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Improving energy efficiency among low-income households in the United Kingdom

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Improving energy efficiency among low-income households in the United Kingdom

Hazim Mohd Zaidi

A dissertation submitted to the University of Bristol in accordance with the requirements for the award of the degree of Global Environmental Challenges in the Faculty of Engineering.

September 2023

Words: 25,682

Abstract

By the end of 2022, 7.4 million or about one-third of the households in the UK were predicted to be spending more than 10% of their net income on domestic energy to keep their houses adequately warm. In the UK, the average annual energy bills hit a record high in 2022 of £2,316 for gas and electricity and the 2022 energy prices were the largest annual increaserecorded since 1970. This was ultimately an impact of various global issues which led to a rise in energy prices worldwide, the effect of which is worst felt by low-income people and increased the estimated numbers of people falling into energy poverty.

This research uses a qualitative interview with 15 individuals with relevant experience in the energy industry to explore the growing issues of energy poverty in the UK. The results highlight the importance of improving energy efficiency for low-income households which could reduce energy poverty and to an extent, reduce carbon emissions. In addition, the barriers to energy efficiency among low-income households in the UK were identified as the barriers to knowledge, housing conditions, landlord-tenant dilemma and energy policies. This study also found that behaviour and technology has the potential to save up to £60 per month, 31% savings on the average monthly energy bills of £193 per month in the UK. However, there is still a need to further support low-income households through awareness and grant application knowledge to improve energy efficiency and save energy.

The implications of this research are significant as an increasing number of people go into energy poverty each year. By identifying the importance and barriers to energy efficiency among low-income households in the UK, this study highlights the need for improved support for low-income households in improving household energy efficiency in going through the increasing energy prices, especially going into winter.

Dedication and Acknowledgments

This work is dedicated to the people going through hard times in this energy crisis and going into winter. Hopefully, this piece of work can contribute to improving energy efficiency among low-income households, helping people to save money on their energy bills and, at the same time reducing carbon emissions in building a sustainable future.

I would like to thank my supervisors, Dr Hadi Abulrub and Professor Chris McMahon, for guiding me throughout the research and making sure that I am on the right path in fulfilling the requirements of this degree. I would also like to acknowledge Majlis Amanah Rakyat (MARA) as my main sponsor in carrying out this research.

Thank you to my parents, Professor Zaidi Omar and Dr Amnah Zanariah and my family for their unwavering support throughout the degree. My parents are my role models, and they always keep me going on my lowest days. Special thanks to Dr Farid Abraham, Alif Ezrul Esmady and Izzah Nasruddin for their selfless guidance throughout my research journey, sharing their time and experience, especially in the early days of navigating my research until I can proudly say I am done with my master's degree. Finally, thank you to my friends who have been with me throughout the journey making my master'sdegree life much more enjoyable.

Author's declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific references in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: .....  ..... DATE: 28th September 2023

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List of Conference and Presentation

No.	Program	Date
1.	7th International Conference on Energy Economy and Energy Policy (ICEEEP) 2023 in Barcelona, Spain.	27-29th April 2023
2.	MScR Postgraduate Research showcase, Cabot Annual Lecture, University of Bristol, United Kingdom	11th October 2023
3.	Post Graduate Conference 2023, University Sains Islam Malaysia (USIM)	18th October 2023

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Chapter 1 Introduction

By the end of 2022, it was estimated that almost one-third of UK households were in energy poverty (DESNZ, 2023). The gas prices in the UK in winter 2022 increased from £564 per year in 2021 to £1,097 per year in 2022, while electricity prices increased from £769 per year in 2021 to £1,219 per year in 2022 (Bolton & Stewart, 2023). The annual increases in gas and electricity prices in winter 2022 were the largest in the UK since 1970 (Bolton & Stewart, 2023). The rise of energy prices in 2022 is set against a changing global energy landscape, which builds up the soaring energy prices seen in 2022. These changing energy landscapes may be summarised into three interconnected issues, which are 1) the centrality of energy to the economy, 2) climate change disrupting the energy market and 3) the COVID-19 pandemic and war in Ukraine in 2021-2022, which have pushed energy demand and prices to a record high. The rise in energy prices heavily affected low-income people and increased the number of people falling into energy poverty.

The increase in energy prices starts with the role of **energy as central to the development of economic growth** of a nation (Abosedra et al., 2015; Stern, 2011). Ecological economists regard energy as the "central role in energy growth" (Stern, 2011). Studies done in Jordan show a positive correlation between energy consumption, financial development and economic growth, meaning that energy consumption plays a vital role in developing a nation with strong financial and economic development (Abosedra et al., 2015). At the same time, the growing rate of the human population would mean bigger economic growth and a higher need for energy consumption. Since 1950, the world's population has tripled from 2.5 billion to about 8 billion people in 2022 (Gaigbe-Togbe et al., 2022). An increase in global population increases global energy consumption (Holdren, 1991), and if the population continues to grow, there might be a risk of energy consumption in the future (Ganivet, 2020). Any disruption to the supply of energy may lead to a surge in energy prices, hence the need to improve energy security, which can be defined as a steady supply of energy at an affordable price (IEA, 2023).

Climate change as a result of excessive release of anthropogenic greenhouse gasses lead to extreme weather that disrupted the supply of energy. This affects the energy security and increased the energy prices worldwide. Severe weather such as flooding, severe storms and rising sea levels force oil and gas production to shut down, power plants in coastal areas to close and cause damage to electricity grids supplying energy nationwide (European Climate Foundation (ECF), 2014). Other than that, energy supply such as oil and gas pipelines in cold climates are also affected by thawing permafrost underground (European Climate Foundation

(ECF), 2014). Because of climate change, there is increasing pressure to transition from fossil fuel to renewable energy. However, the transition to renewable energy comes with new problems. For example, the peak solar energy output timings at noon compared to the peak human energy consumption in the morning and the afternoon causes imbalances in energy demand and supply. This imbalance has been described as the "duck curve", symbolizing the peaks of energy demand in the morning and afternoon. The duck curve problem highlights the need for an improved battery storage system or a mix of transition fuels such as natural gas during peak times to support the grid to meet its energy demand (Schmalensee, 2022). In addition, there is a growing need to regulate our energy consumption to ensure a smooth transition to a renewable energy future.

With the increase in energy consumption from a growing human population and the pressures of climate change, which disrupts the energy supply, the COVID-19 pandemic and the Russia-Ukraine conflict between 2021-2022 made the issue of rising energy prices much worse. COVID-19 forced lockdowns in many countries, which led to slower economies worldwide. As the world started to recover from the global pandemic in 2021, the energy demand soared higher than expected at the time, and there was not enough supply of energy to fulfil the demand. The sudden rise in energy demand caused the energy prices to skyrocket. At the same time, the war between Russia and Ukraine escalated around February 2022 when Russia started to invade Ukraine, which led to political conflicts between countries, increasing energy prices worldwide by up to 20% from February to July 2022 (Yagi & Managi, 2023). In the UK, household energy prices increased by 36% from 2020 to the end of 2021 and are estimated to rise further up to 50% by the end of 2022 (Bolton & Stewart, 2022).

One of the groups of people most affected by this energy crisis would be low-income people and families. The energy poverty gap, which is the reduction of energy bills needed to bring people out of energy poverty in the UK, has increased **by 37 per cent since 2021** (DESNZ, 2023)**.** Hence, this recent 2021-2022 energy crisis makes the long-term issues of energy sustainability, climate change, and energy poverty more crucial than ever.

The combination of 1) the centrality of energy to the economy, 2) climate change disrupting the energy market, and 3) the COVID-19 pandemic and war in Ukraine in 2021-2022 **ultimately led to an increase in energy prices**, the effect of which is worst felt by low-income households and increased the estimated numbers of people falling into energy poverty.

The issue of energy poverty is a long-term worldwide problem and is described in the literature in different ways. In general, energy poverty can be defined as the "level of

energy consumption that is insufficient to meet certain basic needs" (González-Eguino, 2015). However, the definition of energy poverty might vary depending on different locations. In the UK, the common concern of energy poverty is more focused on having enough energy to heat homes and keep them comfortable throughout the changing seasons. Hence, many energy poverty studies in the scope of the UK use the term **fuel poverty** instead. In the UK, the classification of fuel poverty was set as spending more than 10% of a household's income (after housing costs) on domestic energy (DESNZ, 2023). Since this research focuses on the problems faced explicitly by people in the UK, this research will adopt the definition from DESNZ (2023), which defines **energy poverty** as the group of households **spending more than 10% of their net income (after housing cost) on domestic energy to keep their houses adequately warm**. Energy poverty groups mainly comprise low-income households with limited income to provide enough necessities. Other than that, some people with high income may also be considered energy-poor if their monthly domestic energy bills exceed 10% of their income (after housing costs). Low-income households may need to decide between buying food for their family or paying the energy bills to keep the house warm.

The government plays an essential role in supporting and reducing the number of energy poverty people in a country. Every year, governments allocate a certain percentage of the budget to tackle specific issues each country faces. For example, the higher the budget allocated to tackle the problem of energy poverty, the bigger the programs that can be introduced nationwide to implement actions to help people in energy poverty. Other than that, the government may also implement policies that would guide people from different levels of stakeholders to work together to solve a problem. Good and well-thought policies in place may guide every stakeholder to work together and achieve set goals in a given period. On the other hand, policies which are not well-thought may ruin plans set by the government and bring long- lasting impact to the people.

In general, adding clean energy from renewable sources while reducing energy demand is the primary action to improve energy security, which would help people in energy poverty. These also help in decarbonising the world toward reaching the Net Zero goals. **The main focus of this research is to explore and evaluate the options for demand reduction in low-income households.**

"Energy efficiency" is defined as using less energy to deliver a certain task (*EERE USA*, 2023). The UK government website defines energy efficiency as reducing the amount of energy

households and businesses need to perform a similar task(GOV.UK, 2022). Improving energy efficiency will give a two-fold advantage: reducing energy poverty (Ugarte et al., 2016) and controlling energy demand, which will help decarbonise the current energy system towards a net zero carbon future (Eyre, 2022).

Past studies on **the topic of energy efficiency among low-income households highlight several barriers faced by low-income households**. The report on Energy Efficiency for Low-Income Households by the European Union Policy Department summarised that the barriers cover a wide range of behavioural, informational, economic and administrative barriers (Ugarte et al., 2016). The UK has one of the oldest housing stocks in Europe, which makes improving energy efficiency in the UK a serious challenge (Piddington et al., 2017). In addition, low-income household communities tend to rent their house, hence limiting their ability to improve the housing conditions that they live in, causing the landlord-tenant dilemma (Ástmarsson et al., 2013). Research highlighting the current major barriers to energy efficiency among low-income households in the UK will be an important topic to study.

Following the identification of significant barriers to energy efficiency among low-income households, this research aims to explore the practical approach to mitigation that low-income households could implement to improve energy efficiency and face the energy crisis. Among many themes, **this research identified behavioural change and technology as two practical mitigations** that might be controlled by low-income households and would be interesting to be further studied. Hence, this study will not cover the mitigations to energy efficiency that are not applicable to low-income households, such as the development of expensive renewable technologies or pilot projects to improve energy efficiency or higher level policy making that low-income households may not control.

The definition of **behaviour** in this study is adapted from Gaspari et al., (2021), which refers to the repetitive actions that can be done at home to induce the habit of energy savings. While behavioural changes are subtle, the impacts it has on energy efficiency can be significant. This includes actions such as reducing heater temperature, boiling water only as much as needed and using lower temperatures to wash clothes. A study by Gill et al., (2010) shows that behavioural actions in households improved energy efficiency by up to 51%,37% and 11% of heat, electricity and water consumption, respectively. Hence, introducing proper behavioural change in energy usage may make an impact in reducing energy demand and supporting low-income people to increase their energy savings while reducing greenhouse gas emissions

(Gaspari et al., 2021). Climate policies that target household behavioural decisions are reported as key to a low-carbon future (Dubois et al., 2019).

Technology, as defined by Brown (2020) is "materials and practice that require less energy to deliver a given service". In this study, the definition of technology adapted from Brown (2020) is any material change that could enable less energy to deliver a given service. The term "practices" was dropped from Brown's definition as practices without any material are grouped as behavioural actions. Hence, technology in this study includes housing improvement technologies such as structural repairs, information technology and renewable energy technologies that could help improve a households energy efficiency. Research by Schleich (2019) has demonstrated that low-income households tend to have lower adaptation of energy efficiency technologies. This is because low-income households tend to live in low-cost, non-refurbished houses and often do not have the financial means to pay for the latest energy-efficiency technologies. However, low-cost technologies such as simple structural improvements, improved heating controls, draught-proofing and smart meters could play a role in improving the energy efficiency of the houses. Other than that, the recently introduced heat pumps may benefit energy poor households as heat pumps have lower running costs and are deemed more efficient than traditional gas boilers.

1.1 Research question and objectives

Using literature reviews on the issue of energy efficiency among low-income households and qualitative interviews with participants working in different professions related to the energy industry, the aim of this research is to highlight the latest major challenges faced by low-income households in the UK and suggest mitigations on how to improve the energy efficiency among low-income households.

The research question for this research is:

How can behaviour and technology assist low-income households in making energy savings in the UK?

The objectives of this research are listed below:

1. To present an up-to-date context of the issues that led to the rise of energy poverty in the UK.
2. To present the importance of supporting low-income households in improving their energy efficiency.

3. To highlight the key barriers faced by low-income households in the UK to improve their energy efficiency.
4. To create a framework, which is a list of recommendations based on their ease of implementation, for how behaviour and technology could improve energy efficiency in the UK.

The research advances the knowledge available in existing literature by interviewing a wide range of relevant stakeholders to provide a deeper insight into the challenges of improving energy efficiency in low-income UK households and potential solutions

1.2 Structure of thesis

The thesis is structured as follows:

Chapter 1: Introduction. This chapter gives an overview of the key issues that led to the objective of this research. The method of the research is briefly explained, and the structure of the thesis is introduced to guide readers throughout the following chapters.

Chapter 2: Literature review. This chapter provides the background study for this research. The chapter starts with an overview of energy issues that led to increased energy prices in the UK. Then, the context of energy poverty and low-income households is explained. Following this, the chapter explains how improving energy efficiency might be an important step to assist low-income households in making energy savings. Finally, the chapter provides the context of how behaviour and technology may be the approach to mitigation for low-income households to improve their energy efficiency at home.

Chapter 3: Research Design and Methodology. This chapter starts with a research design which explains the rationale behind choosing qualitative interviews as the main method for this research. The overall research process is visualized in a diagram, followed by a list of the anonymous participants interviewed in this research. The limitations, timeline and ethical concerns of the chosen method are addressed.

Chapter 4: Results and Discussion. Chapter 4 presents the combination of results and discussion in one chapter. The importance of supporting low-income households in improving energy efficiency is discussed, the emerging barriers faced by low-income households in the UK are identified, and the implications of behaviour and technology for low-income households to improve their energy efficiency at home are discussed, which may help to address the

identified barriers.

Chapter 5: Conclusion. The final chapter presents a summary and draws the conclusion of this study. Limitations of this research are discussed, and suggestions for further research are recommended.

Chapter 2 Literature Review

This chapter provides the context for the research. First, the energy-related issues are presented which include the increasing global population, climate change and the global energy crisis which might have contributed to the increase in energy prices. Then, the definition of energy poverty and low-income households are presented. Next, the context of how energy efficiency can assist low-income households, including a study of the existing barriers, is presented. Finally, the proposal of behaviours and technology as an approach to mitigation of energy efficiency problems among low-income households in the UK is discussed. A glossary of the main terms used in this research is presented in **Appendix 1.**

2.1 Energy background

The rise of energy prices in 2022 is set against the background of a changing global energy landscape, a combination of many issues which coincide, which causes energy prices to soar. The changing global energy landscapes are summarized into three "energy issues" or background stories leading to the increase in energy prices, which are 1) the centrality of energy to the economy, 2) climate change which disrupts the energy market and 3) the 2021-2022 global energy crisis including COVID-19 and the Russia-Ukraine conflict which ultimately increased the demand and price of energy. In the following, we discuss how these energy issues led to an increase in energy demand.

2.1.1 The centrality of energy to the economy

Energy consumption has been **central to the development of the human population** and is a key factor in the economic growth of a nation (Abosedra et al., 2015; Stern, 2011). While ecological economists regard energy as the "central role in economic growth" (Stern, 2011), a study done in Lebanon shows a positive correlation between data on energy consumption, financial development and economic growth, which may indicate that energy plays a crucial role in building a country with a strong economy (Abosedra et al., 2015). Countries with strong economies create more job opportunities, resulting in higher disposable income for their residents, thus accelerating business growth and the economy as a whole (Abosedra et al., 2015). Countries with increased capabilities to produce and use energy when needed would have higher gross domestic product (GDP), which shows the country's economic strength (Liao et al., 2022). Increased human population means more reliance on energy consumption to support human activities. The world's population has tripled since the mid-twentieth century from about 2.5 billion in 1950 to about 8 billion people in 2022 (Gaigbe-Togbe et al., 2022).

Between 1850 and 1990, the growth of the global population was responsible for a 52% increase in global energy consumption (Holdren, 1991). If population growth continues, we might risk human overconsumption, which would be a big issue to address in ensuring a sustainable future (Ganivet, 2020).

On the other hand, an undersupply of energy might constrain a country's economic development (Stern, 2011). A weaker economy may lead to fewer job opportunities, lower overall disposable income among residents and less profitable businesses, causing a cycle of a weak economy. Therefore, it is **essential to strengthen energy security, which can be defined as a steady supply of energy at an affordable price** (IEA, 2023) **to ensure a strong economy for a country**. The United Nations came up with a revised set of guides for every nation termed the Sustainable Development Goals (SDG); among the 17 different sustainable development goals, the 7th SDG goal is to ensure "*affordable, reliable, sustainable and modern energy for all*" (United Nations, 2020). SDG goal number 7 highlights the need for sustainable energy security for every nation worldwide.

Energy consumption plays a central role in developing the population and the economy. As the human population grows, economic development will increase, causing the need for more energy consumption in the future. **Any limitation of energy supply during high energy demand may lead to a surge in energy prices** worldwide. Hence, improving energy security is increasingly vital by 1) introducing cleaner renewable energy sources and 2) reducing energy demand.

2.1.2 Climate change disrupts the energy market

Releasing excessive greenhouse gasses leads to global climate change, which disrupts the the supply of energy and affects the energy market. Climate change accelerated the energy transition from a fossil fuel-based energy to a much cleaner renewable energy ecosystem, pushing the need to control energy demand at certain times as renewable energy sources (mainly solar and wind) are inconsistent throughout different times of the day.

