trust*.

EU 1986. THE SINGLE EUROPEAN ACT. http://www.eurotreaties.com/singleuropeanact.pdf, European Community.

EU 2001. EUROPEAN GOVERNANCE — A WHITE PAPER. *COM(2001) 428 final (2001/C 287/01),* European Union.

EU 2004. Promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC:DIRECTIVE 2004/8/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:052:0050:0060:EN:PDF, European Commission.

EU 2004a. Directive 2004/08/EC. *Official Journal of European Union,* 21.2.2004**,** 50-60.

EU 2006c. DIRECTIVE 2006/32/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0064:0085:EN:PDF, European Commission.

EU 2009a. DIRECTIVE 2009/28/EC_use of energy from renewable sources. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF, European Commission.

EU 2010a. Energy performance of buildings:DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF*, European Commission.

EU 2010c. Roadmap 2050. *http://www.roadmap2050.eu/project/roadmap-2050*, European Community.

EU 2011c. Energy 2020 - A strategy for competitive, sustainable and secure energy *https://ec.europa.eu/energy/sites/ener/files/documents/2011_energy2020_en_0.pdf*, European Union Commission.

EU 2012. Energy Efficiency DIRECTIVE 2012/27/EU. *http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1399375464230&uri=CELEX:32012L0027*.

EU 2014. Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy. *https://ec.europa.eu/energy/sites/ener/files/documents/2014_eec_communication_adopted_0.pdf*, European Union.

EURELECTRIC 2015. A reference model for european capacity markets. *http://www.eurelectric.org/media/169068/a_reference_model_for_european_capacity_markets-2015-030-0145-01-e.pdf*, Accessed by 08 August, 2016.

EVANS, J. R. & MATHUR, A. 2005. The value of online surveys. *Internet research,* 15**,** 195-219.

EWERTSSON, L. & INGELSTAM, L. 2004. Large technical systems: A multidisciplinary research tradition. *Systems Approaches and Their Application.* Springer.

FABRIZIO, B. 2013. European Energy Policy and the EU Road Map till 2050. *http://www.neurope.eu/article/european-energy-policy-and-eu-road-map-till-2050*.

FALKUS, M. E. 1967. The British Gas Industry before 1850. *The Economic History Review,* 20**,** 494-508.

FARLA, J., MARKARD, J., RAVEN, R. & COENEN, L. 2012. Sustainability transitions in the making: A closer look at actors, strategies and resources. *Technological forecasting and social change,* 79**,** 991-998.

FE 2015a. Future potential for DSR in GB. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/467024/rpt-frontier-DECC_DSR_phase_2_report-rev3-PDF-021015.pdf*, Frontier Economics.

FINGER, M., GROENEWEGEN, J. & KÜNNEKE, R. 2005. The quest for coherence between institutions and technologies in infrastructures. *Competition and Regulation in Network Industries,* 6**,** 227-259.

FITCH-ROY, W. O. & WOODMAN, B. 2016. Auctions for Renewable Support in the United Kingdom: Instruments and Lessons Learnt. *AURES Project,* http://auresproject.eu/files/media/documents/pdf_uk_rev1.pdf.

FOUQUET, R. 2010. The slow search for solutions: Lessons from historical energy transitions by sector and service. *Energy Policy,* 38**,** 6586-6596.

FOXON, T. J. 2007. The Rationale for Policy Interventions from an Innovation System Perspective. *Governing Technology for Sustainability,* Earthscan, London**,** pp: 129-147.

FOXON, T. J. 2011. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecological Economics,* 70**,** 2258-2267.

FOXON, T. J., GROSS, R., CHASE, A., HOWES, J., ARNALL, A. & ANDERSON, D. 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. *Energy policy,* 33**,** 2123-2137.

FOXON, T. J., PEARSON, P. J. & HAMMOND, G. P. 2008a. TRANSITION PATHWAYS TO A LOW CARBON ECONOMY WORKING PAPER 1 CONCEPTUAL & ANALYTICAL FRAMEWORK. 1-34.

FRANTZESKAKI, N. & LOORBACH, D. Infrastructures in transition role and response of infrastructures in societal transitions. 2008 First International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA), 10-12 Nov. 2008 2008. 1-8.

FREEMAN, C. 1995. The 'National System of Innovation' in historical perspective. *Cambridge Journal of Economics,* 19**,** 5-24.

FRITZ, C. O., MORRIS, P. E. & RICHLER, J. J. 2012. Effect size estimates: current use, calculations, and interpretation. *Journal of experimental psychology: General,* 141**,** 2.

GADLIN, H. 2000. The ombudsman: What's in a name? *Negotiation Journal,* 16**,** 37-48.

GAIL M. SULLIVAN & RICHARD FEINN 2012. Using Effect Size—or Why the P Value Is Not Enough. *Journal of Graduate Medical Education,* 4**,** 279-282.

GARSIDE, B. 2016. EU carbon prices expected to be €11.40 by 2020 -Point Carbon survey. *http://carbon-pulse.com/19474/*, Accessed on the 12th of July, 2016.

GEARTY, M. 2008. Southampton District Energy Scheme - A story of collaboration and steady ambition. A Learning History.

GEELS, F. 2004a. Understanding system innovations a critical literature review and a conceptual synthesis. *System innovation and the transition to sustainability: theory, evidence and policy. Edward Elgar, Cheltenham,* Chapter 2**,** pp. 19-47.

GEELS, F., ELZEN, B. & GREEN, K. 2004. General Introduction: System Innovation and Transition to sustainability. *Book,* System Innovation and the Transition to sustainability, Theory, Evidence and Policy.

GEELS, F. W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy,* 31**,** 1257-1274.

GEELS, F. W. 2011. The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions,* 1**,** 24-40.

GEELS, F. W., HEKKERT, M. P. & JACOBSSON, S. 2008. The dynamics of sustainable innovation journeys. *Technology Analysis & Strategic Management,* 20**,** 521-536.

GEELS, F. W. & SCHOT, J. 2007. Typology of sociotechnical transition pathways. *Research policy,* 36**,** 399-417.

GENON, G., TORCHIO, M. F., POGGIO, A. & POGGIO, M. 2009. Energy and environmental assessment of small district heating systems: Global and local effects in two case-studies. *Energy Conversion and Management,* 50**,** 522-529.

GENUS, A. & COLES, A.-M. 2008. Rethinking the multi-level perspective of technological transitions. *Research policy,* 37**,** 1436-1445.

GENUS, A. & NOR, M. A. M. 2007. Bridging the digital divide in Malaysia: An empirical analysis of technological transformation and implications for E-development. *Asia Pacific Business Review,* 13**,** 95-112.

GIB 2013. Funding Heat Networks http://www.heatandthecity.org.uk/__data/assets/pdf_file/0004/135355/Iain_Watson,_UK_Green_Investment_Bank.pdf, Vanguard conference.

GIB 2014a. A healthy saving: energy efficiency and the NHS. *Green Investment Bank*.

GIB 2015. District heating in smarter, greener cities A guide to commercial structuring and financing. http://www.greeninvestmentbank.com/media/118781/district-heating-finance-final-web.pdf, Green Investment Bank.

GIIKALP, I. 1992. On the analysis of large technical systems. *Science, Technology, & Human Values,* 17**,** 57-78.

GLA 2014. Investment & Performance Board (IPB) - Junior Electricity Supply Licence Update. http://www.london.gov.uk/moderngov/documents/s42098/Energy%20Supply%20Licence%20_Cover%20paper.pdf, Greater London Authority.

GLA 2014a. LONDON heat network manual. https://www.london.gov.uk/sites/default/files/LHNM_Manual2014Low.pdf, Greater London Authority.

GOLAFSHANI, N. 2003. Understanding reliability and validity in qualitative research. *The qualitative report,* 8**,** 597-606.

GOTH, J. 2010. Current thinking on District Heating. *EIBI: The Continuing Professional Development Programme,* Series 8.

GRANT THORNTON & PÖYRY 2015b. Independent evaluation of the Electricity Market Reform: Final Report to the Department of Energy and Climate Change.

GREEN, S. D. 2001. Towards an integrated script for risk and value management. *Project Management,* 7**,** 52-58.

GREENACRE, P., GROSS, R. & SPEIRS, J. 2012. Innovation theory: A review of the literature. *Imperial College Centre for Energy Policy and Technology, London*.

GRIFFITHS, A., HAIGH, N. & RASSIAS, J. 2007. A Framework for Understanding Institutional Governance Systems and Climate Change:: The Case of Australia. *European Management Journal,* 25**,** 415-427.

GRIFFITHS, A. & ZAMMUTO, R. F. 2005. Institutional governance systems and variations in national competitive advantage: An integrative framework. *Academy of Management Review,* 30**,** 823-842.

GROENEWEGEN, J. & STEEN, M. V. D. 2006. The Evolution of National Innovation Systems. *Journal of Economic Growth,,* 40**,** 277-285.

GROSS, R., BLYTH, W. & HEPTONSTALL, P. 2010. Risks, revenues and investment in electricity generation: Why policy needs to look beyond costs. *Energy Economics,* 32**,** 796-804.

GROVES, M. R., FOWLER, J. F. J., COUPER, P. M., LEPKOWSK, M. J., SINGER, E. & TOURANGEAU, R. 2009. Survey Methodology. *Book*.

GROVES, R. M. & PEYTCHEVA, E. 2008. The Impact of Nonresponse Rates on Nonresponse Bias: A Meta-Analysis. *The Public Opinion Quarterly,* 72**,** 167-189.

GRUBB, M. & NEWBERY, D. 2008. Pricing carbon for electricity generation: national and international dimensions *Chapter 11,* Delivering a Low Carbon Electricity System.

GUEST, G., BUNCE, A. & JOHNSON, L. 2006. How Many Interviews Are Enough?: An Experiment with Data Saturation and Variability. *Field Methods,* 18**,** 59-82.

GUNN, H. 2002. Web-based surveys: Changing the survey process. *First Monday,* 7.

GUY, S. & MARVIN, S. 2016. URBAN ENVIRONMENTAL FLOWS: TOWARDS A NEW WAY OF SEEING. *Urban Infrastructure in Transition: Networks, Buildings and Plans,* Chapter 2.

HAGHIFAM, M. R. & MANBACHI, M. 2011. Reliability and availability modelling of combined heat and power (CHP) systems. *International Journal of Electrical Power & Energy Systems,* 33**,** 385-393.

HALCOMB, E. J. & ANDREW, S. 2005. Triangulation as a method for contemporary nursing research. *Nurse Researcher (through 2013),* 13**,** 71.

HALL, S., FOXON, T. & BOLTON, R. The New Civic Energy Sector: implications for ownership, governance and financing of low carbon energy infrastructure. BIEE 10th Academic Conference, 2014.

HAMMOND, G. P. & PEARSON, P. J. G. 2013. Challenges of the transition to a low carbon, more electric future: From here to 2050. *Energy policy,* 52**,** 1-9.

HAMMOND, G. P. & WALDRON, R. 2008. Risk assessment of UK electricity supply in a rapidly evolving energy sector. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy,* 222**,** 623-642.

HANDLEY, D. 2013. Making CfDs work for renewable generators. *www.r-e-a.net/resources/.../GPAM_Presentation_by_David_Handley.pdf*.

HANNON, M. J., FOXON, T. J. & GALE, W. F. 2013. The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition. *Energy Policy,* 61**,** 1031-1045.

HATCHWELL, P. 2015. Green Investment Bank sell-off plan alarms gren business. *the ends report,* http://www.endsreport.com/article/48737/.

HAWKES, A. D. & LEACH, M. A. 2007. Cost-effective operating strategy for residential micro-combined heat and power. *Energy,* 32**,** 711-723.

HAWKES, A. D. & LEACH, M. A. 2008a. The capacity credit of micro-combined heat and power. *Energy policy,* 36**,** 1457-1469.

HAWKES, A. D. & LEACH, M. A. 2008b. On policy instruments for support of micro combined heat and power. *Energy policy,* 36**,** 2973-2982.

HAWKEY, D. 2014. District heating in the UK: Prospects for a third national programme. *Science & Technology Studies,* 27**,** 68-89.

HAWKEY, D. 2016. Implementation of District Heating Policy in the UK. *Chapter 5,* Sustainable Urban Energy Policy - Heat and the city**,** 91-109.

HAWKEY, D. 2016b. Implementation of District Heating Policy in the UK. *Chapter 5,* Sustainable Urban Energy Policy - Heat and the city**,** 91-109.

HAWKEY, D., TINGEY, M. & WEBB, J. 2014. Local Engagement in UK Energy Systems – a Pilot Study of Current Activities and Future Impact. *http://www.eti.co.uk/wp-content/uploads/2014/07/Edinburgh-Report-Version9.pdf*.

HAWKEY, D. & WEBB, J. 2016. Business Models for District Heating Networks. *Chapter 6: Power Capacity,* Sustainable Urban Energy Policy - Heat and the city**,** 114 - 135.

HAWKEY, D., WEBB, J. & WINSKEL, M. 2013. Organisation and governance of urban energy systems: district heating and cooling in the UK. *Journal of Cleaner Production,* 50**,** 22-31.

HAWKEY, D. J. C. 2009. *Will "District Heating Come to Town"? Analysis of Current Opportunities and Challenges in the UK.* Master Thesis, Environmental Sustainability School of Geosciences, University of Edinburgh.

HAWKEY, D. J. C. 2012. District heating in the UK: A Technological Innovation Systems analysis. *Environmental Innovation and Societal Transitions,* 5**,** 19-32.

HCA 2011. District Heating Good Practice: Learning from the Low Carbon Infrastructure Fund. *Homes and Communities Agency, UK,* file:///C:/Users/ag424/Downloads/district-heating-good-practice.pdf.

HEERWEGH, D., ABTS, K. & LOOSVELDT, G. Minimizing survey refusal and noncontact rates: do our efforts pay off. Survey Research Methods, 2007. European Survey Research Association, 3-10.

HEKKERT, M. P., HARMSEN, R. & DE JONG, A. 2007a. Explaining the rapid diffusion of Dutch cogeneration by innovation system functioning. *Energy Policy,* 35**,** 4677-4687.

HEKKERT, M. P. & NEGRO, S. O. 2009. Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. *Technological Forecasting and Social Change,* 76**,** 584-594.

HEKKERT, M. P., SUURS, R. A. A., NEGRO, S. O., KUHLMANN, S. & SMITS, R. E. H. M. 2007b. Functions of innovation systems: A new approach for analysing technological change. *Technological Forecasting and Social Change,* 74**,** 413-432.