The Industrial Revolution started in the 18th century with the invention of the steam engine powered by fossil fuel, followed by the replacement of steam by electricity in the 19th century and the creation of integrated circuits in the 20th century (Coelho et al., 2023). The advancement in the industrial revolution signifies progress in the economy but also causes a significant increase in human-induced emissions, which causes climate change. In recent

years, climate change's impacts became evident with reports of warmer oceans and atmosphere, melting ice caps in the north and south poles of the world, increasing sea levels and extreme weather patterns not seen in the past (European Climate Foundation (ECF), 2014). In 2022, official weather reports show England facing one of the warmest summers since 1884 (*Met Office*, 2022). **Severe weather affects the energy market in a way that storms may force oil and gas productions at offshores sites to shut down**, **rising sea levels would cause powerplants that are situated near coastlines to close, oil and gas pipelines in cold climates would be affected by thawing permafrost underground and extreme storms may damage electricity grids** which supply energy throughout a country (European Climate Foundation (ECF), 2014).

Further studies based on different extreme climate situations, including storms, floods, extreme temperatures and wildfires, show a significant impact on the global natural gas market depending on the type of climate, location and time of events (Shen et al., 2023). These extreme climate events would heavily affect major natural gas-producing countries like the United States. In contrast, Europe and Asia would indirectly be affected through their international trade connections (Shen et al., 2023). Other than the natural gas market, extreme climate also disrupts the global harvest, affecting food prices and making a more significant dent in the economy than previously perceived (De Winne & Peersman, 2021). Extreme weathers that reduce harvest production increase the price of agricultural commodities worldwide. The increase in commodity prices heavily impacts countries that rely on importing their agricultural products from neighbouring countries, while less impacts of climate have been seen from agricultural exporter countries (De Winne & Peersman, 2021). C**limate change and extreme weather on the global scale may ultimately affect the energy market.**

Following the impacts of the excessive release of greenhouse gasses, which lead to climate change, the world is accelerating its efforts to transition from traditional fossil fuel-based energy to a cleaner, renewable energy source. However, the problem with **renewable energy sources is that they may not meet the human population's demand** (Schmalensee, 2022). The mismatch in human demand happens because the production of energy from renewable energy sources, especially solar and wind energy, varies throughout the day depending on the weather conditions and is incompatible with our consumption pattern. For example, the peak energy output from solar energy is around noon, with the highest possibility of solar radiation, and the peak energy consumption is usually in the afternoon when people arrive home from work. The imbalance between renewable solar energy supply and the

demand for electrical power can be explained by the "duck curve" seen in **Figure 1** (Patel, 2018). The peak at 6 a.m. represents the duck's tail while the 9 p.m. represents the duck's head. This duck curve emphasizes the need for thesystematic incorporation of storage into the system (an issue most governments are addressing from the development of better battery storage technology) to ensure solar energy produced matches the peak demand for electricity. In supporting the gap in energy demand at peaktimes, natural gas has been used as a transition fuel to provide extra electricity when needed.(Tanaka et al., 2019). Natural gas is reported to produce less than half the carbon emission released by coal, and natural gas power plants are more efficient than coal power plants (Tanakaet al., 2019).

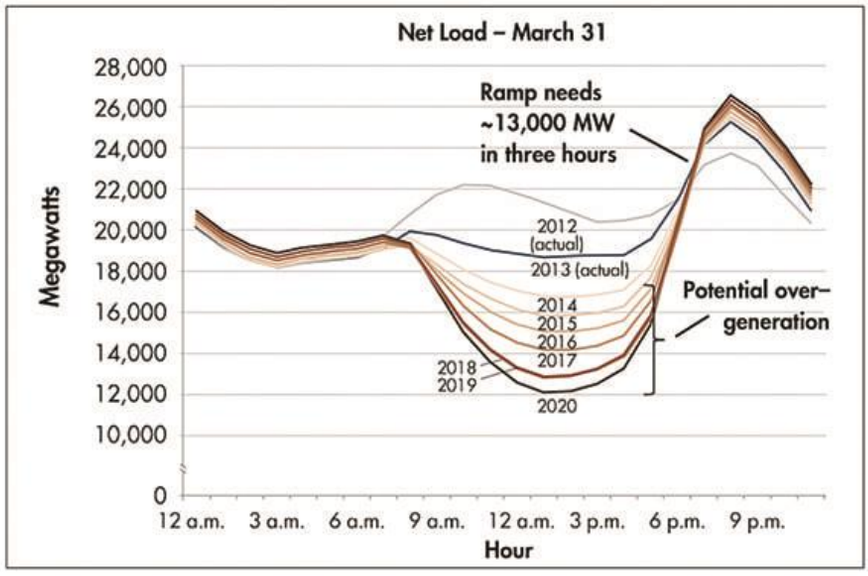

Figure 1: The "Duck Curve" which represents the imbalance of energy demand throughout the day against the supply of solar energy. The peak at 6 a.m. represents the duck's tail while the 9 p.m. represents the duck's head. The development of solar energy means a higher amount of energy generated between 1-3p.m., increasing thepotential of over-generation of electricity. (California Independent System Operator, 2013 as cited by Patel, 2018)

Climate change led to the introduction of the Net Zero goals. Countries across the globe agreed to the Net Zero goal, which aims to reduce greenhouse gas emissions to a point where the cumulative anthropogenic CO_2 emissions are balanced globally by anthropogenic CO_2 removals (IPCC, 2022). The Net Zero goal also includes limiting global warming to 1.5°C relative to pre-industrial levels by 2050 (IPCC, 2022). An increase of more than 1.5°C will cause irreversible impacts on the earth, including increased risk of local species extinction, sea level rise, risk of water and food security, human health, extreme weather and much more (IPCC, 2022). The pathways to Net Zero goals mainly comprise a rapid phase-out of the production of CO_2 and other greenhouse gasses (IPCC, 2022). Countries can achieve Net Zero goals through energy, industry, transport, buildings, agricultural, forestry transformations, and

other land-use sectors (IPCC, 2022). The IPCC recommends lowering energy usage, including enhancing energy efficiency and diversifying energy sources such as renewable energy.

2.1.3 2021-2022 energy crisis

Added to the mounting pressures of energy security from an increased population and the energy transition towards renewable energy, the **economic bounce back after the COVID-19 pandemic and the Russia-Ukraine conflict between 2021-2022 further escalated the energy demand, pushing energy prices higher than ever.**

The energy crisis of 2021-2022 was a combination of different issues, including the recovery from the COVID-19 pandemic and the reliance on natural gas, which heavily impacted global energy prices, pushing countries to improve their energy security policies (Gilbert et al., 2022). The COVID-19 pandemic slowed the global economy, leading to lower energy demands and prices. Some companies had to announce bankruptcy and were forced to shut down because people were in lockdown; hence, the economy was heavily affected. Studies have shown that the damage to the economy caused by the COVID-19 pandemic was slightly worse than the 2008 global financial crisis(Yagi & Managi, 2021). As the global economy started to recover from the global COVID-19 pandemic around the end of 2021, the rise in energy demand overwhelmed the energy supply, causing increased demand for fossil fuel, leading to a massive increase in energy prices worldwide (Gilbert et al., 2022).

European countries, including the UK, have relied on natural gas to power national energy production, mainly supplied from other countries, including Russia (Gilbert et al., 2022). The war between Russia and Ukraine that escalated in 2022 affected countries' political relationships, especially in Europe. The reliance of some European countries on natural gas, which Russia mainly supplies, increased the volatility of energy prices worldwide. For example, the closing down of the Nord Stream 1 pipeline built between Russia and Germany through the Baltic Sea could have up to 60% of natural gas supplies to Germany (Nick Butler, 2022). The reliance on natural gas from Russia, combined with the political tensions between Russia and European countries, led to a gas and energy market strain. This conflict increased energy prices worldwide by up to 20% in 5 months after the Russian invasion from February to July 2022 (Yagi & Managi, 2023).

In summary, subchapter 2.1 explains the background of the rise of energy prices in 2022. The **centrality of energy to the economy** meant that with an increasing population and rising economy, there is a growing need for energy security. Then, **climate change** disrupts the energy market, accelerating the transition to renewable energy, which requires a shift in how we use our energy. Finally, the COVID-19 pandemic and the Russian-Ukraine **conflict in 2021-2022** exacerbated energy demand and prices worldwide.

2.2 Energy-poor and low-income households are heavily affected

The problem of energy poverty is a long-term global issue. To begin with, the terms energy poverty and fuel poverty are used interchangeably in the literature. A study on the differences between the two by Li et al., (2014) found that previous research on energy poverty is mainly based on the lack of electricity access in developing countries. On the other hand, previous research on fuel poverty is mostly done in the cold climate countries such as the United Kingdom (UK) and is focusing on the inability to maintain adequate indoor heating (Li et al., 2014). The main similarities between both terms are that the research covers residential sectors, and the primary group concerned with this issue are low-income people (Li et al., 2014).

The different definitions and measurements of energy poverty can best be summarised into three approaches which are technological, physical, or economic thresholds (González-Eguino, 2015). The technological approach is when the energy poverty is measured through people's ability in accessing modern energy services such as electricity for heating and cooking (González-Eguino, 2015). This method is commonly seen in energy transition studies in developing countries where the availability and access to electricity is used as a measure of energy poverty(Li et al., 2014). The next measurement of energy poverty is from a physical threshold where it looks at energy consumption linked to the people's necessities (González-Eguino, 2015). For example, the electric consumption per person per annum is set at 100 kWh (González-Eguino, 2015). However, the limitation of this method is that there are variations in defining the level of a basic necessity depending on the lifestyle and geography of a location. Finally, the measurement of energy poverty through an economic threshold is by looking at the percentage of income that is spent on energy bills (DESNZ, 2023; González-Eguino, 2015).

In the European Parliament report on energy poverty, energy poverty is defined as a "situation where a household cannot meet its domestic energy needs" (European Parliament, 2022). This definition is more general as domestic energy needs cover a wide range of factors including keeping the house warm, proper air quality, and a good standard of living. In the UK, the preferred term is fuel poverty as the main problem is providing adequate heating for houses, especially in cold seasons (Davey, 2012; Eyre & Killip, 2019; Mejuri, 2019). Fuel poverty is defined differently in each nation of England, Wales and Scotland (BEIS, 2022a). The current definition of fuel poverty in England is defined using a more sophisticated Low-Income Low Energy Efficiency (LILEE) metric where households are considered poor if they live in households with poor energy ratings combined with a disposable income lower than a specific

threshold (DESNZ, 2023). Before 2013, England used a simpler definition of fuel poverty where fuel poverty is defined as spending more than 10% of income (after housing costs on domestic energy (DESNZ, 2023). This measure of 10% indicator is still used as the main method to measure fuel poverty statistics in Scotland and Wales (BEIS, 2022a).

For the context of this study, the researcher decided to use energy poverty over fuel poverty as the main term of discussion, based on the broader definition of energy poverty provided by the European Parliament (European Parliament, 2022). This research defines energy poverty as adapted by DESNZ (2023) as households spending more than 10% of their income (after housing costs) on domestic energy.

Energy poverty and low-income households are closely related. Low-income households are defined as people that live in households with an income below 60% of the median household income, adjusted for inflation (Francis-Devine, 2023). People with low monthly income may need to pay more of their income on energy bills compared to those of higher income groups which puts many low-income earners in the energy poverty group. Extreme situations of energy poverty may lead to people having to choose between buying for their families or paying for gas to keep the house warm for the month, especially during cold winter seasons (*Energy Saving Trust*, 2021). Hence, in this research, when addressing the issues of energy poverty, the main target group to be supported are low-income households.

The inability to keep houses warm may lead to mouldy houses in the winter and can lead to serious health complications, degrading the health of their occupants and potentially leading to an increased rate of mortality (Kolokotsa & Santamouris, 2015). An EU report on energy efficiency among low-income households further supports this claim by summarizing the three main factors that lead to a vicious cycle causing energy poverty, which are: 1) low-income, 2) poor energy efficiency houses and 3) high energy bills (Figure 2) (Ugarte et al., 2016).

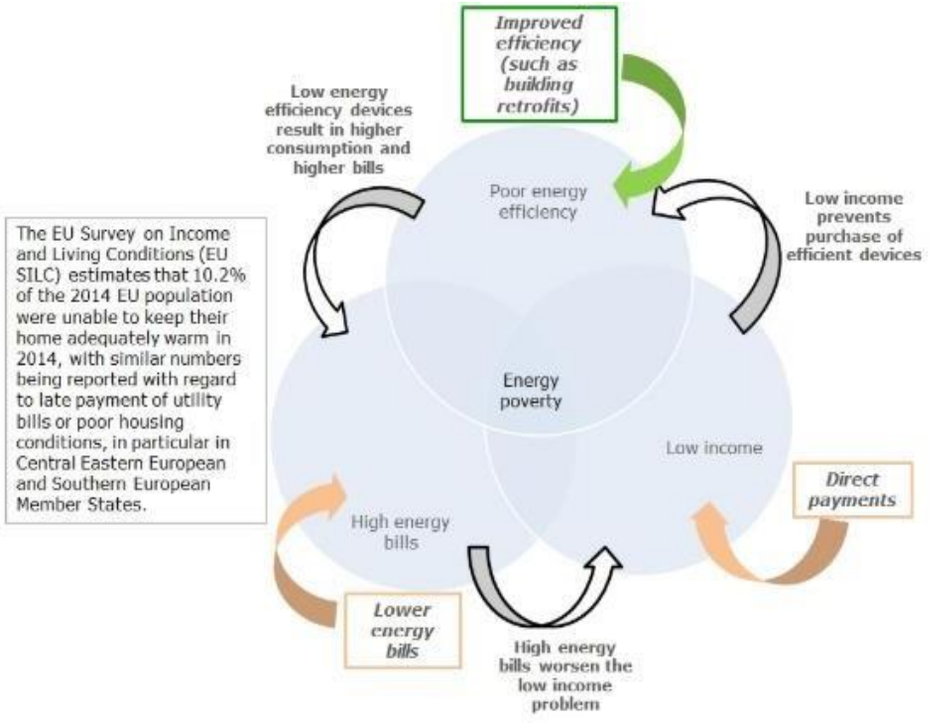

Figure 2: Cycle of energy poverty include three main factors which are low-income, poor energy efficiency and high energy bills. Source: Ugarte et al 2016.

Figure 2 explains the relationship between the three factors that aggravate the cycle of energy poverty. Low-income people receive little money for their monthly spending. This prevents them from installing high quality retrofits to improve building conditions, or installing energy efficiency equipment. The low energy efficiency equipment then results in higher energy use compared to average equipment which leads to increased energy bills to be paid each month. The increased energy bills will add to the burden on low-income people to be paid monthly. This is the energy poverty cycle for low-income households.

2.2.1 Context of energy poverty in the UK

In previous sections after looking at the issue of energy poverty and its relationship to low-income households in general, it is important to look at the issue of energy poverty in the specific context of the United Kingdom.

In 2022, **30.3%** (7.39 million) of households spent more than 10% of their income (after housing costs) on domestic energy (DESNZ, 2023) and by definition are categorized as living in **energy poverty**. The **average income** after housing costs is £500 per week (or £26,000 per year) in the year 2022. (UK.GOV, 2023). This equates to about £2000 average income per month.

Price cap and increasing energy bills in the UK

A news article reported unpublished studies on how more than three-quarters of UK households would be in fuel poverty by the new year of 2023 (Bradsh, 2022). Official UK domestic energy prices (as shown in **Figure 3**) report that the average annual energy bills recorded for 2022 doubled since 2010, and the annual increases in both gas and electricity prices to October 2022 were the largest ever increase recorded since 1970 (Bolton & Stewart, 2023). The average annual gas bills for households in the UK increased from £520 per year in 2010 to about £691 per year in 2014 before staying below £610 for the next years until 2021, when the prices skyrocketed to **£1,097 in 2022** (Bolton & Stewart, 2023). The electricity bills on the other hand gradually increased from £451 in 2010 to around £769 in 2021 before the prices jumped to **£1,219 in 2022** (Bolton & Stewart, 2023). One of the main reasons behind this spike in energy prices is the increase in the price cap by the UK government on 1 October 2022. Hence, the **average annual energy bills for the whole year in 2022 for gas and electricity combined is about**
£2,316 per year, or £193 per month (Bolton & Stewart, 2023).

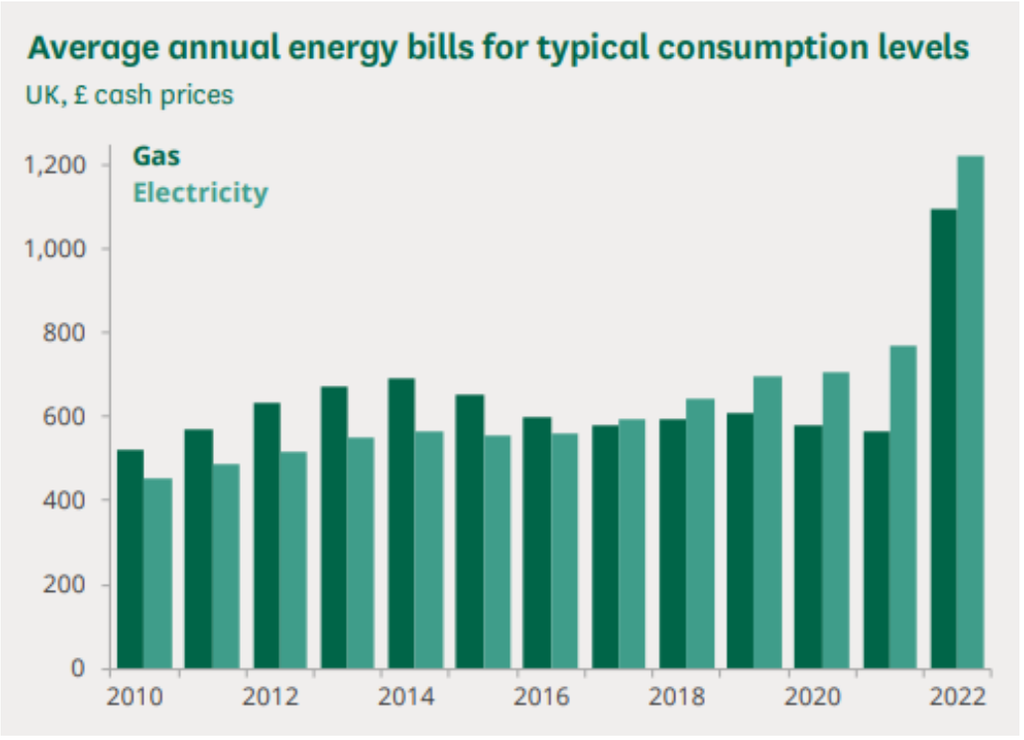

Figure 3: The average UK annual energy bills for gas and electricity consumption increment from 2010 to 2022. Source: Annual domestic energy bills, BEIS. (B.P. Bolton, 2023)

A price cap is a limit set by the government on the price per kilowatt hour (kWh) of energy set by the suppliers to the consumers. Traditionally, UK citizens are covered by the price cap which limits the monthly energy bills paid each month. However, the various global events of 2020-2022, particularly COVID-19, supply chain distributions and the political conflicts involving Ukraine have caused the global price of energy to soar. One of the reasons is that the supply of fuel did not recover in time for the increase in demand for energy post-pandemic COVID-19 (Gilbert et al., 2022). Noting the fact that this was a global issue, every country was affected. However, countries which heavily relied on natural gas such as the UK would face exacerbated impacts on their energy prices. When the UK energy price cap was raised on October 2022, people were left to pay higher energy bills than ever to get a supply of gas and electricity. Under the ruling of Liz Truss, an Energy Bills Support Scheme was introduced where households are provided with a £400 one-off discount on energy bills from October 2022 to March 2023 (GOV.UK, 2023). This helped to ease the burden of households in the UK in facing the cold winter times.

In summary, the spike in energy bills and the energy crisis in 2021-2022 further intensifies the problem of energy poverty in the UK.

Energy Performance Certificate (EPC)

In the UK, the measure of energy efficiency in buildings is rated using the Energy Performance Certificates (EPC). This EPC rating would then be used as a measure to implement the Minimum Energy Efficiency scheme explained in the next sections of the discussion, hence it would be important to understand how the EPC rating is read (GOV.UK, n.d.). The EPC rating are listed from A to G with rating A being the most efficient and G as the least efficient, as shown in **Figure 4**. This is done by an accredited house assessor which rates various criteria of the house including the amount of energy used per square meter, conditions of walls, roof, windows, lightning and heating controls. Hence, this measure is a great measure to regulate the housing conditions in the UK.

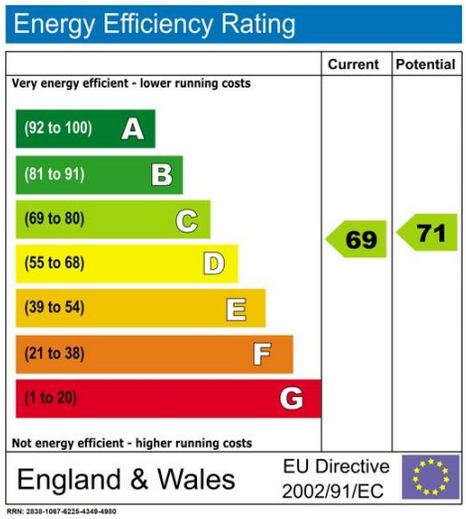

Figure 4: Energy Performance Certificate rating as a measure of housing energy efficiency standards used in the UK. Source:(EDF EPC Rating, n.d.)

Minimum Energy Efficiency Standards

One way to improve energy efficiency standards in the UK is by introducing the Minimum Energy Efficiency Standard (MEES), which is a guide for private rented property landlords set out by the government to keep high-level standards of energy efficiency (*Minimum Energy Efficiency Standard*, 2020). Past MEES rule sets that properties in the UK must at least have an EPC rating of E or better for it to be rented. Recently, this standard has been suggested to be increased to a minimum EPC level of C instead of E for private rented houses by 2028 to support the UK's aspirations of reaching net zero carbon emissions by 2050 (Committee on Climate Change, 2020).

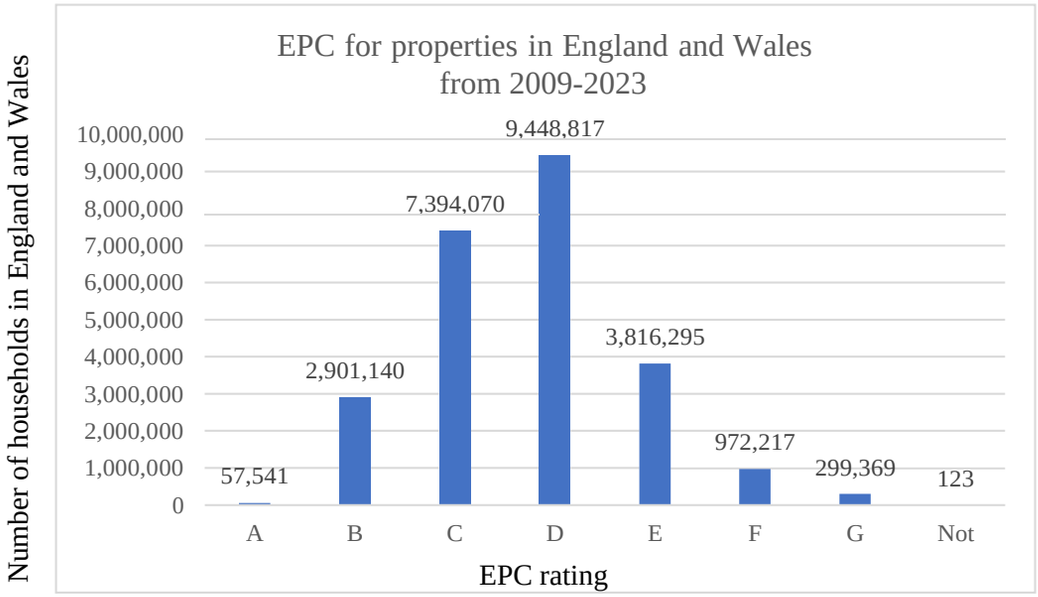

Figure 5: Statistics of the Energy Performance Certificate EPC ratings of houses recorded in the United Kingdom from 2009 to 2023. Source: Table D1: Domestic Energy Performance Certificates for all dwellings by energy efficiency rating (*Live Tables on Energy Performance of Building Certificates*, 2023)

Figure 5 shows the official statistics of the 2009- 2023 EPC reported for existing dwellings in England and Wales obtained from the UK government database (*Live Tables on Energy Performance of Building Certificates*, 2023). As of the latest update on 27th July 2023, a total of 10,352,751 out of 24,889,572 properties (41.6%) are reported to have an EPC rating of C and above compared to the overall buildings for England and Wales. Hence, raising the bar of a minimum energy efficiency standard of C for rented houses will be expected to drastically increase the overall energy efficiency of houses in the UK.

In summary, this sub-chapter explains the difference between the term energy poverty and fuel poverty, by which the term energy poverty is preferably chosen for this research. The context of the energy landscape in the UK such as the energy price cap, EPC rating and MEES were introduced which would provide a context for the following discussions.

2.3 How to assist low-income households: Improving household energy efficiency

In previous sections, the factors that escalate the issue of energy poverty were discussed. In this section, the research looks at existing actions that could be done to assist these low-income households in going through the energy crisis.

Various institutions work specifically on eradicating energy poverty and supporting low-income households. These institutions include the Centre for Sustainable Energy (CSE), Bristol Energy Network, and National Energy Agency, as well as energy suppliers such as Octopus Energy and OVO Energy which consistently try to support vulnerable people going through the energy crisis. As people struggle to pay the increasing energy bills, the guidance that these organisations provide is becoming more important than ever.

According to the Centre for Sustainable Energy, this energy crisis in 2022 has doubled the number of households falling into fuel poverty (*CSE*, 2022). In going through the energy crisis in 2022, CSE suggests that the UK government must do more to support vulnerable people, improve building insulations and improve the energy efficiency of households depending on the physical and financial capability of each people (*CSE*, 2022). From the information obtained from CSE, this research is interested in looking at what consumers can do on the ground, which among these are reducing energy consumption, insulating homes and improving energy efficiency (**Figure 6**).

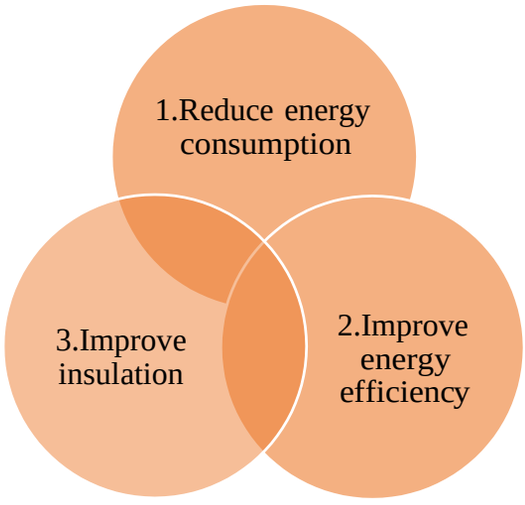

Figure 6: Demand side suggestion that can be done to help overcome the energy crisis in 2022. Source: (*CSE*, 2022; Eyre, 2022)

The first important step for consumers in facing the energy crisis is to cut unnecessary energy consumption and reduce energy demand. According to data, the main factors that dominate energy usage in buildings are heating, cooling, lighting and appliances (Eyre & Killip, 2019) Hence, simple behavioural changes such as switching the lights off when not in use, only boiling water as much as needed, and setting up timers for central heating should give an impact in reducing energy consumption at the household level.

As the impacts of energy demand in the energy transition are seen as increasingly important, the Centre for Research into Energy Demand Solutions (CREDS) was established. In a report by CREDS titled "Shifting the focus: reducing energy demand in a net-zero carbon UK", CREDS listed several main suggestions for improving energy demand in the UK. This includes recommendations to reduce energy demand in the transport, buildings, industry, and electricity sectors which are the main sectors contributing to energy consumption in the UK (Eyre & Killip, 2019). By improving energy demand in these sectors, it would help the UK to transition to a secure and affordable low-carbon energy system in the future (Eyre & Killip, 2019).

The next step after reducing demand is to increase energy efficiency to keep houses warm. This can be achieved by improving the house conditions with actions such as improving insulation and making sure houses are draught-free. Draught-proofing doors and windows to prevent ingress of cool air is a low-cost solution to keeping houses warm. In addition, double-glazing windowpanes, installing mineral wood fibre and other insulation in between drywalls help to contain heat inside buildings. The details of available actions that could be done to improve energy efficiency will be discussed in detail in the following sections.

Hence, the literature study shows that the main recommendations to assist low-income households on the demand side are to reduce energy consumption, improve every aspect of energy efficiencies in their daily lives and, most importantly, improve housing insulation to help keep houses warm throughout cold days.

2.3.1 Barriers to energy efficiency among low-income households

This section looks at previous studies related to the topic of barriers to improving energy efficiency faced by low-income households. Some of the most relevant research focused on barriers to energy efficiency among low-income households was done in the wider scope of Europe (Kolokotsa & Santamouris, 2015; Ugarte et al., 2016), while there was also research done on barriers to energy efficiency specific to the fuel poor in the UK (Fylan et al., 2016).

In addition, there were studies done on energy efficiency strategies for the UK which cover people from all levels of income (Davey, 2012) and also studies on the problems faced by the fuel-poor and low-income people in the UK in general which were not specifically mentioned to relate to energy efficiency (Anderson et al., 2012; Middlemiss & Gillard, 2015). Other than that, studies were done on the topics of behavioural change (Hafner et al., 2019) and smart meters which may relate to improving energy efficiency actions which were found in the literature. The wide range of background studies which were related to the aim of understanding barriers to improving energy efficiency among low-income households were summarised and listed to provide an overall context of the study as described in **Table 1**.

While the list of barriers is divided into separate groups, it is acknowledged that some barriers may be inter related with other barriers, as will be explained in the discussion.

Table 1: List of barriers identified from previous studies related to energy efficiency among low-income households.

Types of barriers	Description	Region	Source
Building	Poor housing conditions	EU, UK	Kolokotsa & Santamouris 2015, Middlemis 2015, Anderson 2012
	Retrofitting installation issues	UK	Fiona 2016
	Smart meter installation	Global	Batalla-Bejerano et al., 2020
Economic	**Financial**		
	Lack of savings	EU	Ugarte 2016
	Low credit score	EU	
	Energy market or policies that does not support the energy efficiency sector	EU, UK	Ugarte 2016, Davey 2012
	Incentives		
	Landlord-tenant split incentive	EU, UK	Middlemis 2015,
	Subsidies on energy price	EU	Ugarte 2016
	Misaligned financial incentive	UK	Davey 2012
	Risk aversion		
	Uncertain about the future situation		
	Fear to acquire debt	EU	Ugarte 2016
	High upfront cost with less obvious benefit		
Informational	**Dwelling**	EU	
	No knowledge of energy consumption	EU	Ugarte 2016
	No knowledge of savings potential	EU	
	External	EU	
	Lack of information about support programmes/grants	EU, UK	Ugarte 2016, Davey 2012
	Lack of information on consultancy	EU	
	Lack of information on person-specific information	EU	Ugarte 2016
Behavioural	Tendency to procrastinate	Global	
	Copying other people	Global	Hafner 2019
	Fear of regret to be wrong	Global	
	Hassle costs of repairing	UK	Davey 2012

Building

The previous study shows a lot of barriers related to building conditions which impact low-income households. In most European countries heating is necessary for people to keep warm during cold seasons. One of the main issues with building conditions in Europe is inadequate heating which causes people to live in cold houses which are below the average human comfort level (Kolokotsa & Santamouris, 2015). Low-income households live in bad building conditions which may lead to dampness (Kolokotsa & Santamouris, 2015). The dampness

problems tend to occur in buildings with improper ventilation which could harm human respiratory systems and lead to several health conditions. In research done in the UK, two-thirds of people reporting physical health problems such as respiratory problems live in cold homes and inappropriate heating (Anderson et al., 2012). Another study on the vulnerability of fuel-poor people suggested the low quality of dwelling fabrics which were reported to be inappropriate or deteriorating as one of the main challenges for low-income households (Middlemiss & Gillard, 2015).

Other than that, the quality of installing energy efficiency measures such as external wall insulation is also a reported problem. Fylan (2016) reported that participants of their retrofit survey in the UK emphasize the need for improving site surveying before installing energy efficiency measures. For example, in the previous Green Deal government scheme, there was a slight problem between the system designer and installers where it was reported that the system designer's inaccurate planning for external wall insulation had to be corrected by installers on the site which impacted the quality of the installation(Fylan et al., 2016).

Old housing stocks in the United Kingdom

One of the biggest factors affecting the energy poor in the United Kingdom is the issue of housing stocks. The United Kingdom has one of the oldest housing stocks in Europe with only about 15% of existing stock built since 1990 (Business Energy and Industrial Strategy Committee, 2022). The old housing stocks have lower insulating capabilities to contain heat to keep the house warm. In terms of carbon emissions, the heating sector contributes to about one-third of the economy UK's annual carbon footprint. In 2019, 17% of the building emissions came from heating homes (Business Energy and Industrial Strategy Committee, 2022). A less efficient house would relatively produce more carbon emissions as these houses could not contain the heat efficiently, increasing the need to continuously heat the home to a certain level of comfort. But the owner of a poorly insulated home may choose to live in a lower comfort level if they are not prepared to pay for the energy. Hence, the quality of the buildings in the UK will give a big impact on the ability of people to keep safe and warm.

The UK government set out a national target of reaching net zero greenhouse gas emissions by 2050 compared to the 1990 levels (Business Energy and Industrial Strategy Committee, 2022). By targeting to reduce emissions, the government would need to accelerate the decarbonization of housing stocks as well. In the Sixth Carbon Budget: The UK's path to Net Zero, the plan is to improve the energy efficiency of all buildings in the next 10-15 years

while phasing out the installation of new fossil fuel heating in 2020 and expanding heat networks such as the installation of heat pumps instead of gas boilers, especially targeting main buildings such as schools and hospitals through to 2050 (Committee on Climate Change, 2020).

Economic

The next barrier to energy efficiency among low-income households is the economic factors which cover financial, incentives and risk aversions.

In financial terms, low-income households tend to have low-paying jobs which makes life difficult as people are left with limited options. This also means people will lack savings for additional house improvements (Ugarte et al., 2016). Low-income households tend to have lower credit scores which makes it more difficult for them to apply for government and other loans (Ugarte et al., 2016). In addition to that, reported that the UK has an "embryonic market" where the energy efficiency market is not as developed as other countries such as seen in the USA. Compared to countries like the USA, the UK might still not consider the energy efficiency market as a priority. Other than residential houses, there must be more emphasis on developing the energy efficiency market in different sectors such as commercial, industrial and public sectors to improve investment in the energy efficiency market (Davey, 2012). For example, industrial buildings such as offices and manufacturing companies, and public buildings such as government offices and local amenities are less mentioned when talking about energy efficiency. These places should be promoted to improve their building energy efficiencies, in hopes to develop the energy efficiency market in the country and attract investments.

In terms of incentives, the barriers identified include subsidies on energy prices from the government (Ugarte et al., 2016). Subsidies on energy prices make people more complacent on their energy usage as people may consume more energy than they actually need without thinking of energy saving because of the lower prices (Ugarte et al., 2016). Other than that, the policies set out by the government also impact investments in the energy market. For example, the long periods of debt payback make investment in energy efficiency less attractive to investors (Ugarte et al., 2016). Misaligned financial incentives are also a big barrier to energy efficiency (Davey, 2012). This is most commonly seen in rented properties where the responsibility to upgrade the house is split between the landlord and the tenant. This is called the landlord-tenant dilemma where there are "difficulties in agreeing upon a common strategy

for energy efficiency improvement of a property" (Ástmarsson et al., 2013). Tenants are usually from lower-income groups, and about 30% of people in Europe live as tenants (Ugarte et al., 2016). As tenants, people would want to have energy efficiency upgrades to save on energy costs but as landlords, if these upgrades cost a lot and do not give a beneficial return, it can be seen as not worth improving the state of the property. Hence, it is difficult to target the right groups for incentivizing rented properties.

Informational

In terms of informational barriers, these can be divided into two different categories which are dwelling and external information.

Dwelling information can be a barrier when people do not know their energy consumption or the energy-saving potentials that could be done in the households (Ugarte et al., 2016). This might happen when people have no awareness of the impacts of their daily behaviour and how it impacts their energy bills. In addition, the lack of information on energy savings measures outside the households is also a barrier to be highlighted. This includes people with no knowledge of support grants available to them (Davey, 2012; Ugarte et al., 2016) or knowledge about organisations that could offer them support (Ugarte et al., 2016). The lack of information on the campaigns and support programs available for low-income households prevents them from making full use of the opportunities available.

Behavioural

The behaviours of people also act as a barrier to improving energy efficiency among low-income households. A study on promoting behavioural change in households shows that barriers arise when people tend to procrastinate in making house improvements. Other than that, people tend to copy their peers before deciding, and finally, the fear of making the wrong decision stands in the way of promoting behavioural change in a certain household (Hafner et al., 2019). The nature of the energy efficiency impacts which are not large scale or obvious in the short term makes it difficult for people as it incurs a lot of "hassle cost". Hassle cost here can be defined as the additional tasks associated with the main action which annoys or frustrates the individuals. In terms of energy efficiency, hassle costs include the survey needed before any construction work, disruptions by building works and efforts for maintenance, which makes people reconsider if energy efficiency improvements are worth it (Davey, 2012).