HELLSMARK, H. 2010. *Unfolding the formative phase of gasified biomass in the European Union: The role of system builders in realising the potential of second-generation transportation fuels from biomass*, Chalmers University of Technology.

HELLSMARK, H. & JACOBSSON, S. 2009. Opportunities for and limits to Academics as System builders—The case of realizing the potential of gasified biomass in Austria. *Energy Policy,* 37**,** 5597-5611.

HELM, D. 2014a. What future for vertically integrated energy companies? *Energy Futures Network,* 5**,** http://www.dieterhelm.co.uk/energy/energy/what-future-for-vertically-integrated-energy-companies/.

HELM, D. 2014b. Electricity and energy prices. *Energy Futures Network Paper,* http://www.dieterhelm.co.uk/energy/energy/electricity-and-energy-prices/**,** Accessed on 3rd of August, 2016.

HELM, D. 2014c. The return of the CEGB? Britain's central buyer model. *Energy Futures Network Paper,* 4.

HENDRY, C., BROWN, J. & HARBORNE, P. 2008. Firms, markets and the fuel cell technology innovation system in an international perspective. *Book,* Chapter 5**,** 112-141.

HEY, C., JACOB, K. & VOLKERY, A. 2007. Better regulation by new governance hybrids? Governance models and the reform of European chemicals policy. *Journal of Cleaner production,* 15**,** 1859-1874.

HILLMAN, K., NILSSON, M., RICKNE, A. & MAGNUSSON, T. 2011. Fostering sustainable technologies: a framework for analysing the governance of innovation systems. *Science and Public Policy,* 38**,** 403-415.

HILLS, J. 2012. Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review.

HM GOVERNMENT 1989. Electricity Act 1989. *http://www.legislation.gov.uk/ukpga/1989/29/contents*.

HM GOVERNMENT 2010. 2050 Pathways Analysis. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/42562/216-2050-pathways-analysis-report.pdf*.

HM TREASURY 2015. Chancellor George Osborne's Summer Budget 2015 speech. *https://www.gov.uk/government/speeches/chancellor-george-osbornes-summer-budget-2015-speech*.

HMRC 2010. Carbon price floor: support and certainty for low-carbon investment. *Her Majesty's Revenue and Customs, UK*.

HMRC 2011a. Capital Allowances: Feed-in Tariffs and the Renewable Heat Incentive. *http://webarchive.nationalarchives.gov.uk/20140109143644/http://www.hmrc.gov.uk/tiin/tiin684.pdf*, HM Revenue and Customs.

HMRC 2014. Carbon price floor: reform and other technical amendments. *Her Majesty's Revenue and Customs, UK*.

HMRC 2016. VAT Notice 701/19: fuel and power. *HM Revenue and Customs, UK,* https://www.gov.uk/government/publications/vat-notice-70119-fuel-and-power/vat-notice-70119-fuel-and-power#gases.

HMRC 2016a. Policy paper - Climate Change Levy: main and reduced rates. *https://www.gov.uk/government/publications/climate-change-levy-main-and-reduced-rates/climate-change-levy-main-and-reduced-rates*, Her Majesty Revenue & Customs.

HOC 2013. Community Energy Saving Programme (CESP). *http://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN06197#fullreport*, Accessed on 5th of August 2016.

HOC 2014a. Local authorities: the General Power of Competence. *House of Commons Library*.

HOC 2014b. Local government in England: capital finance. *House of Commons Library*.

HOC 2015. Implementation of Electricity Market Reform. *Eighth Report of Session 2014–15,* http://www.publications.parliament.uk/pa/cm201415/cmselect/cmenergy/664/664.pdf.

HOOGHE, L. & MARKS, G. 2003. Unraveling the central state, but how? Types of multi-level governance. *American political science review,* 97**,** 233-243.

HOP 2017. Decarbonising the gas network. *PostNote,* Number 565.

HUGHES, T. P. 1987. The evolution of large technological systems. *The social construction of technological systems: New directions in the sociology and history of technology,* Eds: E. Bijer, T.B. Hughes, & T.J. Pinch**,** 51-82.

HUGHES, T. P. 1993. *Networks of power: electrification in Western society, 1880-1930*, JHU Press.

IAN, B. 2013. Aberdeen Heat and Power. *http://apse.org.uk/apse/assets/File/APSE%20Presentation%20-Ian%20Booth.pdf*.

IEA 2014a. Linking Heat and Electricity Systems. *http://www.iea.org/publications/freepublications/publication/LinkingHeatandElectricitySystems.pdf*, International Energy Agency.

IEA 2014c. HEATING WITHOUT GLOBAL WARMING - Market Developments and Policy Considerations for Renewable Heat *https://www.iea.org/publications/freepublications/publication/FeaturedInsight_HeatingWithoutGlobalWarming_FINAL.pdf*, International Energy Agency.

IEA 2014d. Energy Technology Perspective 2014: Electricity by the Numbers. *http://www.iea.org/media/etp/etp2014/ETP14_factsheets_electricitybynumbers.pdf*, International Energy Agency.

IEA 2016. World Energy Outlook - Executive Summary. *http://www.iea.org/publications/freepublications/publication/WorldEnergyOutlook2016ExecutiveSummaryEnglish.pdf*, International Energy Agency.

IET 2008. Combined Heat and Power. *http://www.theiet.org/factfiles/energy/combined-heat-page.cfm?type=pdf*, Institute of Energy and Technology, London.

IPPR 2014. A NEW POWERHOUSE FOR BRITAIN. *http://www.ippr.org/files/publications/pdf/city-energy_Jul2014.pdf?noredirect=1*, Institute for Public Policy Research, London.

ISLINGTON 2013. Bunhill Heat and Power case study. *http://www.isep.org.uk/wp-content/uploads/BUNHILL-case-study-2013.pdf*.

JACOBSSON, S. & BERGEK, A. 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and Corporate Change,* 13**,** 815-849.

JACOBSSON, S. & JOHNSON, A. 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy policy,* 28**,** 625-640.

JAFFE, A. B., NEWELL, R. G. & STAVINS, R. N. 2005. A tale of two market failures: Technology and environmental policy. *Ecological Economics,* 54**,** 164-174.

JAFFE, A. B. & STAVINS, R. N. 1994. The energy paradox and the diffusion of conservation technology. *Resource and Energy Economics,* 16**,** 91-122.

JAMASB, T., NUTTAL, W., POLLITT, M. & MARATOU, A. 2008. Technologies for a low-carbon electricity system: an assessment of the UK's issues and options. *Chapter 3,* Delivering a Low Carbon Electricity System: Technologies, Economics and Policy.

JARVIS, I. 1986. Can a successful city-wide CHP scheme be launched in the UK? *Energy policy,* 14**,** 160-163.

JESSOP, B. 1998. The rise of governance and the risks of failure: the case of economic development. *International social science journal,* 50**,** 29-45.

JESSOP, B. 2001. The Regulation Approach, Governance, and Post-Fordism: Alternative Perspectives on Economic and Political Change? *Regulation Theory and the Crisis of Capitalism: Developments and extensions,* 5**,** 420.

JICK, T. D. 1979. Mixing Qualitative and Quantitative Methods: Triangulation in Action. *Administrative Science Quarterly,* 24**,** 602-611.

JOERGES, B. 1988. *Large Technical Systems: Concepts and Issues,* Mayntz, Renate and Hughes, Thomas P, Frankfurt am Main: Campus Verlag.

JOHNSON, A. Functions in innovation system approaches. Documento presentado a la Conferencia Nelson-Winter. Aalborg: Dannish Research Unit for Industrial Dynamics (DRUID), 2001.

JOHNSON, C. 2014. District heating: a hot idea whose time has come. *theguardian,* https://www.theguardian.com/cities/2014/nov/18/district-heating-a-hot-idea-whose-time-has-come.

JOHNSON, R. B. & ONWUEGBUZIE, A. J. 2004. Mixed methods research: A research paradigm whose time has come. *Educational researcher,* 33**,** 14-26.

JOHNSTONE, N., HAŠČIČ, I. & POPP, D. 2010. Renewable energy policies and technological innovation: evidence based on patent counts. *Environmental and resource economics,* 45**,** 133-155.

JONSSON, D. K. 2005. The nature of infrasystem services. *Journal of infrastructure systems,* 11**,** 2-8.

JOSKOW, P. L. 2013. Symposium on 'Capacity Markets'. *http://www.faee.fr/files/file/aee/IAEE%20TOC/EEEP2013_2_editorial.pdf*.

JUHLER, H. 2013. Norway - District Heating. *Norwagian District Heating Association,* https://dbdh.dk/download/member_contries/NORWAY.pdf.

JULIAN, C. 2014. Creating Local Energy Economies: Lessons from Germany. *A Respublica Essay,* http://www.respublica.org.uk/wp-content/uploads/2015/01/creating-local-energy-economies-lessons-from-germany.pdf.

KAJORNBOON, A. B. 2005. Using interviews as research instruments. *E-journal for Research Teachers,* 2.

KAPLOWITZ, M. D., HADLOCK, T. D. & LEVINE, R. 2004. A Comparison of Web and Mail Survey Response Rates. *The Public Opinion Quarterly,* 68**,** 94-101.

KAVVADIAS, K. C., TOSIOS, A. P. & MAROULIS, Z. B. 2010. Design of a combined heating, cooling and power system: Sizing, operation strategy selection and parametric analysis. *Energy Conversion and Management,* 51**,** 833-845.

KEIRSTEAD, J. & SCHULZ, N. B. 2010. London and beyond: Taking a closer look at urban energy policy. *Energy Policy,* 38**,** 4870-4879.

KELLY, S. & POLLITT, M. 2009. Making Combined Heat and Power District Heating(CHP-DH) networks in the United Kingdom economically viable: a comparative approach *EPRG Working Paper 0925* Cambridge Working Paper in Economics 0945

KELLY, S. & POLLITT, M. 2010. An assessment of the present and future opportunities for combined heat and power with district heating (CHP-DH) in the United Kingdom. *Energy Policy,* 38**,** 6936-6945.

KELLY, S. & POLLITT, M. 2011. The Local Dimension of Energy *http://www.econ.cam.ac.uk/dae/repec/cam/pdf/cwpe1114.pdf*.

KEMP, R., SCHOT, J. & HOOGMA, R. 1998. Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management. *Technology analysis & strategic management,* 10**,** 175-198.

KEMPEGOWDA, R. S., SKREIBERG, Ø. & TRAN, K. Q. 2012. Techno-economic Evaluations of Various Biomass CHP Technologies and Policy Measures Under Norwegian Conditions. *Energy Procedia,* 20**,** 1-10.

KERN, F. 2015. Engaging with the politics, agency and structures in the technological innovation systems approach. *Environmental Innovation and Societal Transitions,* 16**,** 67-69.

KERSBERGEN, K. V. & WAARDEN, F. V. 2004. 'Governance'as a bridge between disciplines: Cross-disciplinary inspiration regarding shifts in governance and problems of governability, accountability and legitimacy. *European journal of political research,* 43**,** 143-171.

KIDDER, L. H. & FINE, M. 1987. Qualitative and quantitative methods: When stories converge. *New directions for program evaluation,* 1987**,** 57-75.

KING, M. 2016. Building Trust in Heat. *International Magazine on District Heating and Cooling***,** 12 - 13.

KING, S. P. 1998. Principles of price cap regulation. *Infrastructure Regulation and Market Reform: Principles and practice***,** pp: 46-54.

KINGSTON, C. & CABALLERO, G. 2009. Comparing theories of institutional change. *Journal of Institutional Economics,* 5**,** 151-180.

KITZING, L., MITCHELL, C. & MORTHORST, P. E. 2012. Renewable energy policies in Europe: Converging or diverging? *Energy Policy,* 51**,** 192-201.

KLEIN WOOLTHUIS, R., LANKHUIZEN, M. & GILSING, V. 2005. A system failure framework for innovation policy design. *Technovation,* 25**,** 609-619.

KLESSMANN, C., NABE, C. & BURGES, K. 2008. Pros and cons of exposing renewables to electricity market risks—A comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy,* 36**,** 3646-3661.

KLIJN, E.-H., BUUREN, V. A. & EDELENBOS, J. 2012. The Impact of Governance: A Normative and Emperical Discussion. *The Oxford handbook of Govenance,* Chapter 21.

KOTHARI, C. R. 2004. Research Methodology - Methods and Techniques. *Second revised edition*.

KPMG 2016. 2050 Energy Scenarios The UK Gas Networks role in a 2050 whole energy system.

KUKK, P., MOORS, E. & HEKKERT, M. 2015. The complexities in system building strategies—The case of personalized cancer medicines in England. *Technological Forecasting and Social Change,* 98**,** 47-59.

KÜNNEKE, R., GROENEWEGEN, J. & MÉNARD, C. 2010. Aligning modes of organization with technology: Critical transactions in the reform of infrastructures. *Journal of Economic Behavior & Organization,* 75**,** 494-505.

LAM, K. C., WANG, D., LEE, P. T. K. & TSANG, Y. T. 2007. Modelling risk allocation decision in construction contracts. *International Journal of Project Management,* 25**,** 485-493.

LANGSDORF, S. 2011. EU Energy Policy:From the ECSC to the Energy Roadmap 2050. *Green European Foundation,* http://gef.eu/uploads/media/History_of_EU_energy_policy.pdf.

LARSSON, R. 2006. *A comparative case study of non technical barriers for combined heat and power and district heating diffusion in Sweden and the United Kingdom.* MSc thesis. United Kingdom: Cranfield University at Silsoe.

LCP/FRONTIER 2015. What next for UK auctions of renewable Contracts for Difference? *https://www.frontier-economics.com/documents/2015/03/lcp-frontier-economics-next-uk-auctions-renewable-contracts-difference.pdf*.

LE GRAND, J. 1991. The Theory of Government Failure. *British Journal of Political Science,* 21**,** 423-442.

LEHTONEN, M. & NYE, S. 2009. History of electricity network control and distributed generation in the UK and Western Denmark. *Energy Policy,* 37**,** 2338-2345.

LEMON, M., POLLITT, M. G. & STEER, S. J. 2013. Local Energy Policy and Managing Low Carbon Transition: The Case of Leicester. Faculty of Economics, University of Cambridge.

LEP 2007. Making ESCOs Work: Guidance and Advice on Setting Up & Delivering an ESCO. *http://www.lep.org.uk/uploads/lep_making_escos_work.pdf,* London Energy Partnership.