2.4 Approaches to mitigation

Following the literature review on the barriers to energy efficiency among low-income households, the barriers are divided into two themes, which are external and internal. External themes are those which are out of the low-income people's control, including policies and government incentives, while internal themes cover scopes which could be done by the low-income people, such as informational, low-cost house retrofitting and behavioural actions.

In answering the research aims of helping low-income households save energy, this research will further focus on two internal themes: behaviour and technology. The behaviour and technology themes were chosen because they are internal themes that can be practical mitigations for low-income people to apply on the ground. Other than that, the themes of behaviour and technology have surfaced in several debates on their impact on energy saving. This will ensure that the findings of this research can be beneficial and directly applied by the low-income household groups in going through the rising energy prices, especially going into winter. The external themes which may not be directly applied by low-income households, such as government-level policy planning, are essential but are not the central focus of this research.

Hence, this research will explore the impacts of behavioural and technological actions by low-income households in improving household energy efficiency.

2.4.1 Behaviour

Behaviour has been defined in different ways in the literature. Gill et al. (2010) defined behaviour in an energy context as a consequence of complex interactions which impact electric, heat and water consumption, while Palmer et al. (2012) defined behaviour more generally as a change in the way people use energy in their homes which may include the use of technological upgrades at home. For the context of this study, the definition of behaviour is adopted from Gaspari et al., (2021), which refers to the repetitive actions that can be done at home to induce the habit of energy savings without including any technological improvements. This includes measures such as reducing heater temperature, boiling water only as much as needed and using lower temperatures to wash clothes (**Figure 7**). While these behavioural changes are subtle, their impacts on energy efficiency can be significant. The definition by Palmer et al.(2012) and Gill et al. (2010) were not chosen in this research to separate behaviour from technological improvements.

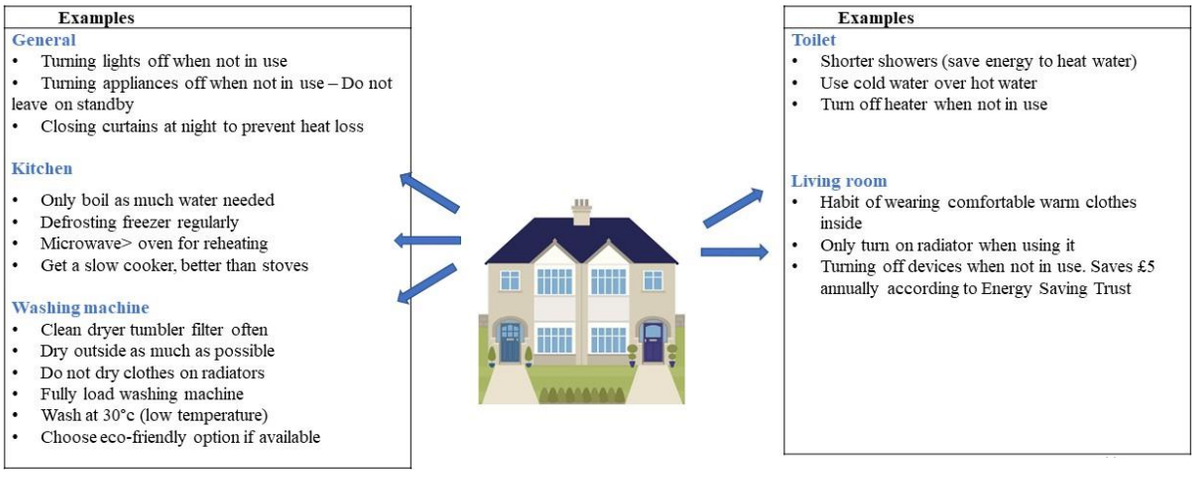

Figure 7: Compilation of behavioural actions to improve energy efficiency.
Sources: (Martiskainen,2014), (Centre for Sustainable Energy), (British Gas).

Several studies have demonstrated the impacts of behavioural changes on improving household energy savings. Gill et al., (2010) shows that by implementing subtle behavioural actions, households improved energy efficiency by up to 51%, 37% and 11% of heat, electricity and water consumption, respectively. Behavioural change in energy usage also gives a two-fold advantage of reducing the energy demand and supporting the energy transition (Gaspari et al., 2021). In moving forward, climate policies that target household behavioural decisions would be key to a low-carbon future (Dubois et al., 2019).

However, some authors argue that behaviour does not give much of an impact (Nisa et al., 2019). The study on testing behavioural intervention impacts on six different areas related to mitigating climate change including energy consumption at home, transportation, consumption of animal products, food waste, water consumption and recycling shows that behaviour alone does not give a direct impact on climate mitigation actions (Nisa et al., 2019). The impacts of behavioural actions on energy savings may also be countered by the rebound effect (Abrahamse et al., 2005). A good example is when houses save money from energy efficiency actions, they tend to increase the time to heat houses, resulting in the same amount of money spent in total. Finally, the behaviours of humans are complex and affected by many factors. The different patterns of energy consumption *" vary with gender, age, race, education, health, disability status, cultural attributes and also the occupation of members* which all impacts the behavioural actions of energy consumption (Brown et al., 2020).

2.4.1 Technology

The other theme identified as an internal barrier that could be overcome by people on the ground is technology. Technology in this study was adapted from Brown (2020) and is defined as "materials that require less energy to deliver a given service", which includes structural repairs, information technology and renewable energy technologies that could help improve a households energy efficiency There are a variety of technologies that could be suggested to improve the lives of low-income households, as seen in **Table 2**. This includes housing improvement technologies such as **structural improvements,** which include adding secondary glazing on windows and draught proofing. In addition, **information technology,** where users are informed about their energy usage through advanced metering, has the potential to assist low-income households in making energy savings (Brown et al., 2020). Other than that, the **integration of renewable energy** is currently being developed which could help improve housing energy efficiency. Some examples are solar rooftops and microgrids in isolated regions that use solar and battery storage to move off the grid are interesting available technologies.

Table 2: Compilation of possible technologies available for low-income households to increase energy efficiency. Sources: (Kolokotsa& Santamouris, 2015), (Centre for Sustainable Energy),(Brown 2020),(British Gas)

Technological types	**Example**
Structural improvements	-Draught proof windows & doors
	-Secondary glazing
	-Insulating hot water cylinder
	-Loft insulation
	-Cavity wall insulation
	-Solid wall insulation
	-Heat pumps
Information technology	-Company time-of-use tariff schemes
	-Smart meters
	-Smartphone applications connected to smart - thermostats
	-Installation of smart electrical appliances: smart lighting, smart thermostat, smart oven
Integration of renewable energy	-Solar rooftops
	-Microgrids in isolated regions
	-Community solar arrays & battery storage for off-grid consumers

To further understand the activities for each term, the examples of technological actions that could be done to improve energy efficiency are further explained (*Energy Saving Trust*, 2023):

Draught-proofing- Refers to improvements that help to prevent excessive cold air into house spaces, thus helping to prevent heat loss. These improvements include self-adhesive foam strips, silicon sealants or brush strips.

Secondary glazing- This can range from the most expensive level of fitting new, improved windows for the entire house to cheaper do-it-yourself options such as insulating films that help to contain the heat in the windows.

Insulating hot water cylinder- Insulating hot water cylinders or tanks include wrapping the tank that stores hot water for houses using a layer of thick insulating jacket.

Cavity wall insulation: Insulation material is fitted in the cavity of the wall using specified equipment.

Loft insulation: Lofts or attic are the upper-most areas of a house which can impact the whole house's temperature if not insulated properly. Loft insulation is usually done with rolls of mineral wool or other insulation.

Solid wall insulation: Solid wall insulation can be divided into two, which are internal and external. These both involve installing an additional layer of insulation on top of the solid wall.

Information technology: Company time-of-tariff initiatives such as the Octopus Energy Saving sessions encourage households to reduce their energy consumption during peak hours when the price of electricity is high. This can be assisted by smart meters which displays real time information on the household energy consumptions. Smartphone applications may also help to save energy by connecting the applications with smart thermostats. Therefore, households can control the electrical appliances, especially heating for specific rooms, to heat the house more systematically.

Renewable energy: Solar energy is one example of integrating renewable energy to improve energy efficiency. By installing solar panels into the housing system, the users can save on electricity, as well as sell excess electricity back to the grid.

Hopkins (2023) found that, in the UK, “about 9 million people could lack sufficient energy for meeting decent living standards in 2050”, which can be mitigated by “ensuring highly energy-efficient technologies are available at all income levels”. This research highlights the importance of technologies to assist low-income households in making energy savings. The technologies for low-demand strategies include installing heat pumps through funding, phasing out gas boilers, fabric improvements, efficient lighting & appliances, smart metes and controls and demand response. Heat pumps are proposed as a means of heating a house efficiently using heat stored in the ground, which is a cleaner alternative than standard gas boilers. However, they are a bit more controversial to apply in cases of energy poverty because the capital cost is high, and the savings may be small if electricity prices are high.

Research by Schleich (2019) has shown that low-income households tend to have lower adaptation to energy efficiency technologies. This is because low-income households tend to live in low-cost, non-refurbished houses and do not have the financial means to pay for the latest energy-efficiency technologies. Low-cost technologies such as insulation, improved heating controls and smart meters could play a role in improving the energy efficiency of the houses. Awareness of the available support for the replacement of gas boilers with heat pumps also would have an impact on improving the energy efficiency of low-income households.

However, several studies claim that the implementation of technology is rendered useless if not paired with the right attitude and information (Batalla-Bejerano et al., 2020; Brown et al., 2020). It was also found that information technology such as smart thermostats was impactful but inadequately incorporated into low-income energy programmes such as in government financial incentives and regulations (Brown et al., 2020). Hence, this research is interested in exploring how far behaviour and technology could impact energy efficiency actions among low-income households.

Key points and research gap:

- This chapter discusses the context of the changing energy landscape, which increased energy prices worldwide in 2022. The rise in energy prices starts with the increasing demand for energy and the growth of the economy and human population. This is then followed by climate change and extreme weather, which disrupts the supply of energy and the balance of the energy market. Finally, the 2021-2022 events such as the bounce back in economic activity after the COVID-19 pandemic and the Russia-Ukraine conflict further exacerbated the energy prices worldwide.
- The increase in energy price has the greatest impact on low-income households, increasing the number of people falling into energy poverty. In 2022, **30.3%** (7.39 million) of households in the UK spentmore than 10% of their income (after housing costs) on domestic energy (DESNZ, 2023).
- One way to assist low-income households is by improving their energy efficiency and housing insulation to keep houses warm throughout cold weather, which is a prominent issue in the UK. Previous barriers to improving energy efficiency among low-income households were identified as a basis of the study. This research advances the knowledge available in existing literature by presenting the conflicts of supporting low-income households to improve energy efficiency, as well as providing an updated review of barriers after the energy crisis in 2021-2022.
- Literature studies highlight several debates on the impact of behaviour and technology in improving energy efficiency. This research interviews participant's perspectives on the potential of behaviour and technology as approaches to mitigation in improving energy efficiency among low-income householdsin the UK.

Chapter 3 Research Methodology

This chapter starts with the research aims and objectives followed by the research design and method of data collection. The results and analysis from the research are explained in detail in the following chapters 4 and 5.

3.1 Research Aim and Objectives

As listed in the introduction, the objectives of this research are:

1. To present an up-to-date context of the issues that led to the rise of energy poverty in the UK.
2. To present the importance of supporting low-income households in improving their energy efficiency.
3. To highlight the key barriers faced by low-income households in the UK to improve their energy efficiency.
4. To create a framework, which is a list of recommendations based on their ease of implementation, for how behaviour and technology could improve energy efficiency in the UK.

3.2 Research Design

The "Research Onion" by Saunders in the Research Methods for Business Students book was followed as a guide to designing this research (as shown in **Figure 8)** (Saunders et al., 2007). The research onion guides researchers to think critically about each step of designing research, from the different ways of thinking, termed philosophy, to the final step of choosing the best method for the research. The arrangement of the layers of research is philosophies, approaches, strategies, choices, time horizons and techniques and procedures.

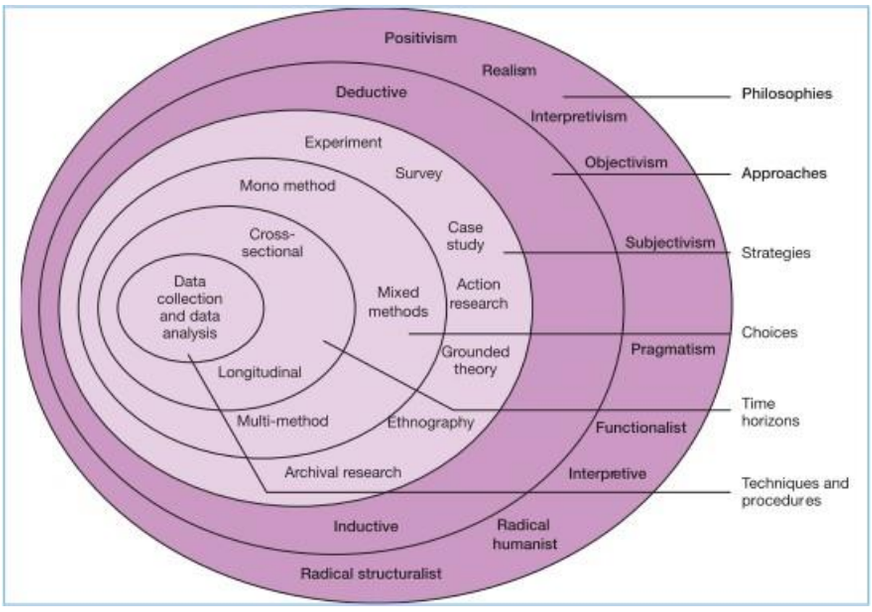

Figure 8: The research 'onion' by Saunders et al., 2007

The first layer of a research design is identifying the **philosophy** of the research. This is important as there are various ways of thinking on what knowledge is sought and the process chosen to obtain it. Among the different philosophies listed by Saunders et al., (2007), **interpretivism** was more relevant to the aim of this study. "Interpretivism is an epistemology that advocates that it is necessary for the researcher to understand the differences between humans in our role as social actors" (Saunders et al., 2007). This is relevant as this research aims to understand the challenges faced by low-income households from different perspectives of the experienced participants. These philosophies are not to choose one from, rather they are a way of thinking about the research process (Saunders et al., 2007).

As for the **approach** of the study, the possibilities are this research can be more inductive or deductive. Inductive research is more concerned with building theories and following data obtained, compared to deductive research where it is more concerned with

testing theories. As this study starts with a comprehensive literature review on the existing issues and barriers on energy efficiency, this research will follow a more deductive approach. A **strategy** that would be suitable for deductive research in this study includes interviews, case studies and surveys among others, but interviews were chosen as the most suitable strategy forthis study (Saunders et al., 2007). Case studies were not chosen as topics of interest could not be explored to the level of detail which is possible through interviews, while surveys are better suited to identify overall trends associated with a topic. In the case of getting detailed, personal and meaningful data on the topic of low-income households and energy efficiency, interviews are best suited for this study. For **choice, time and technique,** it was decided that a mono method of interviewanalysis done at a longitudinal timeline would be the best option in the given timescale and capacities of the researcher. This means a single method of interview done at a single time.

3.3 Qualitative Interview

From the research design guided by the research onion in **Figure 8**, the method chosen for this study are interviews. Interviews fall under qualitative technique which mainly analyses non-numerical data such as words, picture or audio data instead of quantitative technique which focuses more on numerical data and statistics (Saunders et al., 2007).

Under qualitative research there are several methods such as interviews, focus groups and use of secondary sources. Among these options, the interview method is chosen as the best method for this study. The reason behind this is that interviews are ideal for exploring experience-type research questions (Braun & Clarke, 2013). Interviewing participants from different groups who all have years of experience in dealing with household energy would make it easier for participants to share their personal experiences dealing with low-income households. In addition, interviews are best suited to explore the perceptions of the participants that have some personal stake in the issues, as the responses will be rich and detailed (Braun and Clarke, 2013). People without any personal stake in the issues are better studied using focus groups or survey methods (Braun & Clarke, 2013).

Qualitative interviews require a significant amount of time for data collection and interpretation. The process starts with designing interview strategy and interview questions, identifying suitable participants, approaching them for interview, the interview process itself, continued with post interview stages which are transcribing and interpreting the interview data. Qualitative research will give a detailed understanding of each participant, while quantitative research looks at bigger scale patterns of the results(Braun & Clarke, 2013). As the focus of

this research is to understand the challenges faced by low-income households at a deeper level, it is less concerned on the numbers and patterns of the low-income households. Hence, this research will mainly focus on the findings from qualitative interviews, with some additional quantitative data from the literature to support the discussion of this study.

3.4 Overall research process

Figure 9 presents a map of the overall research flow which starts from Chapter 1: Literature Review until Chapter 4: Conclusion along with the chapters and subchapters covered in this dissertation.

The research started with a literature review of the ever changing landscape of energy which was exacerbated by the increasing demand of energy because of the growing economy, climate change which disrupts the energy market and conflicts in 2021-22 such as the COVID-19 and Ukraine-Russia conflict, pushing energy prices to a record high. The rise in energy prices heavily affects low-income households, which subsequently increases the number of households falling into energy poverty. A further literature review was done to analyse the efforts which could be made to help these low-income household groups. Findings showed that one of the main ways to help low-income households in going through the rise of energy prices is by increasing the energy efficiency of their homes.

From the literature review on the topic of energy efficiency, possible barriers to energy efficiency among low-income households were identified which covered the European countries. Other than that, two main themes of behaviour and technology were identified as possible mitigations for the problem of energy efficiency among low-income households.

This research aims to use **qualitative interviews** to further delve into the topic of energy efficiency among low-income households, specifically in the UK, while exploring the possibilities of recommending behaviours and technologies as themes to assist low-income households in the UK in improving their energy efficiency and in saving on energy bills.

The interviews were done in a semi-structured qualitative interviews, whereby interviewees were asked open-ended questions with a degree of flexibility on the questions which would allow for detailed responses. This is to ensure that the interviewees have the chance to expand what feels most important to them (Braun & Clarke, 2013). Structured interviews were not chosen as it would be too rigid and would not allow participants to further explore topics that they find meaningful, while unstructured interviews would make the interview answers too

open, making it difficult for the researcher to set a limitation for the interview answers given.

A set of questions were prepared before the interviews as seen in **Appendix 2**. The interview questions were displayed in PowerPoint slide presentations with some context based on literature study to assist participants in answering the questions, without introducing any bias to the interviews (**Appendix 3**). Questions were divided into three main themes which were the importance of supporting low-income households in improving their energy efficiency, barriers to energy efficiency and also recommendations based on behaviour and technology (as seen in **Figure 10**). The theme of the questions were chosen to meet the research objectives and address the key topics for exploration identified in the literature review. Answers were discussed and expanded to a point where additional data fails to generate new information, which is called the saturation point (Braun & Clarke, 2013).

There were **two stages of interviews** carried out in this research. The first stage of interviews was conducted with the first nine participants, which were done from June until September 2022. The second stage interviews were conducted on the following six people, which were done from June 2023 until August 2023 to further explore key areas of interest and address gaps in knowledge identified in the first stage of interviews. Further details of the respondents are given below in**Table 4**.

After data collection, the **interviews were transcribed** with filler words removed and broken sentences fixed to improve readability. The interview transcriptions are then put through the **data analysis software NVIVO** to identify, group and sort identified themes to be discussed in the results and analysis section (**Appendix 5**). A sample of the interview transcription analysis with codes was cross checked with two supervisors, a method termed as "triangulation" to gain better understanding of a topic (Braun & Clarke, 2013).

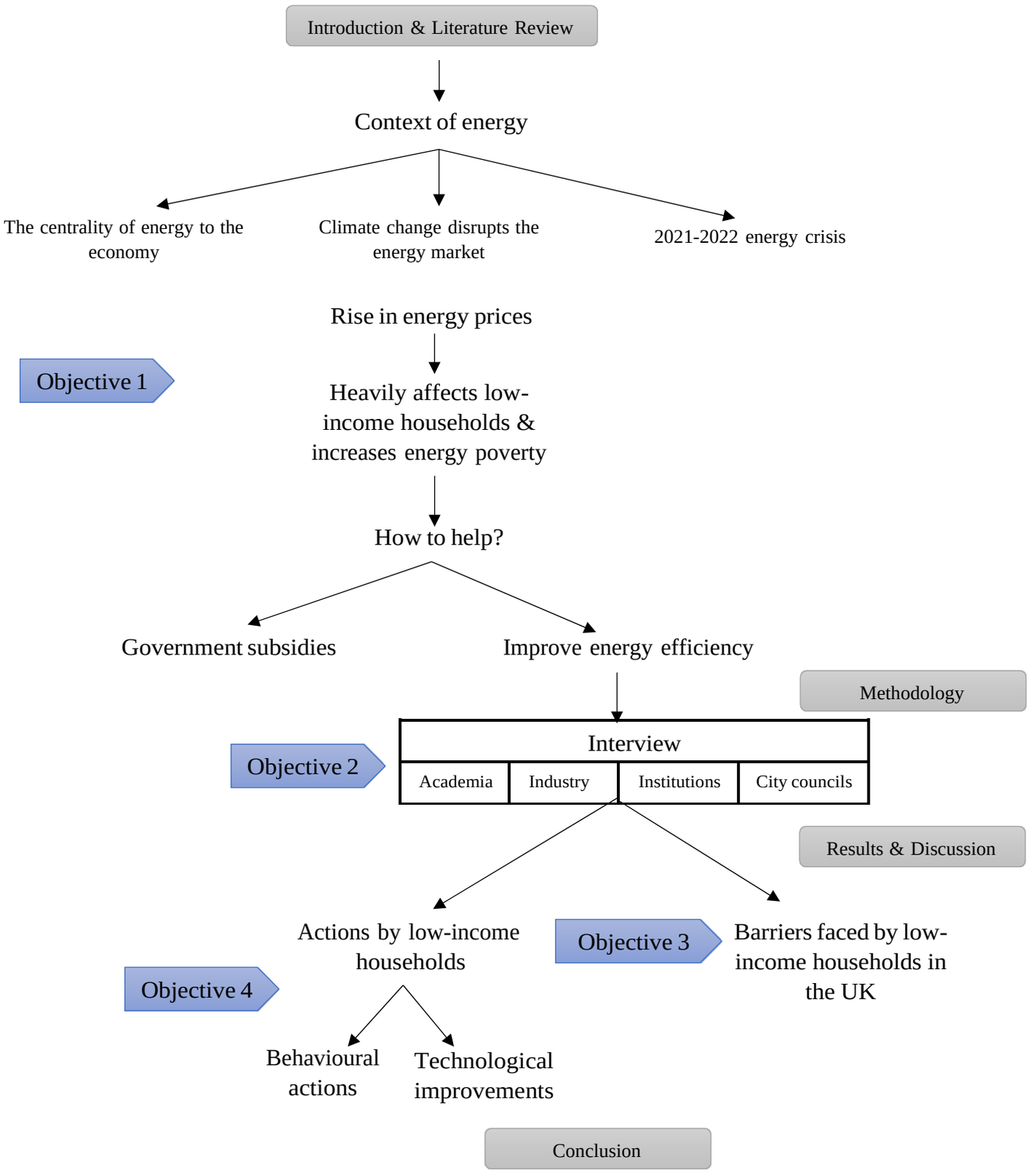

Figure 9: The overall flow of research from Introduction to Conclusion. The literature review answers objective one, which presents an up-to-date context of energy transition and the rise of energy poverty in the UK. The discussion on the importance of energy efficiency for low-income households answers objective number 2. Identifying barriers faced by low-income households in the UK answers objective number 3. Studying how behaviour and technology can help low-income households save energy answers objective number 4 of this research.

3.5 Participants

In deciding the group of people to be interviewed, this research adopted the findings of Biresselioglu (2020) on the importance of including different decision-making groups in studying energy transition. The findings identified three levels of decision-making groups: formal social units, collective decision-making units and individual consumers, to have a holistic analysis of the energy transition (Biresselioglu et al., 2020). **Table 3** shows the groups and description identified by Biresselioglu (2020), followed by the categories chosen to suite this research.

Initially, this research planned to focus on low-income people directly. However, the nature of directly approaching low-income people was decided as a sensitive approach. First, it is difficult to establish who the low-income people are as this will breach people's privacy. Secondly, people identified as low-income, or energy poor might be offended with the targeted questions. Hence, this research did not make direct contact with low-income or energy poor households. Instead, those that have day-to-day experience working with such groups are interviewed. Keeping in mind that the research is a UK-wide research, the participants interviewed were selected from all around the UK to prevent regional disparities from the interview data collected.

Table 3: Table of groups and its description of different levels of decision-making in an energy transition by Biresselioglu (2020), compared to the researchers' chosen categories.

Group names	**Description**	**Chosen categories for this research**
Formal social units	"...refer to policy makers and / or energy providers with the widest influence over energy choice decisions"	City councils & Academics
Collective decision-making units	"...refer to energy producer and consumer associations, commerce and industrial chambers..."	Industry experts
Individual consumers	"...such as groups of households, condominium management, and association of households"	Institutions- (organizations that directly deal with low-income households such as Centre for Sustainable Energy)

By following the recommendations of Biresselioglu (2020), the categories of people interviewed in the research are city councils, academics, industry experts and institutions. Industry experts and institutions might inter relate with one another but in this research, the industry experts category are focused on participants which work in energy provider companies, consulting or working with the government which affects energy consumers in general, while the institutions category refer to the institutions which directly deal with low-income households specifically such as the Centre for Sustainable Energy. Interviews with people identified in these categories ensured a critical overview of the issues of energy efficiency among low-income household in the UK.

The group of interviewees were categorised into four different groups which were the city councils, academics, energy institutions and industry experts. A total of 15 interviews were conducted throughout the research in two separate stages. The first stage consists interviews with 9 participants, followed by the second stage interview with another 6 participants which further explored the results obtained from stage one interviews. The participants were selected based on their category and experience in dealing with the issues of energy poverty as shown in **Table 4**. Most of the chosen participants have experience of more than 5 years in dealing with energy poverty groups.

Table 4: Table of interview participant details. The code refers to the category of the participants, followed by their order of the interviews. Hence, Code "C01" indicates the first interview was done with a participant from the city council category.

Category	Code	Experience
City councils	C04	9 years as city council
		Co-founder of an energy efficiency company
		4 years as EU smart city advisor
		Policy advisor
	C07	7 years as city council
		Cabinet member for climate, ecology, waste and energy
	C10	13 years working in the city council
		Policy regeneration officer
Academics	A03	10 years of experience in energy research
		Mainly researches on energy governance
		5 years as community energy director
	A05	Main research on energy poverty, microgrids and energy systems
		Collaboration with academic institutions, government and non-governmental groups
	A08	9+ years as scholar

		Professor in global energy policies. Editor-in-chief of a Q1 journal in energy research
Institutions	I01	5 years in a renowned sustainable energy institute supporting energy poverty households
	I06	2 years in the energy network organization with vast experience with energy poverty
	I11	12 years of experience in decarbonisation
		Decarbonisation consultant
		Director for an energy community group
		4 years of experience in the city council
	I12	Retrofit coordinator and assessor
		6 years in the energy poverty industry
		2+ years working with the city council
	I15	Senior project worker for an energy project
		2 years as case worker in energy advice
Industry experts	IE02	CEO of a public listed energy company
		8 years as renewable energy consultant
		Climate activist
		Community energy director
	IE09	11+ years in building energy efficiencies
		Head department of an energy firm
	IE13	Head of local Net Zero for the government
		5+ years of experience in policy and governance
		Senior policy advisor for the government
	IE14	Founder of a 16 years energy efficiency website
		Director of an environmentalist group collaborating with the government to provide consumer information on green choices

3.6 Limitations

The limitations of this research were that data could not be collected from low-income household groups. Primary data on low-income groups would be very valuable and direct in discovering the complex challenges of energy poverty. However, the ethical and privacy concerns related to approaching targeted low-income household groups halted the approach to collecting data directly from low-income groups.

Hence, data were collected from participants that have valuable experience in dealing with low-income households and the energy industry. Other than that, this research is limited to focus on the energy efficiency faced by low-income households in the UK. This limits the boundary of study to the UK but makes the finding more impactful as the challenges are different

depending on the location. Finally, the boundaries set by the research also meant the analysis is focused on the practical mitigations by behaviour and technology that can be directly applied by households rather than external factors such as political and economic aspects which give a big impact to the issue of energy poverty.

3.7 Timeline

The master's research program officially started on the 18th of October 2021, with a year of research and another suggested year for writing up. In the first six months of the research, priority was given to reading existing literature and focusing down on a particular topic of study. After identifying the specific area of knowledge to be researched, an additional literature study was done to prepare questions to start with the interview data collection. Ethics for the proposed method was approved in February 2022 before starting data collection in June 2022.

3.8 Ethics

Application of ethics through the University of Bristol Research Ethics Committee has been approved on the 17th of February 2022 with ethics approval number 10162 (**Appendix 4**). Before each interview, the participants were emailed a set of Personal Information Statement containing all related information about the research. Participants were then sent a consent form to be signed before the interview started. In addition, an important ethical issue was to keep the privacy of the participants of the research. Each participant was labelled with codes to keep their identity confidential. This includes making sure no obvious details were shared that would make the participants identifiable. Interview questions were discussed and reviewed with supervisors (**Appendix 2**) and all the interview questions were presented on PowerPoint (**Appendix 3**) via Zoom and Microsoft Teams.

Chapter 4 Results and discussion

The previous chapter explained the research design and methodology for data collection. In this chapter, the interview transcripts are grouped and analysed. The results were arranged into three main themes (**Figure 10**). The first theme of **importance** aims to answer research objective 2 which is to understand the importance of supporting low-income households in improving energy efficiency. The second theme of **barriers** aims to identify the emerging barriers to energy efficiency among low-income households in the UK. Finally, the third theme is an analysis of behaviour and technology as **recommendations** to improve energy efficiency among low-income households in the UK. These three themes aim to answer the second, thirdand fourth research objectives stated in Chapter 1.

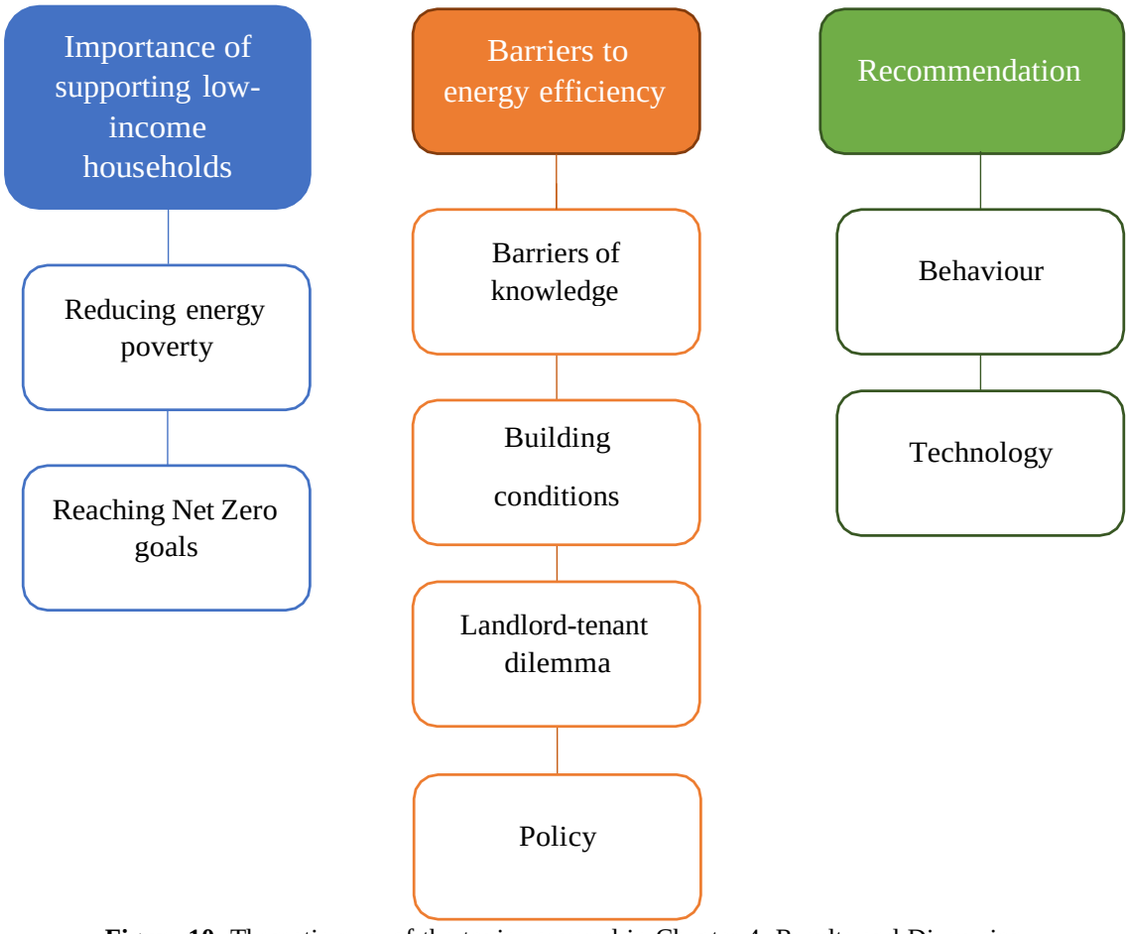

Figure 10: Thematic map of the topics covered in Chapter 4: Results and Discussion.

4.1 Importance of energy efficiency among low-income households

A European-wide report conducted by the European Parliament in 2016 recognized the improvement of energy efficiency as one of the key tools to address energy poverty among low-income households (Ugarte et al., 2016). Several studies have shown that not only do energy efficiency actions help to reduce energy poverty (Büchs et al., 2023; Sovacool, 2015), but energy efficiency also helps to reduce carbon emissions to achieve Net Zero goals (Eyre, 2022; Eyre & Killip, 2019).

The first stage interview responses to questions under the theme of 'The importance of energy efficiency among low-income households' showed areas of both agreement and disagreement depending on the question asked. For the first two questions, 'How important is it to include low-income households in the energy transition towards net zero carbon?' and 'What is your opinion on the role of energy savings in accelerating the energy transition?', all participants agreed that this was vital. However, for the third question 'Do you think it is relevant to impose energy saving/energy efficiency actions on low-income households?', the majority of the participants expressed how low-income households should not be imposed with further energy saving actions. This is because the contribution of low-income households to carbon emissions is often overstated and there needs to be more focus on higher-income people instead. In particular, the responses revealed different views on the role of improving energy efficiency in reaching the two goals of reducing energy poverty and reaching net zero goals; therefore these were key areas further discussed in the stage 2 interviews. Further discussion of the interview responses is now provided using both quotes from the participants and, where relevant, reference to supporting literature.

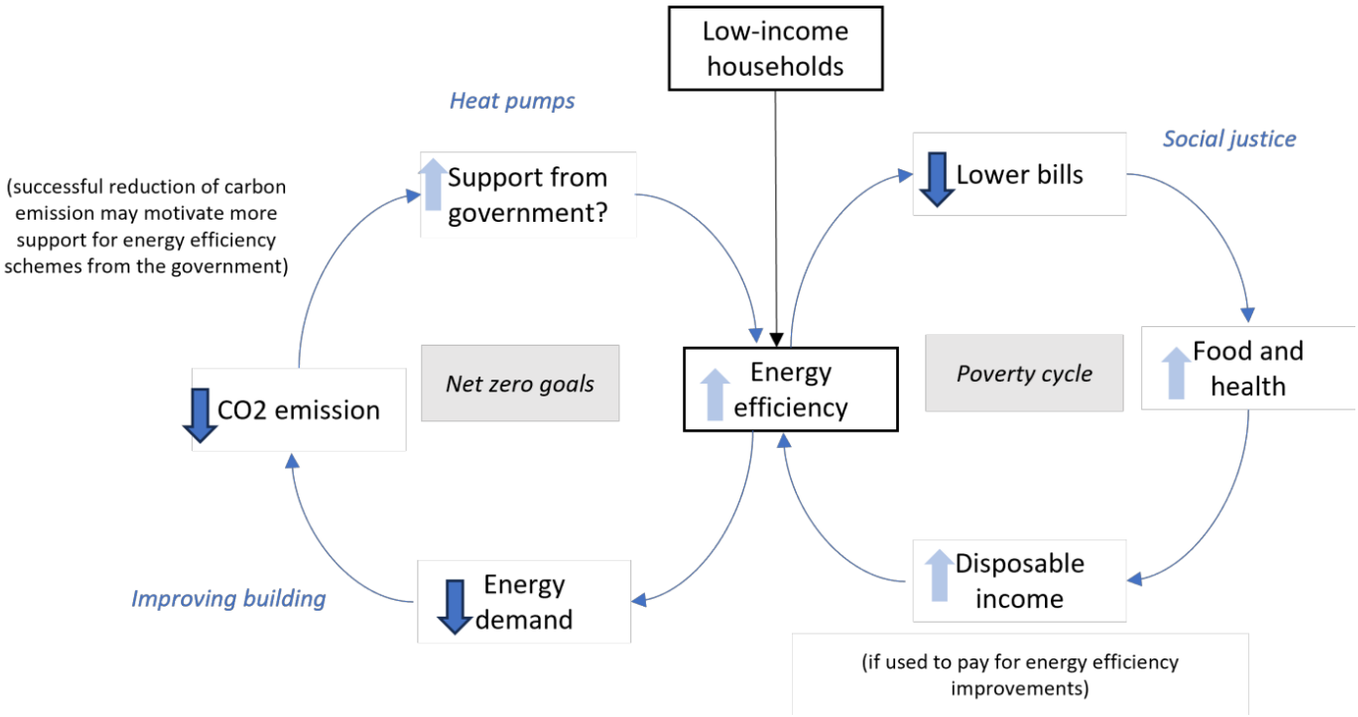

Figure 11: Supporting low-income households to improve their energy efficiency may reduce the energy poverty cycle while contributing to net zero goals. On one hand, improved energy efficiency may lead to lower energy consumption, causing lower energy bills, providing a better chance of getting nutritious food and good health, and may increase the chance to earn more income, which can be used to pay for better energy efficiency improvements. On the other hand, improved energy efficiency may lead to lower energy consumption, causing lower energy demand and, hence, lower overall carbon emissions. Successful efforts in reducing carbon emissions may lead to increased government support to continue improving energy efficiency.