LEVI-FAUR, D. 2012. From "BIG GOVERNMENT" TO BIG GOVERNANCE"? *The Oxford handbook of Govenance,* Chapter 1**,** Oxford University Press.

LGA 2013. 400,000 homes with planning permission still waiting to be built *http://www.local.gov.uk/media-releases/-/journal_content/56/10180/4107631/NEWS,* Local Government Association.

LGA 2013b. The General Power of Competence Empowering Councils to make a difference. *http://www.local.gov.uk/c/document_library/get_file?uuid=83fe251c-d96e-44e0-ab41-224bb0cdcf0e&groupId=10180*, Local Government Association.

LGA 2013e. Municipal bonds a step closer to reality. *http://www.local.gov.uk/media-releases/-/journal_content/56/10180/5706251/NEWS*, Local Government Association.

LGA 2014a. Project team appointed to prepare Bonds Agency. *LGA press release,* http://www.local.gov.uk/media-releases/-/journal_content/56/10180/6507616/NEWS.

LGA 2014b. Polling on resident satisfaction with councils. *http://www.local.gov.uk/documents/10180/11981/January+2014+Resident+Satisfaction+Polling+-+Final+Report.pdf/75ae9b61-2826-468c-a73f-616b926cc330*, Local Government Association.

LGA 2015. LGA membership. *http://www.local.gov.uk/membership*, visited on the 13/11/15.

LINDBLOM, C. E. 2002. *The market system: What it is, how it works, and what to make of it*, Yale University Press.

LIPP, J. 2007. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. *Energy policy,* 35**,** 5481-5495.

LOORBACH, D., FRANTZESKAKI, N. & THISSEN, W. 2010. Introduction to the special section: Infrastructures and transitions. *Technological Forecasting and Social Change,* 77**,** 1195-1202.

LUCIA, U. 2014. Overview on fuel cells. *Renewable and Sustainable Energy Reviews,* 30**,** 164-169.

LUNDVALL, B.-A. 2007. Innovation System Research, Where it came from and Where it might go. *www.globelics.org*, 1.

LUNDVALL, B.-Å. 1998. Why study national systems and national styles of innovation? *Technology Analysis & Strategic Management,* 10**,** 403-422.

MACDONALD, S. & HEADLAM, N. 2011. Research Methods Handbook - Introductory guide to research methods for social research. *The Centre for Local Economic Strategies (CLES),* http://www.cles.org.uk/wp-content/uploads/2011/01/Research-Methods-Handbook.pdf.

MAGNUSSON, D. 2012. Swedish district heating—A system in stagnation: Current and future trends in the district heating sector. *Energy Policy,* 48**,** 449-459.

MALERBA, F. 2002. Sectoral systems of innovation and production. *Research Policy,* 31**,** 247-264.

MALERBA, F. 2005. Sectoral systems of innovation: a framework for linking innovation to the knowledge base, structure and dynamics of sectors. *Economics of innovation and New Technology,* 14**,** 63-82.

MANDERS, I. & GROTH, T. 2016. The PipeCo: an alternate approach to financing heat networks. *https://www.carbontrust.com/news/2016/02/pipeco-alternate-approach-to-financing-heat-networks/*.

MARINO, A., BERTOLDI, P., REZESSY, S. & BOZA-KISS, B. 2011. A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. *Energy Policy,* 39**,** 6190-6198.

MARKARD, J. 2011. Transformation of Infrastructures: Sector Characteristics and Implications for Fundamental Change. *Journal of Infrastructure Systems,* 17.

MARKARD, J., HEKKERT, M. & JACOBSSON, S. 2015. The technological innovation systems framework: Response to six criticisms. *Environmental Innovation and Societal Transitions,* 16**,** 76-86.

MARKARD, J., MUSIOLIK, J. & WORCH, H. System resources in emerging technological fields: Insights from resource-based reasoning for innovation and transition studies. 2nd International Conference on Sustainability Transitions, Lund, 2011.

MARKARD, J. & TRUFFER, B. 2006. Innovation processes in large technical systems: Market liberalization as a driver for radical change? *Research Policy,* 35**,** 609-625.

MARKARD, J. & TRUFFER, B. 2008a. Actor-oriented analysis of innovation systems: exploring micro–meso level linkages in the case of stationary fuel cells. *Technology Analysis & Strategic Management,* 20**,** 443-464.

MARKARD, J. & TRUFFER, B. 2008b. Technological innovation systems and the multi-level perspective: Towards an integrated framework. *Research policy,* 37**,** 596-615.

MARSHALL, W. 1977. District heating combined with electricity generation in the United Kingdom. *District Heating Working Party of the Combined Heat and Power Group,* Energy Paper Number 20.

MARTIN, M. & THORNLEY, P. 2013. The potential for thermal storage to reduce the overall carbon emissions from district heating systems. *Tyndall Working Paper 157.*

MASKELL, P. 1996. Localised low-tech learning in the furniture industry. *Danish research unit for industrial dynamics,* Druid Working Paper No. 96-11.

MATHISON, S. 1988. Why Triangulate? *Educational Researcher,* 17**,** 13-17.

MATHUR, G., JUGDEV, K. & SHING FUNG, T. 2013. Project management assets and project management performance outcomes: Exploratory factor analysis. *Management Research Review,* 36**,** 112-135.

MAYNTZ, R. & HUGHES, T. P. 1988. *The development of large technical systems*, Frankfurt am Main: Campus Verlag.

MCGLADE, C., PYE, S., WATSON, J., BRADSHAW, M. & EKINS, P. 2016. The future role of natural gas in the UK. *REF UKERC/RR/RV/2016/01,* UK Energy Research Centre (UKERC).

MCWILLIAMS, B. & ZILBERMANFR, D. 1996. Time Of Technology Adoption And Learning By Using. *Economics of Innovation and New Technology,* 4**,** 139-154.

MEHTA, R. & SIVADAS, E. 1995. Comparing responses rates and response content in mail versus electronic mail surveys. *Journal of the Market Research society,* 37**,** 429-440.

MEKHILEF, S., SAIDUR, R. & SAFARI, A. 2012. Comparative study of different fuel cell technologies. *Renewable and Sustainable Energy Reviews,* 16**,** 981-989.

MENDONÇA, M. 2007. Feed-in Tariffs: Accelerating the deployment of renewable energy. *World Future Council,* Earthscan UK.

MENDONÇA, M. 2011. The UK Feed-in Tariff: A User Survey. *Birkbeck Institute of Environment, Birkbeck College, University of London*.

METCALFE, J. S. 1995. Technology systems and technology policy in an evolutionary framework. *Cambridge Journal of Economics,* 19**,** 25-46.

METCALFE, J. S. 1997. Science policy and technology policy in a competitive economy. *International Journal of Social Economics,* 24**,** 723-740.

MILES, B. M. & HUBERMAN, A. M. 1994. Qualitative data analysis: an expanded sourcebook. *Second Edition*.

MILLS, A. 2001. A systematic approach to risk management for construction. *Structural Survey,* Vol. 19**,** pp. 245 - 252.

MISA, T. J. 1994. Retrieving sociotechnical change from technological determinism. *Does technology drive history***,** 115-141.

MITCHELL, C. 2008. The Politcal Economy of Sustainable Energy. *Palgrave Macmillan*.

MITCHELL, C. 2014. Change and Inertia in the UK Energy System–getting our institutions and governance right. EPG working paper 1403.

MITCHELL, C. & CONNOR, P. 2004. Renewable energy policy in the UK 1990–2003. *Energy policy,* 32**,** 1935-1947.

MITCHELL, C., FROGGATT, A. & HOGGETT, R. 2014. Governance and disruptive energy system change. *International Workshop on Incumbent – Challenger Interactions in Energy Transitions,* Session 1 Incumbent – Challenger – Interactions.

MORGADO, D. 2014. Energy Service Companies and Financing. *https://www.iea.org/media/training/presentations/latinamerica2014/8A_Energy_Service_Companies_and_Financing.pdf*.

MUSIOLIK, J., MARKARD, J. & HEKKERT, M. 2012. Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. *Technological Forecasting and Social Change,* 79**,** 1032-1048.

NEGRO, S. O., ALKEMADE, F. & HEKKERT, M. P. 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. *Renewable and Sustainable Energy Reviews,* 16**,** 3836-3846.

NELSON, R. R. & SIDNEY, G. W. 1982. An evolutionary theory of economic changeter. *THE BELKNAP PRESS OF HARVARD UNIVERSITY PRESS***,** 929-964.

NEUHOFF, K. & TWOMEY, P. 2008. Will the market choose the right technologies? *Chapter 10,* Delivering a Low Carbon Electricity System: Technologies, Economics and Policy.

NEWBERY, D. 2015. Missing Money and Missing Markets: Reliability, Capacity Auctions and Interconnectors. *EPRG Working Paper 1508,* Cambridge Working Paper in Economics 1513.

NEWBERY, D. & GRUBB, M. 2014. The Final Hurdle?: Security of supply, the Capacity Mechanism and the role of interconnectors. *EPRG Working Paper 1412,* Cambridge Working Paper in Economics 1433.

NEWTON, K. & VAN DETH, J. 2010. Foundations of comparative Politics. *Book,* Cambridge University Press, New York.

NG 2015a. Provisional Auction Results: T-4 Capacity Market Auction for 2019/20. *https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/2015%20T-4%20Capacity%20Market%20Provisional%20Results.pdf,* National Grid, UK.

NG 2015d. Final Auction Results: T-4 Capacity Market Auction 2014. *https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/T-4%202014%20Final%20Auction%20Results%20Report.pdf,* National Grid, UK.

NG 2016a. NG-EMR. *http://investors.nationalgrid.com/~/media/Files/N/National-Grid-IR/EMR%2016-05-17_v2.pdf,* National Grid, UK.

NG 2017b. 2017 Electricity Ten Year Statement. *National Grid, UK,* https://www.nationalgrid.com/sites/default/files/documents/ETYS%202017.pdf.

NHS 2010. Saving Carbon, Improving health. *Sustainable Development Unit*.

NIELSEN, K. & PEDERSEN, O. K. 1988. The Negotiated Economy: Ideal and History. *Scandinavian Political Studies,* 11**,** 79-102.

NILSSON, M., HILLMAN, K. & MAGNUSSON, T. 2012. How do we govern sustainable innovations? Mapping patterns of governance for biofuels and hybrid-electric vehicle technologies. *Environmental Innovation and Societal Transitions,* 3**,** 50-66.

NILSSON, M., RICKNE, A., KOKKO, A. & VIRGIN, I. 2007. Sustainable Innovation Governance. *www.sei-international.org/.../Bilaga_A_Forskningsprogramme_Sustainab...* Bilaga A. Forskningsprogram.

NOORDERMEER, J. 2000. Cogeneration/CHP Principles: An overview and iintroduction to the principles of cogenerations with typical cycle and applications. *Gryphon International Engineering Services,* www.gryphoneng.com.

NORRIS, P. 2011. Measuring Governance *Chapter 12,* The Sage Handbook of Governance**,** SAGE Publications Limited.

NORTH, D. C. 1990. *Institutions, institutional change and economic performance*, Cambridge university press.

OECD 1997. National Innovation Systems. *http://www.oecd.org/science/inno/2101733.pdf,* Organisation for Economic Co-operation and Development.

OECD 2005a. Governance of Innovation Systems. *VOLUME 1: SYNTHESIS REPORT,* ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT.

OFFE, C. 2009. Governance: An "empty signifier"? *Constellations,* 16**,** 550-562.

OFGEM 2008a. Distributed Energy - Further Proposals for More Flexible Market and Licensing Arrangements. *https://www.ofgem.gov.uk/sites/default/files/docs/2008/06/de-june-con-doc---final.pdf,* Office of Gas and Electricity Market, London.

OFGEM 2008b. Energy Supply Probe - Initial Findings Report. *https://www.ofgem.gov.uk/ofgem-publications/38437/energy-supply-probe-initial-findings-report.pdf*, Office of Gas and Electricity Market, London.

OFGEM 2009a. Project Discovery Energy Market Scenarios - Consultation. *Office of Gas and Electricity Market, London*.

OFGEM 2009b. Regulating Energy Networks for the Future: RPI-X@20 History of Energy Network Regulation. *Office of Gas and Electricity Market, London,* https://www.ofgem.gov.uk/ofgem-publications/51984/supporting-paper-history-energy-network-regulation-finalpdf.

OFGEM 2010a. Low Carbon Network Fund. *https://www.ofgem.gov.uk/ofgem-publications/64028/lcnbro.pdf*, Office of Gas and Electricity Market.

OFGEM 2010b. RIIO: A new way to regulate energy netwrks. *Office of Gas and Electricity Market, London*.

OFGEM 2010c. Handbook for implementing the RIIO model. *Office of Gas and Electricity Market, London*.

OFGEM 2013c. Electricity Capacity Assessment Report 2013. *https://www.ofgem.gov.uk/ofgem-publications/75232/electricity-capacity-assessment-report-2013.pdf*, Office of Gas and Electricity Market.

OFGEM 2013h. Community Energy Saving Programme Update. *https://www.ofgem.gov.uk/sites/default/files/docs/2013/05/cesp-update-6_final-300413_0.pdf*, Office of Gas and Electricity Market.

OFGEM 2013i. Eletricity Network Innovation Competition Governance Document. *https://www.ofgem.gov.uk/ofgem-publications/53526/spnic.pdf*, Office of Gas and Electricity Market.

OFGEM 2014. State of competition in the energy market assessment. https://www.ofgem.gov.uk/gas/retail-market/market-review-and-reform/state-competition-energy-market-assessment.

OFGEM 2014f. Wholesale Power Market Liquidity: Interim Report. *https://www.ofgem.gov.uk/ofgem-publications/92181/liquidityinterimreport2014.pdf*, Office of Gas and Electricity Market, London.

OFGEM 2015a. Treatment of white label providers in the domestic retail market. *https://www.ofgem.gov.uk/sites/default/files/docs/2015/06/wl_decision_document_v10_-_web.pdf_03.06_0.pdf*, Office of Gas and Electricity Market, London.

OFGEM 2015b. Non-Domestic Renewable Heat Incentive scheme (RHI). *https://www.ofgem.gov.uk/sites/default/files/docs/2015/10/guidance_volume_1_v5_publish_0.pdf*, Office of Gas and Electricity Market, London

OFGEM 2015f. Energy Companies Obligation Final Report. *https://www.ofgem.gov.uk/sites/default/files/docs/2015/09/eco_final_report_0.pdf*, Office of Gas and Electricity Market, London.

OFGEM 2015g. RIIO-TI Gas Transmission Price Control –Regulatory Instructions and Guidance: Version 2.2. *Office of Gas and Electricity Market, London*.

OFGEM 2016a. Social outcomes, bills and quality of service - Households in fuel poverty (UK): At-a-glance summary. https://www.ofgem.gov.uk/about-us/how-we-work/promoting-sustainability/sustainability-reporting, Accessed on the 3rd of August, 2016.

OFGEM 2016b. Wholesale Energy Markets in 2016. https://www.ofgem.gov.uk/system/files/docs/2016/08/wholesale_energy_markets_in_2016.pdf, Accessed on the 8th October, 2016.

OFGEM 2016a. Non-Domestic Renewable Heat Incentive (RHI) Quaterly Report, April 2016. https://www.ofgem.gov.uk/system/files/docs/2016/04/ndrhiquarterly_april2016.pdf, Accessed on the 13th of July, 2016.

OFGEM 2016b. Renewable Obligation Annual Report 2014-15. https://www.ofgem.gov.uk/system/files/docs/2016/03/renewables_obligation_annual_report_2014-15.pdf, Office of Gas and Electricity Market.

OFGEM 2016d. Domestic Renewable Heat Incentive (RHI) Quaterly Report. https://www.ofgem.gov.uk/system/files/docs/2016/05/drhiquarterly_report_issue8.pdf, Accessed on the 13th of July, 2016.

OFGEM 2016f. About the ECO scheme. https://www.ofgem.gov.uk/environmental-programmes/eco/about-eco-scheme, Office of Gas and Electricity Market, London.

OFGEM 2017b. State of the energy market - 2017 Report. https://www.ofgem.gov.uk/system/files/docs/2017/10/state_of_the_market_report_2017_web_1.pdf, Office of Gas and Electricity Market, London.

OKAY, N. & AKMAN, U. 2010. Analysis of ESCO activities using country indicators. *Renewable and Sustainable Energy Reviews,* 14**,** 2760-2771.

OLAND, C. B. 2004. Guide to Combined Heat and Power Systems for Boiler Owners and Operators. *Prepared for the U.S. Department of Energy Industrial Technologies Program* ORNL/TM-2004/144

ONSITESYCOM 1999. Review of Combined Heat and Power Technologies. *California Energy Commission with US Department of Energy,* http://www.distributed-generation.com/library/chp.pdf.

ONWUEGBUZIE, A. J. & LEECH, N. L. 2007. Validity and qualitative research: An oxymoron? *Quality & Quantity,* 41**,** 233-249.

ORCHARDS, W. 2013. A review of methodologies analysing electricity and heat production from Combined Heat and Power, CHP, and their signals to heat and electricity sectors. Cross subsidy of electricity sector by heat sector. *Paper presented at the International Association for Energy Economics,* http://www.orchardpartners.co.uk/Docs/IAEEpaper&HeatNetworkDirectiveProposal.pdf.

OSBORNE, D. 1993. Reinventing government. *Public Productivity & Management Review***,** 349-356.

ØSTERGAARD, D. S. & SVENDSEN, S. 2016. Replacing critical radiators to increase the potential to use low-temperature district heating – A case study of 4 Danish single-family houses from the 1930s. *Energy,* 110**,** 75-84.

OXERA 2007. Reform of the Renewables Obligation: What is the likely impact of changes? http://webarchive.nationalarchives.gov.uk/+/http://www.berr.gov.uk/files/file39039.pdf, Oxford Energy Research Associattes.

OXERA 2014. CfD auctions, bidding strategies, and insights from auction theory. *Oxera Agenda,* http://www.oxera.com/getmedia/166f8509-c106-4825-ae23-e9c4cfcca6bd/CfD-auctions,-bidding-strategies,-and-insights-from-auction-theory.pdf.aspx?ext=.pdf.

PARKER, L. 1992. Collecting data the e-mail way. *Training & Development,* 46**,** 52-55.

PATEL, P. & PAVITT, K. 1994. National Innovation Systems: Why They Are Important, And How They Might Be Measured And Compared. *Economics of Innovation and New Technology,* 3**,** 77-95.

PATRONEN, J., KAURA, E. & TORVESTAD, C. 2017. Nordic heating and cooling:- Nordic approach to EU's Heating and Cooling Strategy. *http://norden.diva-portal.org/smash/get/diva2:1098961/FULLTEXT01.pdf*.

PEALER, L. N., WEILER, R. M., PIGG, R. M., MILLER, D. & DORMAN, S. M. 2001. The Feasibility of a Web-Based Surveillance System to Collect Health Risk Behavior Data from College Students. *Health Education & Behavior,* 28**,** 547-559.

PEARSON, P. & WATSON, J. 2012. UK Energy Policy 1980 - 2010: A history and lessons to be learnt. *The Institute of Enegineering and Technology/Parliamentary Group for Energy Studies, London*.

PERSSON, U. & WERNER, S. 2011. Heat distribution and the future competitiveness of district heating. *Applied Energy,* 88**,** 568-576.

PETERS, G. B. 2012. Governance as Political Theory. *The Oxford handbook of Govenance,* Chapter 2**,** Oxford University Press.

PETERS, G. B. 2012b. Information and Governing: Cybernetic Models of Governance. *The Oxford handbook of Govenance,* Chapter 8**,** Book.

PETERS, M., FUDGE, S. & WADE, J. 2011. Local authority perspectives on energy governance and delivery in the UK: a thematic assessment of enabling and restricting factors. *http://www.surrey.ac.uk/ces/files/pdf/01-13_Peters_Fudge_Wade_LocalAuthorityPrespectives.pdf*.

PINDYCK, R. S. & RUBINFELD, D. L. 2001. Microeconomics, 8th.

POLLITT, C. & TALBOT, C. 2004. Unbundled Government, A critical analysis of the global trend to agencies, quangos and concractualisation. Routledge, London and New York.

POLLITT, M. 2002. The economics of trust, norms and networks. *Business ethics: a European review,* 11**,** 119-128.

POLLITT, M. 2008. The future of electricity (and gas) regulation in a low-carbon policy world. *The Energy Journal,* 29**,** 63-94.

PÖYRY 2009. The Potential and Costs of District Heating Networks. *http://www.ecolateral.org/distributedheatpoyyre0409.pdf*.

PRAETORIUS, B., SAUTER, R. & WATSON, J. 2008. On dynamics of microgeneration diffusion in Germany and the UK. *Innovation for a low carbon economy: economic, institutional and management approaches,* Chapter 6, **,** pp 142- 175.

PX 2010. Project TransmiT - Response to call for evidence. *https://www.ofgem.gov.uk/ofgem-publications/54210/pxlimited.pdf*.

RAO, K. U. & KISHORE, V. V. N. 2010. A review of technology diffusion models with special reference to renewable energy technologies. *Renewable and Sustainable Energy Reviews,* 14**,** 1070-1078.

RCEP 2000. Energy - The Changing Climate. *http://www.rcep.org.uk*, Royal Commission on Environmental Pollution.

REZAIE, B. & ROSEN, M. A. 2012. District heating and cooling: Review of technology and potential enhancements. *Applied Energy,* 93**,** 2-10.

RHODES, R. A. 1997. *Understanding governance: policy networks, governance, reflexivity and accountability*, Open University Press.

RHODES, R. A. 2007. Understanding governance: Ten years on. *Organization studies,* 28**,** 1243-1264.

RHODES, R. A. 2012. Waves of Governance. *The Oxford handbook of Govenance,* P. 33-48**,** Oxfor University Press.

RICARDO-AEA 2013. Projections of CHP capacity and use to 2030. *Report to DECC*.

RICARDO-AEA 2014. Bespoke Gas CHP Policy– Cost curves and Analysis of Impacts on Deployment.

RICARDO-E&E 2015. National Comprehensive Assessment of the Potential for Combined Heat and Power and District Heating and Cooling in the UK. *https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/499417/Final_NCA_Report_for_publication.pdf*.

RIP, A. & KEMP, R. 1998. *Technological Change. In: Rayner S., Malone EL (editors)*, Battelle Press.

RISSE, T. 2012. Governance in areas of limited statehood. *The Oxford handbook of Govenance,* Chapter 49.

RITCHIE, J., LEWIS, J. & ELAM, G. 2003. Designing and Selecting Samples *1st Edition,* QUALITATIVE RESEARCH PRACTICE: A Guide for Social Science Students and Researchers.

RITCHIE, J. & SPENCER, L. 2002. Qualitative Data Analysis for Applied Policy Resaerch. *The Qualitative Researchers Companion,* Chapter 9**,** pp. 305-329.

ROBERTS, P., PRIEST, H. & TRAYNOR, M. 2006. Reliability and validity in research. *Nursing Standard (through 2013),* 20**,** 41.

ROBSON, C. 2002. *Real world research,* Book, Oxford: Blackwell.

ROBSON, C. 2011. *Real world research*, John Wiley & Sons.

ROELICH, K., SCHMEIDER, T., STEINBERGER, J. & KNOERI, C. 2013. The role of governance in accelerating transition towards more integrated, service-oriented infrastructure operation. *White Rose Research Online URL for this paper:http://eprints.whiterose.ac.uk/76697/*, Accessed on the 20th of March, 2016.

ROGERS, E. M. 2010. *Diffusion of innovations*, Simon and Schuster.

ROSE, N. 1996. Governing “advanced” liberal democracies. *The Anthropology of the State: a reader***,** 144-162.

ROTMANS, J., KEMP, R. & VAN ASSELT, M. 2001. More evolution than revolution: transition management in public policy. *foresight,* 3**,** 15-31.

ROWE, M. P. 1995. Options, functions, and skills: What an organizational ombudsman might want to know. *Negotiation Journal,* 11**,** 103-114.

RTPI 2013. Delivering Large Scale Housing: Unlocking Schemes and Sites to Help Meet the UK's Housing Needs. *http://rtpi.org.uk/media/630969/RTPI%20large%20scale%20housing%20report.pdf*.

RÜDIG, W. 1986. Energy conservation and electricity utilities A comparative analysis of organizational obstacles to CHP/DH. *Energy policy,* 14**,** 104-116.

RUSSELL, S. 1993. Writing energy history: explaining the neglect of CHP/DH in Britain. *The British Journal for the History of Science,* 26**,** 33-54.

RUSSELL, S. 2010. Background Paper: CHP and DH to the mid-1990s http://www.heatandthecity.org.uk/__data/assets/pdf_file/0004/62419/HatC_history_paper_SR.pdf.

SABATIER, P. A. 1988. An advocacy coalition framework of policy change and the role of policy-oriented learning therein, Policy Science 129 - 168.

SAVIOTTI, P. P. 2005. Innovation Systems and Evolutionary Theories. *Book,* Systems of Innovation Technologies, Institutions and Organizations**,** 180 - 199.

SCHOLL, N., MULDERS, S. & DRENT, R. 2002. On-line qualitative market research: interviewing the world at a fingertip. *Qualitative Market Research: An International Journal,* 5**,** 210-223.

SCHOT, J. 1998. The usefulness of evolutionary models for explaining innovation. The case of the Netherlands in the nineteenth century. *History and Technology, an International Journal,* 14**,** 173-200.

SCHOUTEN, B., COBBEN, F. & BETHLEHEM, J. 2009. Indicators for the representativeness of survey response. *Survey Methodology,* 35**,** 101-113.

SCHRANK, A. & WHITFORD, J. 2011. The Anatomy of Network Failure*. *Sociological Theory,* 29**,** 151-177.

SCHUMPETER, J. A. 1934. *The theory of economic development: An inquiry into profits, capital, credit, interest, and the business cycle*, Transaction publishers.

SHAHNAZ, A. 2013. Economic and Environmental Benefits of CHP-based District Heating Systems in Sweden. *Linköping Studies in Science and Technology Dissertation* 1524.

SHANE, S., LOCKE, E. A. & COLLINS, C. J. 2003. Entrepreneurial motivation. *Human resource management review,* 13**,** 257-279.

SHARAF, O. Z. & ORHAN, M. F. 2014. An overview of fuel cell technology: Fundamentals and applications. *Renewable and Sustainable Energy Reviews,* 32**,** 810-853.

SHEEHAN, K. B. & MCMILLAN, S. J. 1999. Response variation in e-mail surveys: An exploration. *Journal of advertising research,* 39**,** 45-54.

SIEVERS, J., STADLER, I. & SCHMID, J. 2005. Analysis of CHP designs and boundary conditions in different European countries *DESIRE Project*.

SILLS, S. J. & SONG, C. 2002. Innovations in survey research an application of web-based surveys. *Social science computer review,* 20**,** 22-30.

SIMKINS, G. 2015. Drax challenges end of climate change levy renewables exemption. *http://www.endsreport.com/index.cfm?go=49611,* Accessed 3rd of September, 2015.

SIMMONDS, G. 2000. THE UK GAS INDUSTRY 2000/2001 *INDUSTRY BRIEF* Center for the study of regulated industries - University of Bath.

SIMONDS, V. & HALL, B. 2013. Overcoming grid connection issues for community energy projects for Co-operatives UK and the Co-operative group *Cornwall Energy*.

SMITH, A., VOß, J.-P. & GRIN, J. 2010. Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. *Research policy,* 39**,** 435-448.

SMITH, K. 2000. Innovation as a systemic phenomenon: rethinking the role of policy. *Enterprise and innovation management studies,* 1**,** 73-102.

SMITH, K. 2005b. Economic Infrastructure and Innovation Systems. *Science Technology and The International Politcal Economy,* Book**,** pp: 86- 106.

SÖDERHOLM, P. & WÅRELL, L. 2011. Market opening and third party access in district heating networks. *Energy Policy,* 39**,** 742-752.

SØRENSEN, E. V. A. & TORFING, J. 2009. MAKING GOVERNANCE NETWORKS EFFECTIVE AND DEMOCRATIC THROUGH METAGOVERNANCE. *Public Administration,* 87**,** 234-258.

SOROYE, K. & NILSSON, L. 2010. Building a business to close the efficiency gap: the Swedish ESCO Experience. *Energy Efficiency,* 3**,** 237-256.

SORRELL, S. 2007. The economics of energy service contracts. *Energy Policy,* 35**,** 507-521.