The following part of the dissertation further discusses the issues related to how energy efficiency actions among low-income households can achieve the two goals of reducing energy poverty by breaking the poverty cycle and achieving net zero goals to help counter global warming (**Figure 11**). While energy efficiency measures can be applied in many sectors such as transport, building, industry and electricity generation, the scope of energy efficiency in this discussion refers to energy efficiency actions related to buildings which play a big role in energy usage for low-income households.

4.1.1 Poverty cycle

It has been proposed that home energy efficiency schemes such as draught-proofing, installing insulation and free energy audits are effective in reducing the number of people falling into energy poverty and that improving the energy efficiency of households may lead to more money savings and improved overall health (Sovacool, 2015). This can be explained by viewing household energy poverty as one of the centres of the poverty cycle. When the houses of low-income people are poorly insulated and less efficient, a lot of gas and electricity usage is wasted to heat the house because the heat produced cannot be retained in the buildings. Because of this, low-income households need to pay more than necessary for their energy bills, leaving them limited money to buy healthy food, which affects their health. Also, neglecting expenditure on energy bills may cause cold and damp house issues that could lead to various diseases and health problems. Poor health conditions can then affect their ability to work and gain more disposable income, hence repeating the loop of a poverty cycle. Of course, this is a more generalized explanation of a poverty cycle. Still, it shows how household energy poverty is related to other forms of poverty, such as food and health. The interview with Participant I11 supports the study by Sovacool (2015). Participant I11 explains how energy poverty is heavily related to other kinds of poverty, and by improving energy efficiency, other aspects of our lives could be improved.

"It's really important to recognise that when people are in fuel poverty or energy poverty they're often in kind of other types of poverty as well. So, you know, poverty isn't singular and you're more likely to have a chaotic life….. which is why we talk about things like energy efficiency because it helps to resolve the kind of the root of some of the issues that those people are affecting and you can see benefits and other aspects of their life by tackling that" [Participant I11].

The people facing energy poverty may directly affect food poverty and health. Participant C10, who had 20 years of experience working with the local council, shared his experience working with people in energy poverty who prefer to use microwaves over kitchen stoves to save energy, affecting their choice of diet. *"I come across people that buy processed food and use their microwave to cook their food because they say to us that having a cooker to cook the food costs more energy and is too expensive"[Participant C10].* Processed food contains high amounts of salt and sugar with less actual nutrition which could give negative impacts on overall health. However, given that processed food is often much cheaper in the market and microwave saves more money on energy bills compared with a gas stove, people

in poverty may be left with no other choice than to keep on the cheapest available option to survive and get stuck in the poverty cycle.

Another important factor in reducing energy poverty is to ensure **a social justice element in taking the steps to improve energy efficiency actions**. The social justice element in this context means ensuring everyone deserves equal access and opportunity in taking energy efficiency measures. The pathways suggested for low-income households to improve energy efficiency still need to be improved to cater to the complex challenges of low-income households. Findings co-led by The Office of Gas and Electricity Markets (Ofgem), which is the main regulator of gas and electricity in the UK, show that low-income households face the challenges of feeling powerless in making household adaptations (Ofgem & Design, 2022). In taking steps to improve energy efficiency, low-income households are often left with few options. To maximise improving the energy efficiency of buildings through cavity or solid wall insulation, for example, would require a large amount of capital to be paid upfront. Low-income people with limited money would not have the opportunity to maximize their building energy efficiency. This is supported by Participant A08 who states that we are living in one of the most unequal societies ever. *"Thomas Piketty, who is an economist, have found that we are now living in the most unequal society ever. Our current civilisation is more unequal in the time the kings and queens, aristocrats or feudalism which had servants. Only the super-rich are getting richer, and all of our structures in society, corporate tax, energy subsidies, et cetera, benefit the wealthy " [Participant A08].* Hence, ensuring a social justice element in energy efficiency improvements and giving more opportunities for low-income households to improve their building conditions can contribute to breaking the cycle of energy poverty. This is supported by Participant I06 which suggested the need for everyone to be part of the just transition *"to distribute the benefits of the transition equally and fairly".*

4.1.2 Net zero goals

In this discussion, we look at how low-income households can contribute to the Net Zero goals by improving their household energy efficiency.

A scientific report on energy efficiency shows that the building sector accounts for 36% of CO_2 emissions in Europe and encourages the need to ensure all levels of households reach an adequate level of energy efficiency to reach climate targets (Ugarte et al., 2016). Hence, suggesting low-income households improve energy efficiency in buildings should help to

reduce building carbon emissions and significantly contribute to reaching Net Zero goals. However, a survey shows that low-income groups in the UK find it difficult to participate in the transition to Net Zero Carbon goals mainly because of various barriers that they have to go through, making it difficult to decide the best options to contribute to the transition (Ofgem & Design, 2022). These barriers faced by low-income groups include a lack of information on behavioural changes that could be done, poorly targeted policies, powerless tenants, trust and other vulnerable consumers who need support in implementing any transition to net zero (Ofgem & Design, 2022). Further discussion on each of these barriers will be discussed in the following subchapters. Thus, while the idea of improving energy efficiency among low-income can contribute to Net Zero Goals, low-income households in reality face many other barriers that make it difficult for them to do so.

In reducing carbon emissions and reaching Net Zero goals, the importance of energy demand has been actively researched and promoted. In reaching Net Zero goals, countries have been developing renewable energy technologies such as solar, wind and biomass energy to improve the energy supply side, reducing the reliance on traditional fuel-based energy production and cutting carbon emissions. Electric vehicle schemes are encouraged nationwide instead of traditional petrol or diesel cars as one of the solutions to cut carbon emissions. Other than renewable energy production and electrification of transport, the Centre for Research in Energy Demand Solutions (CREDS) reported that improving energy efficiency is one of the ways to reduce energy usage which could play a larger role than the energy supply side in reducing overall UK greenhouse gas emissions(Eyre, 2022). There is also growing action toward producing a flexible energy demand to support the variable sources of renewable energy electricity. This is supported by Participant I06 who emphasized energy demand as an important key to the transition to Net Zero goals.

“ This is a great question and a really important one that I think is massively missing from especially central government plans and in terms of transition to net zero because, fundamentally, we need to use less energy, we can't just electrify everything and turn everything to green renewable sources tomorrow” *[Participant I06]*

However, in looking at the improvement in the energy demand specifically in the scope of buildings, CREDS mainly suggests improving building fabric as well as investments in heat pumps as one of the biggest potential to reduce energy demand (Eyre, 2022). While improving building fabric to a certain extent can be done by low-income people, heat pumps

improvements do not seem to apply well to low-income households. At the moment, heat pumps are expensive to be installed and would need a properly insulated building to ensure heat pumps work well to keep the house at a certain temperature. Without proper funding and support from the government, low-income households will find it difficult to take such measures to reduce energy demand and contribute to the Net Zero goals.

4.1.3 The reality can be more complicated

Figure 1 shows how energy efficiency can help break the poverty cycle and contribute to Net Zero goals. This is ideally true given the best cases of how energy efficiency can give a positive impact. However, further discussion with interviewees in this research revealed the concerns and reality of the impacts of encouraging low-income households to improve their energy efficiency.

"*Well, I guess I would say in theory this, looks great, but, in reality, it can sometimes be more complicated"* *[Participant I12]*

The aim of reducing carbon emissions can conflict with reducing energy poverty (CSE, 2023). While improving building conditions through insulation or draught proofing could help people to reduce excessive energy use to heat their houses and at the same time save energy on energy bills, this is not the same case for heat pump installations. Replacing a gas boiler with an air-source heat pump reduces a massive amount of carbon emissions but it does not help low-income people to save money as the heat pumps are expensive to install. Low-income households might not even need to be pushed to reduce excessive carbon emissions in the first place as they already consume very little. This is supported by Participant A03 and A05, which believes that the contribution of low-income households is often overstated.

"I think when it comes to low-income households, their contribution to decarbonisation is often overstated" *[Participant A03]*

"*Obviously low income households don't often contribute to a large portion of the carbon emissions. So in that way, in terms of sort of carbon emissions, it's not particularly important (to include low-income households in reducing carbon emissions)"* *[Participant A05]*

Need to focus on top energy consumers instead

Büchs et al., (2023) in their study on 27 European countries found that increasing low-income energy consumption to achieve comfortable conditions may increase carbon emissions, but the increase may be small compared with the reductions achievable by capping the use of the top consumers. Reducing the domestic energy consumption of the top 20% of consumers in Europe can reduce carbon emissions by 11.4%, while increasing energy consumption of the lowest 20% of energy consumers only increases the energy consumption by 1.2% of out of the 11.4% reduction (Büchs et al., 2023). In energy units, the increment of the lowest 20% of energy consumers accounts for ~0.13 exajoule (EJ) of energy (Büchs et al., 2023). Low-income households already contribute to a relatively small amount of carbon emissions, hence more

actions need to be taken on the top consumers of energy instead to reach Net Zero goals. This is in line with the suggestion by Participant A03 in the interviews which mentions "*I think it's the high-income houses who have a lot more to contribute to decarbonisation" [Participant A03]*.

Unsurprisingly, it has been claimed that globally, the richest 10% of the world's population were responsible for 52% of the cumulative carbon emissions (Gore et al., 2020). Hence, finding solutions to reducing carbon emissions among high-income earners would significantly impact reducing carbon emissions. For low-income households, more support would be needed to improve their energy efficiency to reach sufficient comfort levels and help escape from the cycle of poverty.

Key points:

- Energy efficiency measures by low-income households can help to reduce energy poverty, improve comfort and, to an extent, contribute to a reduction in carbon emissions.
- Because their contribution to overall energy demand is a relatively small part of the total, there is an argument that more emphasis should be placed on reduction in poverty and improvement in comfort, as greater savings can be achieved by concentrating on higher consumers.
- In reaching social justice, carbon reduction targets should not be at the expense of health and extreme poverty.
- There are many barriers to energy efficiency improvements owing to the cost of measures such as insulation, and these costs are challenging to low-income households. The measure advocated to have greatest impact on carbon, heat pumps, is particularly expensive.

4.2 Emerging barriers to energy efficiency in the UK

In the earlier Chapter 2 of this research, a literature review was done on the barriers to energy efficiency issues faced by low-income households which covers studies all around Europe (Fylan et al., 2016; Kolokotsa & Santamouris, 2015; Ugarte et al., 2016). The extensive literature gave a wide context of the major problems specifically faced by low-income households. This section aims to identify the key barriers faced by low-income households in the UK to improve their building energy efficiency.

The results from this research highlight four emerging barriers to energy efficiency among low-income households in the UK which are the **barriers of knowledge, housing conditions**, **landlord-tenant dilemma** and **energy policy**. Each of these barriers identified is by no means independent of one another and understanding that each barrier is interrelated can give a better picture of the barriers to energy efficiency among low-income households in the UK.

The first stage interview responses to questions under the theme of 'Barriers to energy efficiency among low-income households in the UK' showed agreement with the past barriers identified in the literature. For the first question ' In your opinion, what are the top three barriers to energy efficiency faced by low-income households in the UK?', the interview responses all agreed with those identified in previous literature and when analysed, the top three barriers were the problems with energy policies, the landlord-tenant dilemma and the poor housing conditions in the UK. This is then followed by the barrier of householders lacking knowledge about energy-saving measures, which plays an important part in each of the barriers identified. For the second question, 'What are the other barriers to energy efficiency faced by low-income households that you can add to the list?' only a few participants introduced barriers not specifically mentioned in previous literature such as the barrier of trust among households. Finally, the responses to the final question of 'How limiting is the landlord-tenant dilemma to achieve energy efficiency for low-income households' showed full agreement between participants that the landlord-tenant dilemma is a problem to be tackled. The findings of the first stage of interviews identified additional issues such as the issue of cold homes, political barriers and the rebound effect which were further explored in the second stage of the interviews. Here we discuss the interview responses and, where relevant, evaluate supporting literature for each barrier in turn.

4.2.1. Barriers to knowledge

In a **previous report** on energy efficiency among low-income households in Europe, the barriers to knowledge were centred around the consumer's lack of awareness of the actions that could be done to improve energy efficiency (Ugarte et al., 2016). The two main informational barriers were dwelling and external information, where consumers lack information about home improvements such as insulation and draught proofing, and lack of information about available support from the government and supporting organisations (Ugarte et al., 2016). In the UK, energy efficiency strategies reported that while energy efficiency information is available, people find it difficult to convert the information into personal actions as people live in different situations (Davey, 2012).

Interviews with high-level stakeholders from this research may indicate that there is **still a problem of lack of knowledge among low-income households**. This may happen because low- income households are too overwhelmed with a multitude of problems that they do not havethe time to improve their awareness of household energy consumption.

The event of the energy crisis which doubled the cost of energy bills pushed more people who are already struggling into worse conditions. The initial group of people who are already struggling with remunerated employment, unemployment and also disabilities would now have to worry about getting enough money to pay for the surging bills. People struggling with these burdens may not even have the time to learn how to manage their energy consumption properly.

"They are struggling to get their kids to school and worry about NHS treatments or they are struggling with Covid or unemployment or disability. They are just scared. They have zero time to learn about energy…It's just not important to them, so they lack the knowledge and skills even those that would help them save money just because they're fatigued and exhausted and struggling" *[Participant A08]*

However, **the event of an energy crisis has also been shown to increase the knowledge among low-income households** as people were left with no choice but to cut energy consumption. Participant IE14 who handles a website on energy efficiency actions mentions how people'sawareness increases as soon as the energy consumption and bills increase.

"Come September, as soon as the heating goes on that awareness comes in and the energy crisis has certainly spiked awareness" *[Participant IE14]*

The spike in energy prices made consumers aware of every action to save as much money on energy bills. Low-income households who try to reduce the cost of paying for energy bills were left with no other option than to seek information and do necessary action to cut back on their energy consumption. This might not be the case for other high-income households that might not find the increase in energy bills a pressing issue as long as they can afford to pay them. Hence, because of the rise in energy prices, low-income households might become more aware of their overall household energy consumption. This is further supported by Participant 105 who states that *"low-income households will know about their energy consumption more than higher-income households now"* *[Participant A05]*

Another important barrier to knowledge among low-income households identified from the interviews is the **aspect of trust**. This includes trust in accepting the advice on improving energy efficiency at home and also trust in the people doing insulation improvements for their buildings. *"It is not necessarily just trust and who has come to you and tried to convince youto get energy efficiency but also the people that are going to come and do the work." [Participant I11].* There could be different sources of information online about different actions that could be done by households but without proper proof of the impacts these actions have on their energy savings, people might just not trust this advice. In terms of trusting workers to improve building conditions, Participant I11 shared their experience: *" There hasbeen lots of stories over the years of people getting bad work done. How do I know that I cantrust you? How do I know that you're not cowboy and you are just going to take my money and run away?" [Participant I11].* Trust is also important in making sure people make use of technologies such as smart meters. From the interviews, it was found that *"some people evenfind the smart meter display confusing and some people will refuse to have a smart meter because they distrust it." [Participant I12].* Smart meters are informational meters that display the real-time reading of electricity and gas used for the house.

As with other technologies, smart meters also have their own settings to ensure accurate readings. If the smart meters are not properly set or regularly maintained, it may reduce people's trust on these technologies which could have helped to improve their energy efficiency actions. Customers have been reported to be overcharged for their electricity bills due to technical problems, which increases people's trust in the reliability of smart meters. In addition, the fact that the household energy consumption data is directly supplied to the energy companies may also induce privacy concerns where the data might be sold to third parties.

4.2.1 Key points:

- Low-income households may find it difficult to find the time to learn about energy consumption as they are already struggling to find enough money to survive. This has become worse as an impact of the increasing energy bills.
- However, interviews show low-income households are becoming more aware of energy consumption compared to the higher income households because they are the most affected by the increase in energy bills and have no other option than to reduce their energy consumption to reduce the energy bills.
- There is also a lack of trust in accepting energy advice, building improvements and smart meter readings which impacts households energy consumption.

4.2.2. Housing conditions

It was reported that one of the main barriers faced by low-income is poor housing conditions (Kolokotsa, 2015). The term poor housing in study is heavily related to the poor fuel households definition which are houses which could not provide sufficient heating to keep warm at a reasonable cost (Sovacool, 2015). In the UK, it was reported that low-quality buildings which were deteriorating were one of the problems faced by low-income people (Middlemiss & Gillard, 2015). On top of that, the problem of inadequate heating causes people to live in cold homes which impacts the health of households (Anderson et al., 2012; Kolokotsa & Santamouris, 2015)

The finding from the interviews in this research suggests that **poor housing conditions are still a big problem in the UK**. The general condition of houses in the UK was reported to be old and have problems with maintaining sufficient levels of heat to live comfortably. Talking from experience, Participant A05 asserts, *"having lived in a number of different rental properties and they were all really poor at keeping heat. They're all old, badly maintained properties."[Participant A05].* Participant A05's personal experience is one of the examples of people living in poor and old housing conditions. Previous studies have reported that the UK has one of the oldest housing stocks in Europe (Piddington et al., 2017). This was partly due to the history of rapid growth in buildings being built in the past, with 77.5% of dwellings in the UK built before the year 1980 (Piddington et al., 2017). The UK has one of the lowest percentage of new houses being built after the year 2000 compared to other 28 European nations which is at 6.9% compared to the 9.8% average (Piddington et al., 2017). In 2006, the government introduced the zero carbon homes plan by 2016 which would require newly built homes to reach a specific level of energy efficiency standards in the UK (Osmani & O'Reilly,2009). However, the zero carbon home plans were scrapped off before it reached its target, reducing the potential for the UK to have more energy efficient housing. The impacts of policy changes on housing conditions are explained further in subsection 4.2.4.

Following the poor and old housing stocks in the UK, low-income people may tend to live in these poor and old houses. Participant C04 who has served 9 years as a city councillor mentioned *"People tend to live in poor quality housing, and that housing will tend to be less energy efficient so that's a really big issue".* The poor housing conditions would make it difficult for their tenants to keep themselves warm and comfortable. When asked what should

be prioritized to support low-income households, Participant A03 reiterates the poor conditions of houses in the UK and recommended the need for better insulation.

"the UK building stock is very draughty and poorly insulated, so that's why I think it is an overarching requirement and homes need to be better insulated". [Participat A03]

Improving insulation was one of the key points mentioned in improving poor and old housing conditions among low-income households. Insulation improvements consist of loft, cavity and solid wall insulations which could help to contain heat in buildings. However, further interviews on the topic of insulation revealed **high upfront costs** as one of the main problems faced by low-income people. The cost for improving building insulation ranges widely depending on the buildings, from £20 to insulate hot water tanks up to £1500 for cavity wallinsulations for an average terrace house in the UK (*Energy Saving Trust*, 2023)

Participant C07 states *"I think you will find with lots of these measures is that the economics of it is high upfront costs with longer-term payoffs, so I think that is probably one of the main economic challenges" [Participant C07].* Low- income households which already have limited income would not have the option to self-fund the expensive cost of insulation unless with the support of government funding. Hence, low-income households are only left with low-cost insulation improvements which can be done by themselves such as Do-It-Yourself (DIY) draught proofing, DIY double-glazing windows and DIY loft insulations. These DIY actions also depend on the extent of the household's knowledge and expertise. For people with physical problems or disabilities, DIY actions would be very difficult.

Recent studies have shown the importance of increasing energy consumption for low-income people to reach a satisfactory level of comfort. The lowest 10% of UK energy consumers have one of the lowest levels of recorded well-being (Baltruszewicz et al., 2023), while Büchs et al., (2023) found that improving the energy consumption of the low energy consumers in Europe to reach a satisfactory level does not give a significant impact on reaching global emission targets. Based on these findings, low-income households should be supported to improve their energy consumption to a comfortable level, addressing the roots of the poverty cycle.

Improving housing conditions to reach a better level of comfort has been studied in the past and is related to the topic of the **rebound effect** (Rajabi, 2022). The rebound effect in the case

of energy at the household level occurs when households decide to use energy efficiency improvements to save energy consumption. However, the impacts of lower energy bills result in households putting on longer hours of heating to improve comfort, resulting in increased energy consumption which counters the initial goal of energy efficiency to save energy consumption (**Figure 12**).

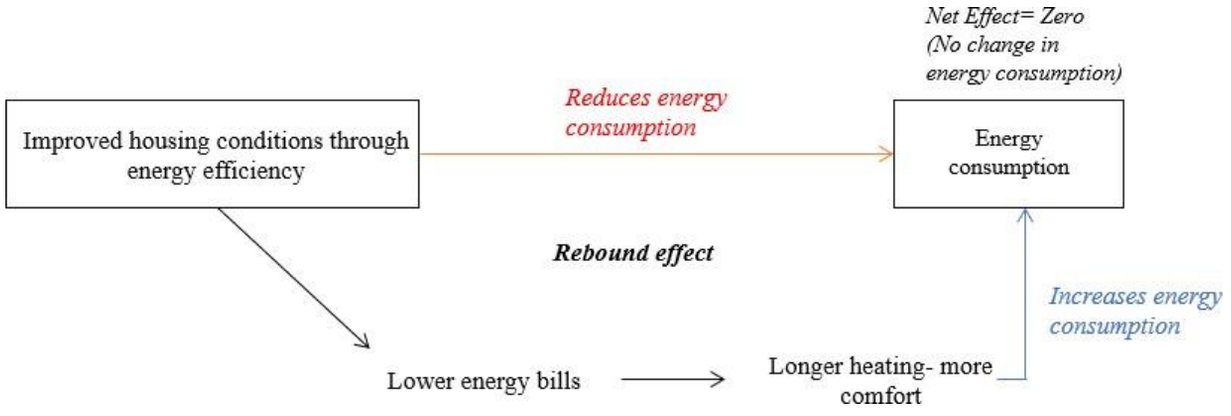

Figure 12: Diagram explaining the rebound effects of improving housing conditions and the impact on energy consumption.

In exploring the impacts of the rebound effect on low-income households, interview with participant I15 found that people are not wary of the impacts of the rebound effect. As there are no particular measures that could clearly show the difference in energy consumption caused by the rebound effect, it is difficult to identify the extent of the rebound effect on any households. *"The rebound effect would be really difficult to measure, because from my personal experience, people will basically use the same because they don't consciously think about the energy they are using in their home"[Participant I15].* While the rebound effect is difficult to measure for households themselves which may lead to less awareness on the impact of the rebound effect, study shows the rebound effect accounts for up to 30% of insulation measure in the UK and may affect low-income consumers worse than average consumers (Rosenow & Galvin, 2013).

The barriers of housing conditions closely relate to the landlord-tenant dilemma explained in the next section.

4.2.2 Key points:

- Much of the housing stock in the UK in general are old and badly maintained which makes them not effective in maintain heat throughout cold seasons.
- The solution to improve the housing conditions is to improve insulation, however, the costs for insulation come with high upfront cost and long-term payoff which may not be affordable for low-income households.
- Improving energy efficiency to reduce energy consumption and improve savings may be hindered by the rebound effect which low-income households especially needs to be aware of.

4.2.3. Landlord-tenant dilemma

The third emerging barrier to energy efficiency among low-income households is the landlord-tenant dilemma. As explained in Chapter 2, the landlord-tenant dilemma occurs when there is a disagreement between the landlord and its tenant in improving the energy efficiency of a property (Ástmarsson et al., 2013). In the UK, households that rent their place, especially in the privately rented sectors, tend to live in low-quality housing and are more vulnerable to energy poverty (Papantonis et al., 2022). Interviews on this topic present the issue of split responsibilities between landlord and tenants, leading to a cycle that discourages building improvements. Related government schemes such as the Minimum Energy Efficiency Scheme are also discussed which tries to address the landlord-tenant dilemma.

A big issue with living in rented properties is **the split responsibility** for improving building conditions. Tenants would want to improve building energy efficiency to pay less for their energy bills. However, the power to implement any building renovation falls on the landlords by which the landlords would not get any benefit from the improvements. A previous study on energy efficiency in the UK shows that landlords are unlikely to invest in buildings unless there are financial benefits to the landlords (Davey, 2012). Participant A03 in the interview states: *"in the UK, the landlord holds all the power, the landlord holds all responsibility for maintenance. There is no incentive for landlords to ever make and use efficient modifications to their homes."* [*Participant A03].* Any building improvements such as installing better wall insulation or getting a new boiler would require a huge amount of investment on the property.

These improvements would help tenants to live in better conditions, however, there are no benefits to the landlords as the building improvements would mean improved energy efficiency and tenants pay less for their energy bills.

In addition, the short **tenancy contracts** in the UK limit tenants' power in making energy efficiency improvements. The average tenancy in the UK is only about 2.5 years compared to 11 years in Germany (Davies et al., 2017). Once the tenancy ends, landlords can renew contracts and increase rents for the next tenancy contract.

Requesting building improvements to improve energy efficiency, for example, may cause the **landlords to increase the rent to cover the costs**, increasing rent for the tenants. Hence, tenants are forced to stay in poor-quality housing for cheaper rents. This is validated by our interview participants that explain "*There is a growing number of cases across Europe where landlords are improving the property and then they want to increase the rent by quite a significant amount. So that ends up pushing the existing tenants out". [Participant I11]*

In the end, no one would take responsibility to improve building efficiency because the landlords would not benefit from the lower bills while the tenants might risk increased rent.

The government introduced the **Minimum Energy Efficiency Standard** (MEES) as a guide for private rented property landlords to have at least an Energy Performance Certificate (EPC) band E for their properties to be rented (Minimum Energy Efficiency Standard, 2020). The implementation of MEES will push landlords to provide better energy efficiency standards for rented properties, benefitting people that rent in privately rented properties.

However, the implementation of MEES was not seen to be enforced and might also create a market of illegal renting which could make it worse for low-income households. From the experience of Participant I12, the implementation of MEES is put on halt as the standard is quite difficult for landlords to follow: *" I heard the plan was to gradually increase (the standard for MEES) that but there has been no update on that and I can only assume that is because people in government are not keen on forcing landlords"*. Other than that, there are

concerns that raising the buildings standards for privately rented properties could create a market of illegal renting which would worsen renting conditions for low-income households.

"So people in insecure housing, people with dodgy landlords.. it (MEES) would not affect them because the tenants are not going to complain because they know if they say something, they are just going to be homeless and that's it" *[Participant I15]*

The problems with the landlord-tenant dilemma in the UK can be associated with landlords holding the major responsibility for their properties while renters have low security and protection in staying in rented properties. A possible solution to improving the landlord-tenant dilemma is by looking at adopting improved rental structures from other countries. Participants A03 and I15 shared their opinion on looking at **Germany as a good role model** for the tenancystructure.

"So like in Germany, a lot more power resides with the tenant, right? So in Germany, for example, if you have been renting for a certain number of years and I don't know how many years it is, the landlord can't just throw you out with a three-month notice... So there's a very different balance between landlord and tenant in other countries" *[Participant A03]*

"I moved to the UK 9 years ago and I saw already Germany as a role model for tenancy agreements…because the renting market in this country is absolutely crazy and it's still a mystery" *[Participant I15]*

To explore the difference in tenancy structure, a comparison was done between the tenancy structures in the UK and Germany. In the UK, the **average tenancy** is 2.5 years compared to 11 years in Germany (Davies et al., 2017). The procedure to end a tenancy in the UK also gives more power to the landlord to forcefully evict tenants with a two months' notice and court order, while in Germany, the tenants have longer notice periods of up to three months and are protected by law in the case that moving houses would lead to hardship for the households (Davies et al., 2017). Longer secured tenancy means the tenants will have more responsibility to improve the building conditions without worrying about being evicted from the property.

Hence, improving tenant security, rent regulations and tenant associations as has been done by Germany can be a good model to improve the landlord-tenant dilemma to improve energy efficiency among low-income households in the UK.

4.2.3 Key points:

- Split responsibility between landlord-tenant, and insecure tenancy contracts lead to a cycle which discourages people from improving their building energy efficiency.
- The Minimum Energy Efficiency Standard was introduced to solve landlord-tenant issues in the UK. Still, there are reports on the lack of implementation and worries about introducing an illegal renting market.
- A good renting model can be seen in other countries such as Germany. German renting models allow tenants to stay at rented properties without annual contracts, making a better balance in the split responsibilities between landlord and tenants

4.2.4. Energy policy

The discussion of energy policies as barriers to energy efficiency has been identified in different ways through literature. The two main issues identified with energy policies were the **inconsistencies of energy efficiency policies** (Rosenow & Eyre, 2016; Sovacool, 2015) and an **under-developed market** (Davey, 2012). These issues were still identified in the interviews of this research. The main impacts on low-income households are **poorly targeted policies**.

4.2.4.1. Inconsistent policies

The inconsistency of the energy efficiency policies has been one of the main issues identified in the UK. The Warm Front scheme, which has successfully removed 2.36 million households from fuel poverty since the year 2000, had its budget cut in 2010, and it was made difficult for people to apply, eventually leading to the program ending in 2013 (Sovacool, 2015). The other example is the Green Deal which was launched in 2013 and was deemed to be the flagship policy for energy efficiency in the UK, but which did not achieve its goals and finally stopped in 2015 (Rosenow & Eyre, 2016). This finding was validated by our interview with Participant A08 who believes inconsistent policy changes may be the most important barrier to energy efficiency in the UK: *"I think that policy may be the single most important point (barrier to energy efficiency). The Green New Deal, zero carbon homes, CCS (Crown Commercial Service), cancelled twice... It's like the UK government has no energy policy. It has a series of* ***inconsistent political changes*** *that seem to do a change every time the wind blows."[Participant A08].* The zero carbon homes were a target set by the government in 2006 for all new homes in the UK to be zero carbon by 2016 (Osmani & O'Reilly, 2009). This was

an ambitious target which would have provided more new houses to be built at high standards of energy efficiency, creating a better chance for people including low-income households to live in proper housing conditions. There were barriers identified to the implementation of the ambitious zero carbon home plans but interview with house builders say that the zero carbon plans could have been technically feasible given more concise action from the government (Osmani & O'Reilly, 2009) However, before the zero carbon homes for 2016 reached its initial target, the program was cancelled and replaced with new building policies with lower energy efficiency standards (BEIS, 2022b).

In early 2023, the work of the Department for Business, Energy and Industrial Strategy (BEIS) was divided between three other departments, namely, the Department for Science, Innovation and Technology, the Department for Business and Trade and the Department of Energy Security and Net Zero (DESNZ) (BEIS, 2023) This introduction of DESNZ as a separate new department shows the government's commitment on securing energy security and reaching Net Zero goals for the UK. In April 2023 the DESZ announced 12 statements on energy security, among which 3 of them are specifically on reducing energy demand and improving energy efficiency. This includes the introduction of the Great British Insulation Scheme which targets to reduce energy demand by 15% by 2030, the Heat Pump Investment Accelerator and also balancing gas and electricity bills to drive down household energy bills (UK.GOV, 2023a).

In improving energy commitments, the government has put more commitment into their energy efficiency and Net Zero plans. This includes announcing a £6 million budget for energy efficiency from 2025-2028 (UK.GOV, 2023a). The 3-year commitment in the future may improve certainty for stakeholders to implement energy efficiency plans.

4.2.4.2. Under-developed market

The other issue to be discussed on energy policies is that back in 2012 the UK was reported to have an "embryonic market" where **the energy efficiency market was not mainstream** and was underdeveloped (Davey, 2012). An underdeveloped market would mean less expertise in the energy efficiency sector and an increased need for financial investments (Davey, 2012). This may still be the case in the UK where interviews have shown challenges in supplying enough skilful workers and the need for private investment in funding energy efficiency plans in the UK. Participant IE13 in the interview states *"So there's not enough people who can*

install a heat pump, that is a massive challenge. So a lot of our work is on kind of funding colleges, for example, to be able to upscale a load of gas people into being able to live in newer green skills that might be needed to take the heat pumps and the kind of challenges around delivery"[Participant IE13].

Other than that, Participant I06 also discusses the **need for private investment** to help reach national targets. *"So I think for London, to retrofit the whole of London is something like 56 billion pounds it's going to cost between now and 2050 to retrofit London. However, we have only 6 billion only it's a lot of money, but we have only 6 billion allocated in this spending review period and the next spending review period… So to pay for energy efficiency on this massive kind of national scale, we need private investment"[Participant IE13].*

Despite the challenges faced in improving the energy efficiency market in the UK, the latest report by the American Council on Energy Efficiency Economy shows that the UK is doing quite well in terms of energy efficiency globally. The UK came in 6th place in the building energy efficiency scoreboard compared to 9th for the US, with the Netherlands as the best country in building energy efficiency (Subramanian et al., 2022). The measures for building energy efficiency were based on 8 different aspects which were judged thoroughly and given points for a max of 25 points. Overall, the Netherlands, the UK and the USA scored 22.5, 19.5 and 17 points respectively (Subramanian et al., 2022). In terms of overall energy efficiency rankings which include national efforts, buildings, industry and transportation, the UK was ranked second place in the world (72.5/100 points), behind France by 2 points (74.5/100 points)(Subramanian et al., 2022). This shows that since 2012, the UK has done well in improving the energy efficiency market at the global level.

4.2.4.3. Poorly targeted policies

Because of the issues surrounding energy policies in general in the UK, the main impacts felt by low-income households are poorly targeted policies. Interview with Participant C04 stated how there should be better policies that could target the most vulnerable groups of people.

"I also think there is a lack of targeting of schemes. So, some people encounter someone who offers support, but others don't. There may be a language barrier, they may never go to the authorities. They may not go to an advice charity because their life is too difficult. They don't

have time to queue and go to an advice workshop. We run workshops and some of the people who could come just didn't get there" *[Participant C04]*

The fact that there are still many poor people struggling to survive means there should be more targeted intervention from the government such as sending out teams to support vulnerable people in targeted areas which may help to improve their standards of living. Participant I06 added that there is funding available that might not be properly designed to target low-income households. *"For example, to get a certain access or a part of funding at the moment in Bristol is you need to not be on gas central heating... most low-income houses will be on gas and but they can't access this funding".*

In addition, it was also reported that existing funding for people may have not been enough, and should be focused more on long term solutions instead. Instead of a short-term solution of a one-off £150 payment, focusing on improving housing conditions could better help low-income households in the long term.

"Most recently the government gave a single £150 rebate… but that £150 was not enough to deal with one quarters increase in energy bills for most people…so you have to target things that make homes more energy efficient...the funds need to be applied to make a lasting solution" *[Participant C04]*

The problem of poorly targeted policies among low-income households could be a complex issue to be discussed and even the government would have limited funds. Participant IE02 when discussing about funding from the government for low-income households added;

"I do not think the government are able to fund this… it has to come from private funding"

[Participant IE02]

Hence, there needs to be an improvement on energy policies in supporting low-income households to improve their energy efficiency standards.

4.2.4 Key points:

- The main barriers related to energy efficiency policies were inconsistent policy changes and an underdeveloped energy efficiency market in the UK. This leads to poorly targeted policies among low-income households.
- Inconsistent policy changes show how there are a number of government schemes which may have improved energy efficiency in the UK but got cancelled. The new energy department by the government, DESNZ, aims to improve certainty in introducing energy plans.
- There are challenges identified in improving the energy efficiency market in the UK, but recent reports show that the UK is ranked 6^{th} in building energy efficiency and 2^{nd} in overall energy efficiency globally.
- Low-income households face poorly targeted policies which make it difficult for them to improve energy efficiency standards.

4.2.5 Summary for 4.2 emerging barriers to energy efficiency among low-income households in the UK

Following the discussion on the emerging barriers to energy efficiency among low-income households in the UK, the main barriers, description and interesting points are summarized in **Table 5** below. The "interesting" category refers to key points obtained from the discussion which are not specifically discussing barriers to energy efficiency. However, they are related to the topic of barriers and may add value to the discussion.

Table 5: Summarized emerging barriers to energy efficiency among low-income households from this research.