STACE, G. 2013. Why the Carbon Floor Price Tax should be scrapped. *http://www.businessgreen.com/bg/opinion/2303740/why-the-carbon-price-support-tax-should-be-scrapped*.

STAR, S. L. 1999. The ethnography of infrastructure. *American behavioral scientist,* 43**,** 377-391.

STOKER, G. 1998. Governance as theory: five propositions. *International social science journal,* 50**,** 17-28.

STRECKIENĖ, G., MARTINAITIS, V., ANDERSEN, A. N. & KATZ, J. 2009. Feasibility of CHP-plants with thermal stores in the German spot market. *Applied Energy,* 86**,** 2308-2316.

STREECK, W. 1991. On the institutional conditions of diversified quality production. *Beyond Keynesianism***,** 21-61.

SWM 2014. Implementing steps to large scale district heating. *West Midlands Local Authoirty Low Carbon Economy Programme,* Final Version.

TAKI, Y., BABUS'HAQ, R. F. & PROBERT, D. 1993. A cogeneration-district-heating scheme for Leicester city, UK. *Energy,* 18**,** 687-698.

TCPA 2006. Using the 'Merton Rule'. *Report of a TCPA survey of local authority planning departments in England, July 2006,* http://www.rudi.net/files/paper/optional_file/using_merton_rule.pdf.

TEISMAN, G. R. & EDELENBOS, J. 2004. Getting through the 'twilight zone' managing transitions through process-based, horizontal and interactive governance. *Book: System innovation and the transition to sustainability: theory, evidence and policy.* **,** pg 168 - 190.

TEISMAN, G. R. & KLIJN, E. H. 2002. Partnership arrangements: governmental rhetoric or governance scheme? *Public administration review,* 62**,** 197-205.

TIETENBERG, H. T. 1976. Energy planning ad policy. *Book*.

TINGEY, M., HAWKEY, D. & WEBB, J. 2016. Assessing Local Government Engagement In Energy Systems Development In The UK And Its Likely Trajectories. *Chapter 8,* Sustainable Urban Energy Policy - Heat and the city**,** 157-178.

TOKE, D. & FRAGAKI, A. 2008. Do liberalised electricity markets help or hinder CHP and district heating? The case of the UK. *Energy Policy,* 36**,** 1448-1456.

TORCHIO, M. F., GENON, G., POGGIO, A. & POGGIO, M. 2009. Merging of energy and environmental analyses for district heating systems. *Energy,* 34**,** 220-227.

TORFING, J. 2012. Governance Networks. *The Oxford handbook of Govenance,* Chapter 7**,** Oxford University Press.

TOVEY, K. N. 2005. Developments in the Electricity Markets in the UK: the move towards BETTA.

TROUTEAUD, A. R. 2004. How you ask counts a test of internet-related components of response rates to a web-based survey. *Social Science Computer Review,* 22**,** 385-392.

UK LEGISLATION 2014. The Heat Network (Metering and Billing) Regulations http://www.legislation.gov.uk/uksi/2014/3120/pdfs/uksi_20143120_en.pdf.

UKDMO 2015. Public Works Loan Board: Annual Report and Accounts 2014-2015. *http://www.dmo.gov.uk/documentview.aspx?docname=publications/annualreports/pwlbrep2015.pdf&page=Annual_Report,* United Kingdom Debt Management Office.

UNEP 2015. DISTRICT ENERGY IN CITIES: Unlocking the Potential of Energy Efficiency and Renewable Energy. *http://www.uncclearn.org/sites/default/files/inventory/unep04032015_1.pdf,* United Nations Environment Programme.

UNRUH, G. C. 2000. Understanding carbon lock-in. *Energy policy,* 28**,** 817-830.

UNRUH, G. C. 2002. Escaping carbon lock-in. *Energy policy,* 30**,** 317-325.

VAN DE VEN, H. A. 1996. Central Problems in the Management of Innovations. *Management Science,,* 32**,** 590-607.

VAN DER VLEUTEN, E. 2004. Infrastructures and societal change. A view from the large technical systems field. *Technology Analysis & Strategic Management,* 16**,** 395-414.

VAN MIERLO, B., LEEUWIS, C., SMITS, R. & WOOLTHUIS, R. K. 2010. Learning towards system innovation: Evaluating a systemic instrument. *Technological Forecasting and Social Change,* 77**,** 318-334.

VERBONG, G. & GEELS, F. 2007. The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy policy,* 35**,** 1025-1037.

VINE, NAKAGAMI, H. & MURAKOSHI, C. 1999. The evolution of the US energy service company (ESCO) industry: from ESCO to Super ESCO. *Energy,* 24**,** 479-492.

VINE, E. 2005. An international survey of the energy service company (ESCO) industry. *Energy Policy,* 33**,** 691-704.

VITAL ENERGI 2014. Vital Energi Finish 13th on the Fastest 50 list. *newsletter,* https://www.vitalenergi.co.uk/blog/vital-energi-finish-13th-on-the-fastest-50-list/.

VOIGT, S. 2004. Constitutional Political Economy. *In:* ROWLEY, C. & SCHNEIDER, F. (eds.) *The Encyclopedia of Public Choice.* Springer US.

WAARDEN, F. V. 2012. The Governance of Markets: On Generating Trust in Transaction. *The Oxford handbook of Governance,* Chapter 25**,** Oxford University Press.

WARD, S. & CHAPMAN, C. 2003. Transforming project risk management into project uncertainty management. *International Journal of Project Management,* 21**,** 97-105.

WB 2007. STRENGTHENING WORLD BANK GROUP ENGAGEMENT ON GOVERNANCE AND ANTICORRUPTION. *World Bank*.

WEBB, J. 2014. Evaluating Urban Energy Systems in the UK–the Implications for Financing Heat Networks. *Science & Technology Studies,* 28.

WEBB, J. 2016a. Urban Energy Governance For Sustainable Heat in UK Cities: Expectations, practices and potential. *Chapter 7,* Sustainable Urban Energy Policy - Heat and the city**,** 137 - 156.

WEBB, J., HAWKEY, D. & TINGEY, M. 2016b. Governing cities for sustainable energy: The UK case. *Cities,* 54**,** 28-35.

WEBBER, C. 2010. TAX INCREMENT FINANCING *Centre for Cities,* http://www.centreforcities.org/wp-content/uploads/2014/09/10-10-25-Tax-Increment-Financing-announcement.pdf.

WEBER, K. M. & ROHRACHER, H. 2012. Legitimizing research, technology and innovation policies for transformative change. *Research policy,* 41**,** 1037-1047.

WERNER, S. & DHCAN 2004. DISTRICT HEATING SYSTEM INSTITUTIONAL GUIDE. *http://projects.bre.co.uk/DHCAN/pdf/InstititionalManage.pdf,* DHCAN Project team.

WESTIN, P. & LAGERGREN, F. 2002. Re-regulating district heating in Sweden. *Energy policy,* 30**,** 583-596.

WG 2018. Information about the end of the Right to Buy & Right to Acquire in Wales - Information for Council and Housing Association Tenants. *Welsh Government,* http://gov.wales/docs/desh/publications/180223-rtb-information-for-tenants-en.pdf.

WHICH? 2015. Turning up the heat:Getting a fair deal for District Heating users. http://www.businessgreen.com/digital_assets/8740/Which_District_Heat_Report__PDF_VERSION_FINAL.pdf, Which Report.

WILLIAMS, J. 2010. The deployment of decentralised energy systems as part of the housing growth programme in the UK. *Energy Policy,* 38**,** 7604-7613.

WILLIAMSON, O. E. 2000. The New Institutional Economics: Taking Stock, Looking Ahead. *Journal of Economic Literature,* 38**,** 595-613.

WINSKEL, M. 2002. When Systems are Overthrown: TheDash for Gas' in the British Electricity Supply Industry. *Social Studies of Science,* 32**,** 563-598.

WINSKEL, M. 2016. From Optimisation to Diversity - Changing scenarios of heating for buildings inthe UK. *Chapter 4,* Sustainable Urban Energy Policy - Heat and the city**,** 68-89

WINSKEL, M., MARKUSSON, N., JEFFREY, H., CANDELISE, C., DUTTON, G., HOWARTH, P., JABLONSKI, S., KALYVAS, C. & WARD, D. 2012. Learning pathways for energy supply technologies: Bridging between innovation studies and learning rates. *Technological Forecasting and Social Change, Elsevier*.

WOOD, G. & DOW, S. 2011. What lessons have been learned in reforming the Renewables Obligation? An analysis of internal and external failures in UK renewable energy policy. *Energy Policy,* 39**,** 2228-2244.

WOODMAN, B. & BAKER, P. 2008. Regulatory frameworks for decentralised energy. *Energy Policy,* 36**,** 4527-4531.

WOODMAN, B. & MITCHELL, C. 2011. Learning from experience? The development of the Renewables Obligation in England and Wales 2002–2010. *Energy Policy,* 39**,** 3914-3921.

WORRALL, L., COLLINGE, C. & BILL, T. 1998. Managing strategy in local government. *International Journal of Public Sector Management,* 11**,** 472-493.

WRAP 2016. Rural Community Energy Fund. http://www.wrap.org.uk/content/rural-community-energy-fund, Waste and Resources Action Programme.

YIN, K. R. 2003. Case study research and design and method. *Book,* Sage Publications.

Appendices

Appendix 1

#	ACTORS/INSTITUTIONS	CODE FORMAT	POST ON INTERVIEWEE
1	CHPDH OPERATOR	CDHOP1	Manager
2		CDHOP2	Engineering Manager
3		CDHOP3	Energy and Compliance assistant
4		CDHOP4	Energy and Environment Manager
5		CDHOP5	Head of Engineering Services
6		CDHOP6	Head of Operations
7		CDHOP7	Technical Engineering manager
8		CDHOP8	Business Development Engineering Manager
9		CDHOP9	Energy Manger
10		CDHOP10	Director of Estates & Facilities
11		CDHOP11	Estates Officer (Contract Support)
12		CDHOP12	Head of Energy & Sustainability
13		CDHOP13	Head of Energy Services
14		CDHOP14	Energy Master planner
15		CDHOP15	Energy Projects & Programmes Team Leader
16		CDHOP16	Energy Projects & Programmes Team Leader
17		CDHOP17	Head of Energy & Sustainability
18		CDHOP18	Sustainability and Low Carbon Manager
19	CHP DEVELOPER	CDHDEV1	Accounts manager
20		CDHDEV2	Sector Manager
21		CDHDEV3	Supply Chain Development and Policy Analysis
22		CDHDEV4	Building Services & Design Director
23		CDHDEV5	Regional Director, Building Engineering
24		CDHDEV6	Director
25	LOCAL AUTHORITIES	LA1	Principal Mechanical, Electrical & Energy Engineer
26		LA2	Lead Officer (Climate Change & Zero Waste)
27		LA3	Project Manager
28		LA4	Sustainable Energy Officer
29		LA5	Team Leader - Sustainable Development & Energy
30		LA6	Energy Manager
31		LA7	Energy Manager
32		LA8	Environmental Policy Manager
33		LA9	Environment and Climate Change Strategic Advisor
34		LAPLAN1	Major projects officer
35		LAPLAN2	Senior Sustainability Officer/Planning officer
36	CONSULTANTS	CTNT1	Manager
37		CTNT2	Energy Manager
38		CTNT3	Manager - Bioenergy & Thermal
39	EQUIPMENT SUPPLIER	EQPSUP	Regional Manager UK
40	ELECTRICITY TRADER	ELECTSUP	Sales Manager Renewables
41	ASSOCIATIONS	ASSO1	Policy Manager (Consultant)
42		ASSO2	Advisor - Climate Local
43	GOVERNMENT	GOVT1	Policy Officer
44		GOVT2	Business Operations Manager
45	REGULATOR	REG1	Head of distribution Policy
46	DH PIPE SUPPLIER	DHP1	UK Sales manager
47		DHP2	Account Manager UK & Ireland
48		DHP3	Business Team Manager - Renewable Energy
49	DISTRIBUTION NETWORK OPERATOR	DNO1	Contract Administrator, Power System Commercial
50		DNO2	Innovation and Low Carbon Networks Engineer

Direct Interviews (blue)
Responded via emails (yellow: rows 16–18 and 49)

Appendix 2 - CHPDH Operators

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Combined Heat and Power and District Heating Systems: Barriers and stimulants to growth in the UK

Thank you very much for taking out time to participate in this survey

BACKGROUND TO SURVEY

In response to new challenges facing the energy sector globally, such as increase in global energy demand, energy resource depletion and the impact of energy on the environment, the UK Government has set targets and timelines to overcome some of these challenges by reflecting on new pathways in redrawing its energy policies. The dominant pathway has been decarbonisation while ensuring energy security and affordability to achieve 80% greenhouse gas emission by 2050. In recognising that about a third of its greenhouse gas emissions come from heating, the consideration of how heat is produced, distributed and consumed is now a major discuss.
The unique advantage of the simultaneous generation of electricity and heat from array of sources by Combined Heat and Power (CHP) and District Heat networks (DH) ability to distribute heat also from array of sources has awakened the debate of the potential contribution of Combined Heat and Power on District heating systems in achieving the long term goal of the energy policy.

WHY THE SURVEY

The underlining concern of CHPs contributing about 21% of its potential to electricity consumption, while only 2% of the total heat consumption of heat in the UK is from Heat networks is the focus of this research. This survey seeks to investigate the factors that have shaped the low penetration of CHP-DH systems in the UK drawing on existing governance arrangements with a view to advance options that would increase its penetration, create competition and ultimately affect energy price as it's obtained in other network industries like gas or electricity. The results are in pursuant of an academic target and to inform the research community.

WHY YOU

In recognition of your contribution as a key participant in the chain of actors in the CHP-DH industry that will impact on the development of CHP-DH systems in the UK, you have been invited to kindly participate in this survey.

MY CONTACT INFORMATION

I can be reached through my contact details below:

Tony Granville
PhD Researcher,
Renewable Energy Department,
College of Engineering, Mathematics and Physical Sciences,
University of Exeter,Tremough Campus,
Penryn, Cornwall,
TR10 9FE
http://emps.exeter.ac.uk/renewable-energy/
Email:ag424@exeter.ac.uk
Tel: 07831893361

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Consent Page

Confidentiality

Your response to this survey will be held in confidence. They will not be used other than for the purpose described below and third parties will not be allowed access to them (except as may be required by law). Your data will be held in accordance with Data Protection Act.
The Purpose of this consent page is obtain your consent to precipitate in the survey to be taken and subsequently to be used by the University of Exeter ("University") in a number of media, including printed publication, exhibition boards, the intranet/web (e.g. University web pages, YouTube) and/or via social media (e.g. Twitter, Facebook, Instagram), to further and promote the work of the University in, for example the following ways:

- **through the sharing of results and recommendations arising from the Project;**
- **as research and teaching material by the University and its students during and after the Project; and/or**
- **as public engagement material, i.e. to showcase the types of research and engagement activities the University carries out**

And in turn, the University offers a commitment to review unedited material to allow it to be used appropriately and sensitively, as well as ensuring that any confidential material or opinion, which you indicate as being confidential at the time of the survey, is only shared for the purpose with your permission.

Anonymity

The questionnaire data will be held and used on an anonymous basis, with no mention of your name, but we will refer to the group of which you are member.

Consent

I voluntary agree to participate in this survey and the use of my data or opinion for the purpose specified above. I can withdraw consent at any time by contacting the researcher

Please click next to agree and proceed to the survey

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Perceived Risk Factors

1. The implementation of CHP-DH in the UK is characterised by a variety of risk factors. In your consideration please scale the under listed perceived risk factors according to their level of seriousness that would hamper investment decisions

	Extremely Serious	Very Serious	Slightly Serious	Less Serious	Not Serious	No Opinion	N/A
Policy uncertainty	○	○	○	○	○	○	○
Absence of State capital incentive	○	○	○	○	○	○	○
Lack of local authority incentive	○	○	○	○	○	○	○
Absence of regulatory regime for heat	○	○	○	○	○	○	○
Absence of a heat market in the UK	○	○	○	○	○	○	○
Electricity off-take risk	○	○	○	○	○	○	○
Heat off-take risk	○	○	○	○	○	○	○
Developmental/Connection to electricity grid risk	○	○	○	○	○	○	○
Potential for change in the taxation regime	○	○	○	○	○	○	○
Tradition of private provision of public goods	○	○	○	○	○	○	○
Level of public opposition to project	○	○	○	○	○	○	○
Land acquisition and compensation	○	○	○	○	○	○	○
Availability of finance							○
Financial attraction of project to investors	○	○	○	○	○	○	○

	Extremely Serious	Very Serious	Slightly Serious	Less Serious	Not Serious	No Opinion	N/A
Cost of Finance	◯	◯	◯	◯	◯	◯	◯
Delay in planning permission	◯	◯	◯	◯	◯	◯	◯
Planning permission risk	◯	◯	◯	◯	◯	◯	◯
Unavailability of CHP-DH construction Skills	◯	◯	◯	◯	◯	◯	◯
Construction time & cost overrun	◯	◯	◯	◯	◯	◯	◯
Operation cost overrun and revenue expectation	◯	◯	◯	◯	◯	◯	◯
Local authority experience in Public Private Partnership/Public Finance Initiative	◯	◯	◯	◯	◯	◯	◯

Any comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

CHP-DH Operations

2. How many sites of operation does your company have

☐

3. What is the capacity of your CHP in operation…..

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
<5MWe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6-10MWe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11-50MWe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
51-100MWe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
>100MWe	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4. What is the capacity of your heat network operation

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
<5MWth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6-10MWth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11-50MWth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
51-100MWth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
>100MWth	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

5. What is the mode of operation of your CHP plant.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Heat Led	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Electricity Led	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Standby	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Other (please comment)

6. How do you trade the electricity from CHPs?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Consolidator	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bilateral	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Direct supplier	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Onsite	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Other (please comment)

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

CHP-DH Operations

7. What is the length of your heat network

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
<1KM	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
2-5KM	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
6-10KM	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
11-20KM	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
>20KM	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

8. What are your class of heat consumers

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Domestic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Industry	☐	☐	☐		☐	☐	☐	☐	☐	☐
☐ Commercial	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Mixed	☐	☐	☐		☐	☐	☐	☐	☐	☐
☐ No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Other (please comment)

9. Do you have thermal storage in your CHP-DH system?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Yes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

10. If yes what size is the thermal storage?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
<10m3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
10-50m3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
51-100m3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
101-200m3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
>200m3	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

11. What type of thermal storage technology is deployed?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Sensible (Water)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Sensible (Underground)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Latent (PCM)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Thermochemical	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Other (please commment)

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

12. Do you have an absorption chiller for cooling effect in your operations?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Yes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

13. If yes above what type of absorption chiller is deployed

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Direct fired	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
In-Direct fired	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Bespoke	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

14. CHP's in your system participate in ancillary service provision to the electricity grid

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Yes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

15. If you do above. What type of ancillary services?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Short Term Operating Reserve (STOR)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Frequency response Services	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Black start	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Reactive power services	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Other (please comment)

16. What nature of electricity distribution is adopted in distributing electricity from CHP

- ○ Only on Private network
- ○ Only on Public network
- ○ Mostly on Private Network
- ○ Mostly on Public Network
- ○ Mostly Hybrid of both
- ○ No answer

Comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

17. If some or all of your electricity is traded, do you experience a slow or defaulting payment on your electricity (counter party risk).

○ Yes always ○ Yes sometimes ○ Yes but rarely ○ Not at all ○ No answer

Comment if you wish

18. Do you experience a slow or defaulting payment on your heat (counter party risk)?

○ Yes always ○ Yes sometimes ○ Yes but rarely ○ Not at all ○ No answer

Comment if you wish

19. Do you experience difficulty in finding a suitable counterparty with which to trade electricity (Market risk)?

○ Yes always ○ Yes sometimes ○ Yes but rarely ○ Not at all ○ No answer

Comment if you wish

20. Do you experience disputes with your heat customers?

○ Yes always

○ Yes sometimes

○ Yes but rarely

○ Not at all

○ No answer

21. If you do experience disputes with your customers, how often is it resolved?

- ◯ Always resolved
- ◯ Often resolved (two out of three)
- ◯ Rarely resolved
- ◯ Not resolved
- ◯ No answer

22. Which third party institution/body do you approach to resolve supplier/customer disputes for heat supply?

- ☐ Energy Ombudsman
- ☐ Local Authourity
- ☐ Ofgem
- ☐ No body/Self resolve
- ☐ Housing Association
- ☐ DECC

Please comment if you wish

23. What option of management of the metering and billing section of the CHP-DH system do you use?

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Fully outsourced from our operations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Only metering outsourced	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Only billing outsourced	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Part of our operations	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please comment if you wish

24. What form of management model is used for the CHP-DH project

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Fully integrated Energy Services Company (ESCO)	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Separate production, distribution and supply entities	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Same production and distribution with different supply entity	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Same production and supply with different distribution entity	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Same distribution and supply with different production entity	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

25. What economic model is adopted for the CHP-DH project

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10
Fully commercial	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Partially commercial with profit caps	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Cooperative/Non Profit	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
No Answer	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

Please comment if you wish

26. There should be a one-stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

27. The EU ETS is a long term incentive for CHP-DH systems

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

28. The renewable heat incentive (RHI) should stimulate the required growth of CHP-DH in the UK

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

29. The Government's energy company obligation has proved an incentive to DH development in the UK

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

30. What do you think is biggest government induced barrier to your operations?

- ◯ Planning permits
- ◯ Taxation
- ◯ market
- ◯ Requisite skill
- ◯ Regulatory ◯

Suggest any

Please suggest

[ ]

31. The UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems.

◯ Strongly agree ◯ Tend to agree ◯ Neither agree not disagree ◯ Tend to disagree ◯ Strongly disagree

◯ No answer

32. it is likely this would require a regulator. Which body should act as the regulator?

- ◯ Ofgem
- ◯ Government
- ◯ Another body (Say who if possible)
- ◯ No regulator is required (Please add comment to expand on this)
- ◯ No answer

Please comment if you wish

[ ]

33. On what basis do you calculate your charges to customers?

- ◯ Fixed charge
- ◯ Floor space
- ◯ Consumption rate
- ◯ Other (Please comment in box below)
- ◯ No answer

Please comment if you wish

34. There is a skill gap in the CHP and DH industry in the UK.

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

35. If you seem to agree to the above question, please could you grade skills below according to your perceived deficiency levels in the UK.

	Extremely deficient	Very deficient	Moderately deficient	Slightly deficient	Not deficient at all	No answer
Design and Manufacture of DH pipes	◯	◯	◯	◯	◯	◯
Manufacture of CHP systems	◯	◯	◯	◯	◯	◯
Business Development	◯	◯	◯	◯	◯	◯
Construction of DH systems	◯	◯	◯	◯	◯	◯
Installation of CHP Systems	◯	◯	◯	◯	◯	◯
Operations and Maintenance	◯	◯	◯	◯	◯	◯

36. What is your assessment of the level of maturity in the UK district heating supplier chain?

- ◯ Mature
- ◯ Infancy but growing
- ◯ Infancy and Stagnant
- ◯ Non-existence
- ◯ No answer

37. Please rank the following in the order you consider most likely to be the growth pathway for district heating network in the UK with 5 as the most prevalent

New builds

Urban centres

Sub-urban areas

Industrial Areas

Remote areas

Appendix 3 - LAs

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

Combined Heat and Power and District Heating Systems: Barriers and stimulants to growth in the UK

Thank you very much for taking out time to participate in this survey

BACKGROUND TO SURVEY

In response to new challenges facing the energy sector globally, such as increase in global energy demand, energy resource depletion and the impact of energy on the environment, the UK Government has set targets and timelines to overcome some of these challenges by reflecting on new pathways in redrawing its energy policies. The dominant pathway has been decarbonisation while ensuring energy security and affordability to achieve 80% greenhouse gas emission by 2050. In recognising that about a third of its greenhouse gas emissions come from heating, the consideration of how heat is produced, distributed and consumed is now a major discuss.

The unique advantage of the simultaneous generation of electricity and heat from array of sources by Combined Heat and Power (CHP) and Heat Networks (HN) ability to distribute heat also from array of sources has awakened the debate of the potential contribution of Combined Heat and Power on District heating systems in achieving the long term goal of the energy policy.

WHY THE SURVEY

The underlining concern of CHPs contributing about 21% of its potential to electricity consumption, while only 2% of the total heat consumption of heat in the UK is from Heat networks is the focus of this research. This survey seeks to investigate the factors that have shaped the low penetration of CHP-DH systems in the UK drawing on existing governance arrangements with a view to advance options that would increase its penetration, create competition and ultimately affect energy price as it's obtained in other network industries like gas or electricity. The results are in pursuant of an academic target and to inform the research community.

WHY YOU

In recognition of your contribution as a key participant in the chain of actors in the CHP-DH industry that will impact on the development of CHP-DH systems in the UK, you have been invited to kindly participate in this survey.

MY CONTACT INFORMATION

I can be reached through my contact details below

Tony Granville
PhD Researcher,

Renewable Energy Department,
College of Engineering, Mathematics and Physical Sciences,
University of Exeter, Tremough Campus,
Penryn, Cornwall,
TR10 9FE
http://emps.exeter.ac.uk/renewable-energy/
Email:ag424@exeter.ac.uk
Tel: 07831893361

Combined Heat and Power - District Heating System in the UK

Consent Page

Confidentiality

Your response to this survey will be held in confidence. They will not be used other than for the purpose described below and third parties will not be allowed access to them (except as may be required by law). Your data will be held in accordance with Data Protection Act.
The Purpose of this consent page is obtain your consent to precipitate in the survey to be taken and subsequently to be used by the University of Exeter ("University") in a number of media, including printed publication, exhibition boards, the intranet/web (e.g. University web pages, YouTube) and/or via social media (e.g. Twitter, Facebook, Instagram), to further and promote the work of the University in, for example the following ways:
• through the sharing of results and recommendations arising from the Project;
• as research and teaching material by the University and its students during and after the Project; and/or
• as public engagement material, i.e. to showcase the types of research and engagement activities the University carries out
And in turn, the University offers a commitment to review unedited material to allow it to be used appropriately and sensitively, as well as ensuring that any confidential material or opinion, which you indicate as being confidential at the time of the survey, is only shared for the purpose with your permission.

Anonymity

The questionnaire data will be held and used on an anonymous basis, with no mention of your name, but we will refer to the group of which you are member.

Consent

I voluntary agree to participate in this survey and the use of my data or opinion for the purpose specified above. I can withdraw consent at any time by contacting the researcher

Please click next to agree and proceed to the survey

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

Perceived Risk Factors

1. The implementation of CHP-DH in the UK is characterised by a variety of risk factors. In your consideration please scale the under listed perceived risk factors according to their level of seriousness that would hamper investment decisions

	Extremely Serious	Very Serious	Slightly Serious	Less Serious	Not Serious	No Opinion	N/A
Policy uncertainty	○	○	○	○	○	○	○
Absence of State capital incentive	○	○	○	○	○	○	○
Lack of local authority incentive	○	○	○	○	○	○	○
Absence of regulatory regime for heat	○	○	○	○	○	○	○
Absence of a heat market in the UK	○	○	○	○	○	○	○
Electricity off-take risk	○	○	○	○	○	○	○
Heat off-take risk	○	○	○	○	○	○	○
Developmental/Connection to electricity grid risk	○	○	○	○	○	○	○
Potential for change in the taxation regime	○	○	○	○	○	○	○
Tradition of private provision of public goods	○	○	○	○	○	○	○
Level of public opposition to project	○	○	○	○	○	○	○
Land acquisition and compensation	○	○	○	○	○	○	○
Availability of finance	○	○	○	○	○	○	○
Financial attraction of project to investors	○	○	○	○	○	○	○
Cost of Finance							○

	Extremely Serious	Very Serious	Slightly Serious	Less Serious	Not Serious	No Opinion	N/A
Delay in planning permission	◯	◯	◯	◯	◯	◯	◯
Planning permission risk	◯	◯	◯	◯	◯	◯	◯
Unavailability of CHP-DH construction Skills	◯	◯	◯	◯	◯	◯	◯
Construction time & cost overrun	◯	◯	◯	◯	◯	◯	◯
Operation cost overrun and revenue expectation	◯	◯	◯	◯	◯	◯	◯
Local authority experience in Public Private Partnership/Public Finance Initiative	◯	◯	◯	◯	◯	◯	◯

Any comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

2. Are you representing a local authority

- ◯ Yes
- ◯ No

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

Energy Strategy

3. Is there an adopted energy efficiency strategy for your local authority

- Yes
- In development
- Considering
- Not considering
- No Answer

4. If there is one, is CHP-DH part of the strategy

- Yes
- Somewhat
- No
- No Answer

5. Is there any CHP-DH project in the area covered by your Local authority

- Yes
- Don't Know
- Not at all

6. Is your local authority directly involved in any CHP-DH project?

- Been Involved
- Ongoing
- Considering
- Not considering
- No Answer

7. If involved or considering a CHP-DH project in your area, which project procurement model approach is planned

- ◯ Turnkey
- ◯ Design and Build
- ◯ Build Own Operate and Transfer
- ◯ Other (Please comment in box below)

Other (please specify)

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

Development Model

8. What form of management model would be/has been adopted for the CHP-DH project

- ◯ Fully integrated Energy Services Company (ESCO)
- ◯ Separate production, distribution and supply entities
- ◯ Same production and distribution with different supply entity
- ◯ Same production and supply with different distribution entity
- ◯ Same distribution and supply with different production entity
- ◯ No Answer

Other (please specify)

9. What economic model would be/has been adopted for the CHP-DH project

- ◯ Fully commercial
- ◯ Partially commercial with profit caps
- ◯ Cooperative/Non Profit
- ◯ Other (Please comment in the box)
- ◯ No Answer

Other (please specify)

10. Has the local authority developed heat maps for its area?

- Yes
- In development
- Considering
- Not considering
- No Answer

11. Does the local authority provide any support/planning guidance for CHP-DH development?

- Yes, Please comment
- Under development
- No
- No Answer

Comment if you wish

12. Who do you consider as the main conceivers/drivers of the CHP-DH project/s within the local authority/ies

- Local Authority
- Local Cooperatives
- Private/Commercial Developers
- DECC
- Hybrid/Other (Please comment below)

13. What nature of electricity distribution is adopted by your LA in distributing electricity from CHP

- Only on Private network
- Only on Public network
- Mostly on Private Network
- Mostly on Public Network
- Mostly Hybrid of both
- No answer

Other comments if you wish

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

Barriers to Development

14. Information on heat demands on local areas is available from local authorities for the development of CHP-DH

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

15. Local authorities have the necessary capacity to engage energy services companies (ESCO) for their areas

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

16. There should be a one-stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

17. The absence of a national integrated CHP and District Heating strategy could hamper the growth of CHP/DH technology in the UK

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

18. The UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems.

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

19. As a follow up to the question above, it It is likely this would require a regulator. Which body should act as the regulator?

◯ Ofgem

◯ Government

◯ Another body (Say who if possible)

◯ No regulator is required (Please add comment to expand on this)

◯ No answer

Comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power - District Heating System in the UK

Barriers to Development

20. Did the localism bill, 2011 succeed in making planning more democratic and effective to impact positively on CHP-DH developments

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

21. I consider the existing process to receive planning consent to be transparent enough to gain the confidence of the applicants for CHP-DH projects and locals

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

22. Planning officers in the Local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

23. In addition to planning permission there are many other consent that are required to commence development of a CHP-DH project, such as environmental permits or street works licence. There is room for a single consent regime or to at least reduce the consent chain in obtaining planning permission for district heating and CHP developers?

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

24. A conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

25. The prevailing policy frameworks provide enough protection for CHP-DH customers

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

26. The housing stock in the UK, which are generally houses/bungalows impact negatively on the growth of DH

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

Appendix 4 - Consultants

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Combined Heat and Power and District Heating Systems: Barriers and stimulants to growth in the UK

Thank you very much for taking out time to participate in this survey

BACKGROUND TO SURVEY

In response to new challenges facing the energy sector globally, such as increase in global energy demand, energy resource depletion and the impact of energy on the environment, the UK Government has set targets and timelines to overcome some of these challenges by reflecting on new pathways in redrawing its energy policies. The dominant pathway has been decarbonisation while ensuring energy security and affordability to achieve 80% greenhouse gas emission by 2050. In recognising that about a third of its greenhouse gas emissions come from heating, the consideration of how heat is produced, distributed and consumed is now a major discuss.
The unique advantage of the simultaneous generation of electricity and heat from array of sources by Combined Heat and Power (CHP) and Heat Networks (HN) ability to distribute heat also from array of sources has awakened the debate of the potential contribution of Combined Heat and Power on District heating systems in achieving the long term goal of the energy policy.

WHY THE SURVEY

The underlining concern of CHPs contributing about 21% of its potential to electricity consumption, while only 2% of the total heat consumption of heat in the UK is from Heat networks is the focus of this research. This survey seeks to investigate the factors that have shaped the low penetration of CHP-DH systems in the UK drawing on existing governance arrangements with a view to advance options that would increase its penetration, create competition and ultimately affect energy price as it's obtained in other network industries like gas or electricity. The results are in pursuant of an academic target and to inform the research community.

WHY YOU

In recognition of your contribution as a key participant in the chain of actors in the CHP-DH industry that will impact on the development of CHP-DH systems in the UK, you have been invited to kindly participate in this survey.

MY CONTACT INFORMATION

I can be reached through my contact details below

Tony Granville

PhD Researcher,
Renewable Energy Department,
College of Engineering, Mathematics and Physical Sciences,
University of Exeter, Tremough Campus,
Penryn, Cornwall,
TR10 9FE
http://emps.exeter.ac.uk/renewable-energy/
Email:ag424@exeter.ac.uk
Tel: 07831893361

Combined Heat and Power/District Heating Systems in the UK

Consent Page

Confidentiality

Your response to this survey will be held in confidence. They will not be used other than for the purpose described below and third parties will not be allowed access to them (except as may be required by law). Your data will be held in accordance with Data Protection Act.
The Purpose of this consent page is obtain your consent to precipitate in the survey to be taken and subsequently to be used by the University of Exeter ("University") in a number of media, including printed publication, exhibition boards, the intranet/web (e.g. University web pages, YouTube) and/or via social media (e.g. Twitter, Facebook, Instagram), to further and promote the work of the University in, for example the following ways:
• through the sharing of results and recommendations arising from the Project;
• as research and teaching material by the University and its students during and after the Project; and/or
• as public engagement material, i.e. to showcase the types of research and engagement activities the University carries out
And in turn, the University offers a commitment to review unedited material to allow it to be used appropriately and sensitively, as well as ensuring that any confidential material or opinion, which you indicate as being confidential at the time of the survey, is only shared for the purpose with your permission.

Anonymity

The questionnaire data will be held and used on an anonymous basis, with no mention of your name, but we will refer to the group of which you are member.

Consent

I voluntary agree to participate in this survey and the use of my data or opinion for the purpose specified above. I can withdraw consent at any time by contacting the researcher

Please click next to agree and proceed to the survey

Combined Heat and Power/District Heating Systems in the UK

Perceived Risk Factors

1. The implementation of CHP-DH in the UK is characterised by a variety of risk factors. In your consideration please scale the under listed perceived risk factors according to their level of seriousness that would hamper investment decisions

	Extremely Serious	Very Serious	Slightly Serious	Less Serious	Not Serious	No Opinion	N/A
Policy uncertainty	○	○	○	○	○	○	○
Absence of State capital incentive	○	○	○	○	○	○	○
Lack of local authority incentive	○	○	○	○	○	○	○
Absence of regulatory regime for heat	○	○	○	○	○	○	○
Absence of a heat market in the UK	○	○	○	○	○	○	○
Electricity off-take risk	○	○	○	○	○	○	○
Heat off-take risk	○	○	○	○	○	○	○
Developmental/Connection to electricity grid risk	○	○	○	○	○	○	○
Potential for change in the taxation regime	○	○	○	○	○	○	○
Tradition of private provision of public goods	○	○	○	○	○	○	○
Level of public opposition to project	○	○	○	○	○	○	○
Land acquisition and compensation	○	○	○	○	○	○	○
Availability of finance							○
Financial attraction of project to investors	○	○	○	○	○	○	○

	Extremely Serious	Very Serious	Slightly Serious	Less Serious	Not Serious	No Opinion	N/A
Cost of Finance	○	○	○	○	○	○	○
Delay in planning permission	○	○	○	○	○	○	○
Planning permission risk	○	○	○	○	○	○	○
Unavailability of CHP-DH construction Skills	○	○	○	○	○	○	○
Construction time & cost overrun	○	○	○	○	○	○	○
Operation cost overrun and revenue expectation	○	○	○	○	○	○	○
Local authority experience in Public Private Partnership/Public Finance Iniative	○	○	○	○	○	○	○

Any comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Barriers to Development

2. The absence of a national integrated CHP and District Heating strategy could hamper the growth of CHP/DH technology in the UK

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

3. Information on heat demand in local areas is available from local authorities for the development of CHP-DH

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

4. There should be a one-stop shop for the necessary information on different technologies to CHP and sources of heat to District Heating network

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

5. Local authorities have the necessary capacity to engage energy services companies (ESCO) for their areas

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

6. The renewable heat incentive (RHI) should stimulate the required growth of CHP-DH in the UK

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

7. The Government's energy company obligation has proved an incentive to DH development in the UK.

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

8. There is little or no role for local authorities in the implementation of central Government's Electricity Market Reform (EMR) programme

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Other (please specify)

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Governance Mechanisms

9. Which Government scheme do you consider as the most effective in driving the penetration of CHP/DH

- ◯ Energy Company Obligation
- ◯ Enhanced Capital Allowance
- ◯ Renewable Heat Incentive
- ◯ Renewable Obligation
- ◯ Green Deal
- ◯ Community Energy Saving Programme
- ◯ Climate Change Levy exemption
- ◯ No answer

Other (please specify)

10. The Government should introduce a unified incentive for CHP-DH systems

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

11. Local authorities have the necessary competencies to govern the network of actors in relation to CHP-DH development

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

12. CHP doesn’t have a dedicated funding limit in the Government's levy control framework (LCF). Is this a risk to investors?

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

13. The UK needs to develop a body of regulation concerning heat provision and its infrastructure such as DH systems.

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

14. It is likely this would require a regulator. Which body should act as the regulator?

◯ Ofgem

◯ Government

◯ Another body (Say who if possible in comment box)

◯ No regulator is required (Please add comment to expand on this)

◯ No answer

Comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Planning and Skills

15. I consider the existing process to receive planning consent to be transparent enough to gain the confidence of the applicants for CHP-DH projects

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

16. Planning officers in the Local authorities are skilled enough to offer proactive guidance to district heating and CHP planning applicants.

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

17. In addition to planning permission there are other consent that are required to commence development of a CHP-DH project, such as environmental permits or street works licence. There is room for a single consent regime or to at least reduce the consent chain in obtaining planning permission for district heating and CHP developers?

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

18. A conveyor belt (one-stop shop) approach with a definite time for the planning system should be introduced.

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

19. The HM Treasury guidance for project appraisals for public sector developments of 25 years is attractive to investors in district heating projects

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

20. There is a skill gap in the CHP and DH industry in the UK.

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

21. If you seem to agree to the above question, please could you grade skills below according to your perceived deficiency levels in the UK.

	Extremely deficient	Very deficient	Moderately deficient	Slightly deficient	Not deficient at all	No answer
Design and Manufacture of DH pipes	◯	◯	◯	◯	◯	◯
Manufacture of CHP systems	◯	◯	◯	◯	◯	◯
Business Development	◯	◯	◯	◯	◯	◯
Construction of DH systems	◯	◯	◯	◯	◯	◯
Installation of CHP systems	◯	◯	◯	◯	◯	◯
Operations and Maintenance	◯	◯	◯	◯	◯	◯

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

Development Issues

22. Private land owners are very receptive to CHP-DH projects

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Other (please specify)

23. Ofgem's regulation demands DNOs should respond to connection request within 3 months of application and its usually valid for 30 – 90 days. Often times, two out of three grid connection offers expire before the planning permission is granted?

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

24. The quotations for electrical grid connection advanced by the DNOs and/or National Grid are transparent.

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

25. The methodology in arriving at grid connection quotations are standardised across the UK and DNOs/National Grid

○ Strongly agree ○ Tend to agree ○ Neither ○ Tend to disagree ○ Strongly disagree ○ No answer

Comment if you wish

26. The housing stock in the UK, which are predominantly houses/bungalows impact negatively on the growth of DH

◯ Strongly agree ◯ Tend to agree ◯ Neither ◯ Tend to disagree ◯ Strongly disagree ◯ No answer

Comment if you wish

27. What is the dominant perceived challenge in the UK before the construction of a CHP-District heating system?

◯ Planning Consent

◯ Electricity market

◯ Land acquisition

◯ heat load

◯ Lack of capital

◯ Others (Please comment)

Comment if you wish

UNIVERSITY OF EXETER

Combined Heat and Power/District Heating Systems in the UK

28. What is your assessment of the level of maturity in the UK district heating supply chain?

- ◯ Mature
- ◯ Infancy but growing
- ◯ Infancy but stagnant
- ◯ Non-existence
- ◯ No answer

29. Please rank the following in the order you consider most likely to be the growth pathways for district heating networks in the UK, with 5 as the most prevalent

[ ]	New builds
[ ]	Urban centres
[ ]	Sub-urban areas
[ ]	Industrial Areas
[ ]	Remote areas

Appendix 5

Questions for Ofgem

Is the connection cost of distributed energy e.g CHP distributed over the technical life or the economics of the asset?

If Ofgem (Under DECC) approves transmission and distribution network investment, while the planning inspectorate (PI) (Under DCLG) approves planning application for transmission connection as national infrastructure project. Is there any interface between them Ofgem and PI?

Are the revenues of DNOs are determined by regulatory process OR whole sale market.

Is there any resource centre to take distributed energy developers like CHP-DH through the process of licencing and connection conditions?

As different supplier offer different tariffs for export electricity is there any one-stop portal to see tariff offered

Is the response time and cost for network connection standardized across the network?

Is there any tariff methodology for export electricity?

Are distributed generators on private networks eligible to policies such as RO or CCL

Do you consider the quotation for the grid connection advanced by the DNOs or National grid as transparent?

Any known incentive to buy electricity from distributed generators

Is it mandatory for distributed generators to install and register their meters?

CHP over 3 MW receive extra revenue through participation in system balancing through short-term operational reserves (STOR) (Kelly and Pollitt, 2010)

In Scotland, small generators such as 5MW provide ancillary services such as reactive power, fast or short term operating reserve. In England and Wales do CHPs have the same opportunities?

Comparatively on in retrospect, do you think liquidity in the wholesale market is improving in the UK

What is the average electricity trading volume compared to the national electricity consumption or the market liquidity ratio?

How is the strike price reached?

Appendix 6

DECC - HNDU

1. Please take me through how the DECC heat map was developed?
2. How often is the DECC heat map updated?
3. What is the future of the heat map?
4. What known financial options is the government offering developers to fund CHP-DH projects?
5. Government underwrites investment for gas and electricity infrastructure for over 25yrs. Why can't this happen to DH networks.
6. DECC provides finance through the Salix finance programme where loans are given to public organisations to finance energy efficiency projects with a payback period of less than five years. Why that low?
7. What do you think the return on investment on CHP-DH projects should be to attract an investment for public finance and private finance?

8. Is the government tinkering with an industry wide regulation for heat, or what is the position and way forward?

Appendix 7

Questions for CHP-DH Operators

1. Please can I hear briefly, the description of the expertise of your company
2. What are the dominant perceived challenges of operation of a CHP-District heating system?
3. What institution or actor that can affect the execution of the development of district heating scheme the most
4. What known policy incentive is available to CHP-DH developers?
5. What are the dominant PPA terms for CHPs.
6. What is the biggest policy burden on CHP electricity suppliers?
7. Which government institution do district heating schemes relate with
8. What is a dominant funding route for district heating in the UK? European Development or Private firms or Energy Company Obligation or Combination of any.
9. Any known incentive to buy electricity from distributed generators.
10. Are distributed generators on private networks eligible to policies such as RO or CCL
11. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
12. On the average what is the number of permits you would require before the construction of DH system
13. What taxes are paid as a CHP-DH developer or operator
14. Do you participate in the EU ETS. What do you consider the impact of carbon price floor and Emission trading scheme on your operations
15. What is your perspective of the contract for difference (CfD) in the new EMR mechanism by the government
16. More clarification on your responses to the questionnaire

Appendix 8

Questions for consultants

1. What are the dominant perceived challenges pre and post construction of a CHP-District heating system in the UK?
2. What institution or actor that can affect the execution of the development of district heating scheme the most
3. What known policy incentive is available to CHP-DH developers?
4. What do you consider the biggest policy burden on CHP electricity suppliers?
5. Which government institution do district heating schemes/developers relate with
6. What is a dominant funding route for district heating in the UK? European Development or Private firms or Energy Company Obligation or Combination of any.
7. What do you think is the dominant market model for a CHP-DH in the UK. For instance is it a fully integrated model (bundled structure) of heat production, distribution and supply or separate value chain
8. What is the dominant governance structure of CHP-DH in the UK. For instance are heat consumers part owners of the heat production and distribution company (cooperative model) or wholly owned by the energy company
9. Any known incentive to buy electricity from CHPs generators.
10. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
11. What are the current taxes levied on the CHP-DH operation
12. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
13. Is there a known knowledge centre or skill transfer/acquisition schemes for CHP-DH development in the UK

In embarking on a DH construction how many permit typically do you require (not highlighting them if it's not handy, just the likely number at least) permanently or temporary. Such as building permits, environmental, cross water, highway, street, rails, safety approval and much more

Appendix 9

QUESTIONS FOR LOCAL AUTHORITIES

1. Please can I know briefly your job description
2. Can you take me through any CHP-DH project in your locality and role of the local authority in the project.
3. What is the relationship between the local authority and the housing authority or association especially in relation to the housing stock (For instance is there an arm's length organisation to manage it)
4. What is the relationship between the local authority and the CHP-DH administration (For instance is there an arm's length organisation to manage it)
5. How much of your housing stock do you still have within your ownership fold or is everything sold out like some other council
6. What is the heat price indexed to?
7. What do you think are the challenges to the uptake of CHP-DH from the local authority perspective?
8. What roles do think the local authorities can play in driving up the usage of CHP-DH in the UK
9. What is your LA/council doing in terms of CHP-DH?
10. If you have a CHP-DH project in your area that the council is involved, do you know how much it cost the council in terms of capital funding to make the project a success. (Manpower, development of information/maps, feasibility and others)
11. Does LA have the ability to directly borrow for investment into energy efficiency projects
12. Does council have the necessary powers to enter into a joint venture with private company to provide energy infrastructure like a CHP-DH system (e.g Tower hamlets couldn't so they decided to concession)
13. Is there a research department within the council
14. Is there also a collaboration with research organisations like University and how do you build capacity
15. Is your LA benefiting from Energy Companies Obligation from big energy companies and how?
16. Is the council benefiting from RHI

Appendix 10

QUESTIONS FOR LGA

1. What is the relationship between the local authorities and LGA
2. Does your organisation have some kind of targets for its members in terms of energy efficiency
3. What is the opinion of LGA regarding councils selling off their housing stock
4. What do you think are the challenges to the uptake of CHP-DH from the local authority perspective?
5. What roles do think the local authorities can play in driving up the usage of CHP-DH in the UK
6. What is the LGA doing in terms of CHP-DH through energy efficiency targets?
7. Do LAs have the ability to directly borrow for investment into energy efficiency projects
8. Do councils have the necessary powers to enter into a joint venture with private company to provide energy infrastructure like a CHP-DH system (e.g Tower hamlets couldn't so they decided to concession)
9. Some respondents have identified delay in planning as a major in embarking CHP-DH projects
10. What is LGA doing in trying to improve the human capacity of councils with interest in these systems

Appendix 11

Questions for LA - Planners

1. Please can you me take me through your job description
2. Can you also take me through any story of CHP-DH system in your locality?
3. From a planner's perspective what do you consider as the challenges of the growth of CHP-DH systems in the UK
4. What role can planner's play in improving the penetration of CHP-DH systems in the UK
5. Can you please, take me through the meeting point between planner's and the energy or sustainability team in the council before energy projects are approved for implementation in the council?
6. Is there any forum planner's meet to share knowledge and information on their various experiences in the UK, if not, what is your thought
7. How do planners build capacity with respect energy efficiency outlook in the council?
8. Please can you take me through how S106 is being implemented by the council with respect to energy projects and in particular CHP-DH projects
9. Similarly, how is community infrastructure levies obtained from CHP-DH developers and how do you arrive at the cost
10. Please can you take me through S50 and the process in applying and obtaining its approvals?
11. When a council owns a land and gives it to a private sector developer, what is the name of the land transfer agreement?

Appendix 12

Questions for Distribution Network Operators

1. Please briefly take me through the process of connection request from a customer to actual connection to a customer
2. Is it all connection request that leads to an actual connection and what do you think is the ratio
3. Network stability charge. When last was the network charge revised and how often.
4. Do you consider the quotation for the grid connection advanced by the DNOs or National grid as transparent?
5. Is the connection cost of distributed energy e.g CHP distributed over the technical life or the economic life of the asset
6. Is the connection cost consistent?
7. Is the network connection standardized (network bus arrangement) across the network?
8. Many CHP and other independent developers have complained of holding off or cancelling their projects due to no connection points from the DNOs. What is the situation to your knowledge in the South west and the UK at large?
9. Is there any fixed time scale for connection of CHP to the network after acceptance and payment of fee?
10. Is your distribution network ready for the perceived growth of DG on the medium and long term
11. Since reduction of distribution losses in the DN is a KPI to the DNOs. Is the reduction of network losses in DNs internalized to the DGs
12. Do you think the Governments EMR mechanism can facilitate deployment of CHPs
13. Are the distributed expansion plans on schedule as forecasted in the business plans predicted in the RIIO for distribution?
14. Are the revenues of DNOs determined by regulatory process OR market.
15. Are the DNOs deploying more intelligent and controllable devices in the distribution networks known as active management as planned?
16. Is there any incentive to LAs that want to generate power from CHP and supply their housing networks

Appendix 13

Questions to DH Pipe Suppliers

1. Please can you take me through your core area of business
2. How is the District Heating piping business regulated in the UK
3. Is there any code of practice?
4. Is there any internship scheme in place to train coming-up installers and how is the government supporting this scheme?
5. What do you think is the average cost of laying the pre-insulated DH pipes per KM in the UK and do you think it's more expensive in the UK than other European countries?
6. To your mind, are there growing numbers of DH pipe manufacturing and installation in the UK or mostly being imported (You can separate manufacturing and installation if you wish)?
7. What is your size perception of how many of these companies are owned by UK business owners?
8. What do you consider as challenges to the growth of DH piping business in the UK (such as taxation, policy, cost of finance, planning permission or others) and what ways could be deployed to improve the industry?
9. In embarking on a DH piping installation, typically how many permits do you require to commence installation?

Appendix 14

Questions for CHP-DH Developers

1. As developers what are the dominant perceived challenges pre and post construction of a CHP-District heating system in the UK?
2. What institution or actor that can affect the execution of the development of district heating scheme the most
3. What known policy incentive is available to CHP-DH developers?
4. What policy option can be adopted to impact on CHP-DH development positively
5. What do you consider the biggest policy burden on CHP electricity suppliers?
6. Which government institution do district heating schemes/developers relate with
7. What is a dominant funding route for district heating in the UK? European Development or Private firms or Energy Company Obligation or Combination of any.
8. What do you think is the dominant market model for a CHP-DH in the UK. For instance is it a fully integrated model (bundled structure) of heat production, distribution and supply or separate value chain
9. What is the dominant governance structure of CHP-DH in the UK. For instance are heat consumers part owners of the heat production and distribution company (cooperative model) or wholly owned by the energy company
10. Any known incentive to buy electricity from CHPs generators.
11. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
12. What are the current taxes levied on the CHP-DH operation
13. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
14. Is there a known knowledge centre or skill transfer/acquisition schemes for CHP-DH development in the UK

In embarking on a DH construction how many permit typically do you require (not highlighting them if it’s not handy, just the likely number at least) permanently or temporary. Such as building permits, environmental, cross water, highway, street, rails, safety approval and much more

Appendix 15

Questions for Association for Decentralised Energy (ADE)

1. What are the dominant perceived challenges pre and post construction of a CHP-District heating system in the UK?
2. What institution or actor that can affect the execution of the development of district heating scheme the most
3. What known policy incentive is available to CHP-DH developers?
4. What is the dominant PPA term for CHPs.
5. What do you consider the biggest policy burden on CHP electricity suppliers?
6. Which government institution do district heating schemes/developers relate with
7. What is a dominant funding route for district heating in the UK? European Development or Private firms or Energy Company Obligation or Combination of any.
8. What do you think is the dominant market model for a CHP-DH in the UK. For instance is it a fully integrated model (bundled structure) of heat production, distribution and supply or separate value chain
9. What is the dominant governance structure of CHP-DH in the UK. For instance are heat consumers part owners of the heat production and distribution company (cooperative model) or wholly owned by the energy company
10. Any known incentive to buy electricity from CHPs generators.
11. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
12. Which is more dominant among heat Suppliers from DH. Is it fixed rate or time of use rates
13. What are the current taxes levied on the CHP-DH operation
14. Planning obligation under S106 of the town and country planning Act 1990, mandates all developers to contribute towards the cost of development of local infrastructure. Is there a standardized methodology for contribution or it varies from local authority to another.
15. Are developers of district heating networks eligible to pay community infrastructure levies under the planning Act 2008 to local authorities?
16. Is there any interactive forum between planning workers and the developers with a view to share and develop skills?
17. Is there an accredited system for district heating installers?
18. Is there a known knowledge centre or skill transfer/acquisition schemes for CHP-DH development in the UK
19. In embarking on a DH construction how many permit typically do you require (not highlighting them if it's not handy, just the likely number at least) permanently or temporary. Such as building permits, environmental, cross water, highway, street, rails, safety approval and much more
20. Any known governmental or institutional database of District Heating schemes in the UK

Appendix 16

Questions for Electricity suppliers

1. Please can you talk me through the functions of your business
2. Are you a member of the balancing and Settlement Code and if yes, what is your position on the admittance of members and the impact on CHP asset owners
3. What do you consider the impact of the UK electricity market on CHP assets
4. Do you see the requirement to cover credit risk by Elexon a challenge to CHP developers
5. What is the dominant PPA terms for CHPs
6. Does the size of your plant influence the type of power contract you enter.
7. Any known incentive to buy electricity from distributed generators
8. Are distributed generators on private networks eligible to policies such as RO or CCL
9. As different suppliers offer different tariffs for export electricity is there any one-stop portal to see tariff offered.
10. If No above do you think we need one.
11. Do you think the prevailing government policies such as EMR, RHI are enough to stimulate the growth of CHP-DH in the UK
12. Can CHP-DH raise the energy awareness of consumers through more direct socio-economic relationship between consumers and energy generation?
13. Do you consider the government's role as important in the diffusion of CHP-DH in the UK
14. Do you consider the success stories of CHP-DH systems are considerably shared amongst local authority or housing developers

Appendix 17

Questions to Public Works Loan Board

Background

The research is on renewable energy policy with focus on the penetration of Combined Heat and Power and District Heating (CHP-DH) systems as low carbon energy generation in the UK using governance instruments such loans, taxes or mechanisms. However, after series of interviews with local authorities and other stakeholders it began to emerge that availability and cost of finance was a major risk to CHP-DH investors in the UK. Sequel to that I have sought to have your view on a number of issues surrounding the lending to local authorities in the UK and what possible route it may take to make cheaper funds available to local authorities in the UK.

Questions

1. Do you lend to LA to finance energy projects like CHP-DH systems with many years of payback time
2. If yes is there any internal policy preference for low carbon energy projects
3. Please talk me through the underlying principles to lend to LAs and do they borrow against revenue or subvention from the state
4. Please talk me through your discount rate approach and preference rates for energy projects if any
5. Does PWLB apply social discount rates to any of their project and what are the considerations, if you indeed apply it.
6. Are there other sources from the state that LAs can borrow finance from to execute huge energy projects like CHP-DH systems
7. Please criticise my proposal of PWLB lending to LAs against the assets of the CHP-DH system (Generation plants and District Heating Network) so as to make cheaper funds available for them to play their role more efficiently in providing low carbon energy to its residents.
8. Your thoughts on how LAs can get cheap finance in sufficient volume as in PWLB to execute low carbon energy projects in the UK and possible signpost to other literatures and sites will also be helpful.

Thank You

Appendix 18

Questions to CHP-DH Equipment Suppliers

1. Please can you take me through your core area of business
2. How long have been in this area and what are your core motivations
3. What are thoughts about the UK CHP-DH market?
4. What do you consider as the barriers to your business in the UK and the growth of the CHP-DH industry at large?
5. What polices or government intervention can make the CHP-DH more attractive or stimulate growth to investors or actors like you?