Types of barriers	Description	Interesting
Barriers of knowledge	-Low awareness of energy efficiency at the household level	-Energy crisis may make low-income households more aware of their energy consumption as they are most affected
	-Distrust in accepting advice, improvements to buildings and smart meter readings	
Building conditions	-Poor and old housing in the UK	-Rebound effect may impact the energy efficiency improvements
	-High upfront cost for insulation and other improvements	
Landlord-tenant dilemma	-Split responsibility between landlord and tenants	-Minimum Energy Efficiency Standard may introduce an illegal renting market
	-Inconvenient tenancy contracts	-Germany as a role model for tenancy agreement
Energy policy	-Inconsistent energy policies	-Department of Energy Security and Net Zero to improve policy certainty
	-Underdeveloped market	-Improved building efficiency ranking
	-Poorly targeted policies for low-income households	

The barriers summarised from the interviews of this study (**Table 5**) builds upon the existing literature on barriers to energy efficiency among the fuel poor in the UK (Fylan et al., 2016), and in Europe (Kolokotsa & Santamouris, 2015; Ugarte et al., 2016). Some of the barriers have been identified from previous studies, however, the emphasis of these four barriers obtained from the interviews puts a spotlight on the current major challenges faced by low-income households in 2022.

4.3 Behaviour and technology for low-income households

This section tries to understand how behavioural actions and technological improvements by low-income households may help them to improve building energy efficiency. This is followed by a discussion on how behaviours and technology might be able to address the barriers to energy efficiency as identified in Section 4.2.

The first stage interview responses to questions under the theme of 'Behaviours and technology as recommendations to improve energy efficiency among low-income households' showed close agreement on the behavioural changes needed but some areas of disagreement on the most important technologies to implement. For the question, 'Which of these behaviours would best suit low-income households in the UK?', participants highlight the importance of heat-related behaviours as the most important behaviours to be implemented. However, for the question of 'Which of these technologies should be prioritized to support low-income households to save energy in the UK?', the interview results show different views on how technology such as smart meters can have an impact on improving energy-saving habits. Some participants believe that smart meters are useful, but others believe smart meters are useless unless paired with the right attitude. Following the responses for the stage 1 interviews, the stage 2 interviews focused on questions to address each of the identified barriers, especially in addressing barriers number 3 and 4 which were addressing the landlord-tenant dilemma and inconsistent energy policies by encouraging the public to be more engaged in local communities which informs policies. All the second-stage interview participants agree that low-income households can help to address the barriers by getting more involved with local communities which work closely with local politicians, hence supporting a strong bottom-up approach in energy policy implementation. They also highlighted that behaviour and technology may help low-income households in improving energy efficiency, but it is essential to have external support from the government or the private sector to achieve the full potential of benefits. The following discussion presents data from literature combined with interview responses on the topic of behaviour and technology for low-income households.

4.3.1 Cost and savings

In this section, the potential cost and savings from each behavioural and technological action are analysed.

4.3.1.1 Behavioural actions

According to the report on "Free and low-cost energy-saving actions to bring down bills, improve energy security and help the planet" a list of the behavioural actions that can be done by households with their estimated amount of bill savings per year are presented in **Table 6** (Palmer et al., 2022).

Table 6: Table of behavioural actions and potential savings over the year for an average house in the UK. Source: "Free and low-cost energy-saving actions to bring down bills, improve energy security and help the planet"(Palmer et al., 2022).

Behavioural actions (Palmer et al., 2022)	Potential savings (£/ year)	Source
Turn the thermostat down by 2 degrees from 20°C to 18°C	313	Palmer et al., 2022
Turn the thermostat down by 1 degree from 19° C to 18°C	157	
Turn down the boiler flow temperature on combi boilers to 60 degrees	97	
Delay start of heating from October to November	69	
Lowering the settings on thermostatic radiator valves and turn off heating in unused room	55-68	
Turn down hot water temperature on combi boilers to 42 degrees	26	
Reduce hot water cylinder temperature to 60 degrees	26	
Turn off pre-heat on combi boilers	10	
Switch off lights when not in use	14	

Wash clothes at 40°C or less	10	CSE, 2022

The list of behavioural actions was obtained from the report done on "Free and low-cost energy-saving actions to bring down bills, improve energy security and help the planet". (Palmer et al., 2022). The main method used in these calculations is based on 12,300 dwellings from the English Housing Survey, which gives an average value of saving for all the different house types in the UK (Palmer et al., 2022).

The behavioural action that has the highest potential for savings is by **turning down the thermostat** temperature throughout the year (especially if the default temperature was initially set at a high temperature) (Palmer et al., 2022). Turning down the thermostat by 1 degree can save up to £157 while turning down the thermostat by 2 degrees can save up to £313 per year (Palmer et al., 2022).

Other than that, a good understanding of **setting the temperature of home boilers** are key behavioural actions to save energy. Combination boilers are boilers systems typically used in the UK which can provide both heating and hot water to homes directly without any hot water tanks. Turning down the boiler flow temperature on combi, or combination boilers to 60°C can save up to £97 per year, while turning down the hot water temperature to 42 °C may save up to £26 per year (Palmer et al., 2022). Typical settings for combination boiler temperature is between 70-80°C (Palmer et al., 2022), hence lowering the boiler temperature will save a significant amount of energy, while still heating houses at an adequate temperature. Another type of boiler is the conventional boiler which requires a water tank and hot water cylinder to supply hot water. Reducing the hot water cylinder temperature to £60 may save up to £26 per year (Palmer et al., 2022).

Households that are willing to **delay their heating** by a month may save up to £69 per year for households (Palmer et al., 2022), but will have to compensate for the cold temperatures by wearing warmer clothes indoors for the month before it gets much colder throughout the winter.

Thermostatic radiator valves are used to control the heating for radiators in different rooms. An awareness of using the radiator valves to reduce the temperature in each room or turning them off for rooms not in use can save £55-£68 per year (Palmer et al., 2022).

Finally, behavioural actions which do not relate to household heating such as **switching lights off** when not in use or **washing clothes at 40°C or less** may save up to £10-£14 per year (*CSE*,

2022). Even though there are uncertainties on the amount of savings on these behavioural actions that vary widely by household, these data were taken from the official website and should present the average savings which are validated these institutions (*CSE,* 2022).

The topic of behavioural impacts on energy actions could be complex and covers a wide scope to be specified before being compared. It is important to establish the context of the study, specific actions and size of buildings to determine the amount of savings made from energy efficiency. But ultimately, when used correctly, small repetitive behavioural actions used to improve building energy efficiencies may reach up to £313 per year in potential savings (Palmer et al., 2022).

4.3.1.2 Technological improvements

Next, the cost and potential savings of technological improvements are analyzed. The list of technological improvements shown in **Table 7** was mostly obtained from the Energy Saving Trust which is an established organisation in the UK which actively promotes energy efficiency and low-carbon solutions (*Energy Saving Trust*, 2023)

Table 7: List of technological improvements including the estimated cost and potential savings. The values are based on an average semi-detached property in 2023 and where marked, are not specified to housing types. Source: (Energy Saving Trust, 2023)

Types	Technological improvements	Cost (£)	Potential savings (£/ year)	Source
Structural improvements	Draught proofing Do-It-Yourself	10 / door	50-70	(Energy Saving Trust, 2023)
	Secondary glazing Do-It-Yourself	20 / window	50-70	
	Insulating hot water cylinder (80mm thick)	20*	50*	
	Loft insulation (0-270mm)	930	285	
	Cavity wall insulation	2,700	300	
	Solid wall insulation - internal	7,500	410	
Information technology	Time-of-use tariff schemes / Demand Flexibility Service + smart meters (Octopus Energy Saving Sessions)	-	36-100*	(Octopus Energy Saving Session, 2023)
	Smartphone applications to control smart thermostat Amazon Alexa Google Home Wiser Heat App	0-1,000*	64*	(Palmer et al., 2022)
Renewable energy	Solar rooftops 3.5kWp	7,000*	428*	(Energy Saving Trust, 2023)

*These are values obtained based on general housing standards

The cost and potential energy savings are obtained from an average semi-detached home in the UK which are one of the four main house types in the UK. The other house types are detached house, terraced and flats (*Energy Saving Trust*, 2023). Specific definitions of each technological improvement are explained in Chapter 2: Literature Review. Here we look at the descriptions of each action in Table 7 in more detail.

Draught proofing could cost about £10 per silicon strip but will depend on the amount used and can save from up to £50-£70 per year, while a whole house professional retrofit could cost up to £270 for a semi-detached house (Energy Saving Trust, 2023). For secondary glazing, households can do Do-It-Yourself glazing improvements such as insulating films which aretemporary up to high-quality sheets specialized for glazing that could be mounted on the windows (Energy Saving Trust, 2023). The other option is to opt for a professional refit and replace old windows with new ones which could cost a lot of money (Energy Saving Trust, 2023). Insulating hot water cylinders should already have an 80mm thick jacket to maximisethe efficiency of storing hot water for the home (Energy Saving Trust, 2023). For loft insulation, the Energy Saving Trust (2023) estimates that the average price of loft insulation for a semi-detached house is £930 (*Energy Saving Trust*, 2023). Cavity wall insulation and solid wall insulation can only be done by professionals and cost from £2,700 to £7,500 or more, depending on property type (Energy Saving Trust, 2023).

Time-of-use tariff schemes, also known as Demand Flexibility Service allow consumers to time their energy consumption during the period when electricity and gas bills are the lowestor reduce energy usage at peak hours(UK.GOV, 2023a). An example of the pioneer for this scheme is the Saving Sessions done by Octopus Energy, which encourages consumers to reduce energy consumption at around 4-7 pm, which are peak hours for energy for the day, potentially saving up to £36-£100 a year (*Octopus Energy Saving Session*, 2023). This may be supported by the smart meter which displays information on real-time energy consumption and costs. The households may also receive points by joining these saving sessions which could be converted to prizes, donations or cash (*Octopus Energy Saving Session*, 2023). In addition, smartphone applications such as Amazon Alexa which could connect with a smart thermostatto be controlled remotely could cost up to £1,000 if there is a need to install a whole new heating system control and save up to £64 per year (Palmer et al., 2022).

Finally, solar rooftops with a 3.5 kW peak output can power enough for a family of four to five people but cost around £7,000 to install (*Energy Saving Trust*, 2023). Note that solar energy is dependent on the sun and weather conditions. In suitable conditions when the sun is out, it may reach peak output and power up to four or five people as mentioned. However, the output would be less in the winter or when there are thick cloud conditions. This does not include the battery required to store the solar energy, mounting systems and other operational costs which could push the prices higher. Energy Saving Trust (2023) estimates savings from a 3.5kWp solar rooftop to range from £325 to £530 for a year. Hence an average value of £428 savings per year from installing solar rooftops (Energy Saving Trust, 2023).

It is not relevant to compare the values of savings from behavioural actions and technological improvements together as these calculations were done:

1) Based on different housing conditions. Behaviour data from average UK house (Palmer et al., 2022), while technology data were obtained from estimates of an average semi-detached house in the UK (*Energy Saving Trust*, 2023)
2) As an estimation of the potential savings. The actual amount of savings is dependent on the actions done by households.

Following the analysis of the free and low-cost behavioural actions and technological improvements that could be done by low-income households, it can be seen that low-income households which do not have enough capital would need government support to be able to afford to build insulation and other capital-intensive improvements. **Table 8** shows a list of government schemes available to help people improve energy efficiency in the UK.

Table 8: List of government schemes offered to assist low-income households in improving energy efficiency.

Government scheme	Target	Scheme details	Source
ECO+ Scheme or The Great British Insulation Scheme	Homes with low Energy Performance Certificate rating of D-G	Loft and cavity wall insulation	CSE, 2023
Connected for Warmth	Private rented tenants	Loft and cavity wall insulation	
Home Upgrade Grants	Identified low-income households	Scheme to improve a wide range of insulation, renewable and low carbon heating	
Social Housing Decarbonisation Fund	Social housing tenants which are usually low-income groups	Scheme to improve a wide range of insulation, renewable and low carbon heating	
Boiler Upgrade Scheme	Households without heat pumps	Instalment of air source heat pump, ground source heat pump and biomass boiler	

4.3.1.3 Combination of behaviour and technology

Previous studies have studied the importance of combining social science with physical science in energy research to improve the potential of energy efficiency (Sovacool et al., 2015; Steg, 2008). The findings from this study might supplement previous studies in a way that behaviour is social science while technology is physical science in improving the energy efficiency of low-income households in the UK.

It can be seen that there is a strong relationship between behavioural and technological actions in this study. For example, reducing thermostat temperature while installing draught-proofing on doors would have a combined impact on improving energy efficiency among low-income households. These behavioural and technological actions supplement each other to make the best out of energy efficiency savings.

4.3.1.4 Framework for low-income households to improve energy efficiency

From the analysis of behavioural actions and technological improvements, **Figure 13** summarizes a general framework for low-income households to follow to best improve household energy efficiency and save energy.

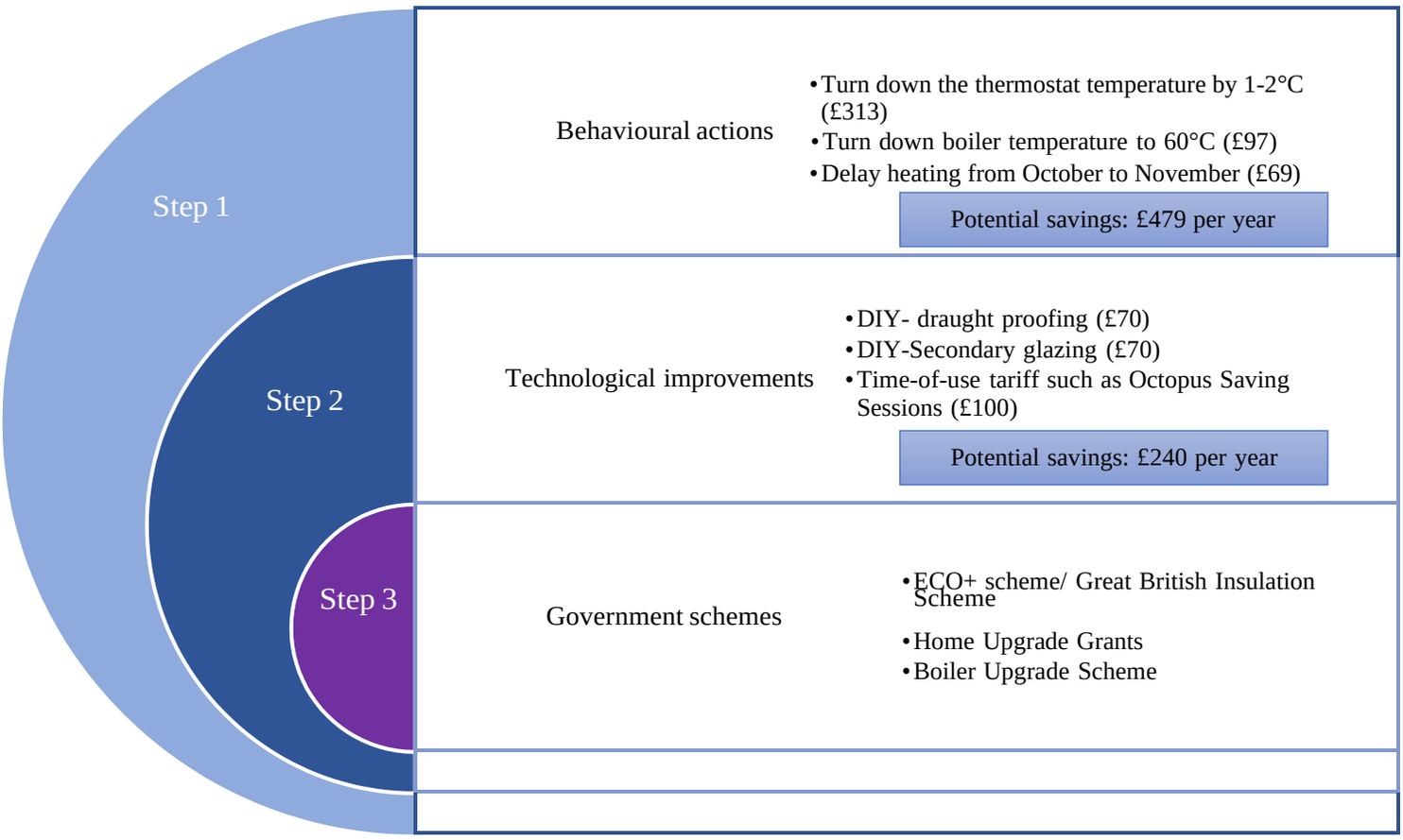

Figure 13: General framework for low-income households to improve energy efficiency in the UK. Values of potential savings from behavioural actions and technological improvements obtained from (Palmer et al., 2012) and (Energy Saving Trust, 2023) as presented in Tables 6 and 7.

Step 1: The first step in improving energy efficiency for low-income households is to turn down the default temperature on the thermostat by 1 or 2°C, hopefully without affecting the level of comfort. Next is to turn down the default boiler temperature to 60ºC which is slightly below the default temperature on boilers. Finally, delaying using heaters from October to November in the early month of winter. Overall, the sum of potential savings from these behavioural actions may go up to £479 per year (refer to Table 6).

Step 2: The second step is to do Do-It-Yourself improvements wherever possible such as draught-proofing doors and secondary glazing windows. These include learning about the DIY improvements such as buying suitable products and the best way to properly draught-proof

doors and windows to minimize cold air from entering the homes. Next is to be aware of the time-of-use tariff schemes such as the Octopus Energy Saving Sessions in order to be rewarded with prizes or cash for using less electricity during peak hours. Overall, these technological improvements may have the potential to save up to £240 per year (Refer Table 7).

Step 3: Finally, it is suggested that low-income households seek funding from government schemes to fund the expensive insulation improvements such as loft, cavity wall and solid wall insulations to improve overall building energy efficiency.

Note: The total estimated potential savings from the behaviour and technology framework in Figure 13 is £719 per year (£479 from behavioural actions and £240 from technological improvements), which is **£60 per month**. The average annual energy bills for gas and electricity combined in 2022 is £2,316 per year, or **£193 per month,** as mentioned in Chapter 2. Hence, it may be possible that **applying the framework in Figure 13 can cut up to 31% of energy bills per month.** Low-income households which are already aware of these actions might have already applied these steps suggested and live in cold homes would not likely achieve the potential savings mentioned. These potential savings are valid for households that have not done the steps as suggested in the general framework in **Figure 13**. Given the fact that there can be a huge potential for financial savings from behavioural actions and technological improvements may motivate households to further implement energy-saving actions.

An interesting takeaway from this study is that the behavioural actions that impact energy savings most significantly are all heating-related. Adjusting the thermostat and boiler temperature would save the most amount of money from energy consumption (from £313-£97 per year). Whereas, the non-heat-related behavioural actions which are actively promoted, such as turning lights off when not in use or washing clothes at 40ºC or less, save a relatively smaller amount (£14-£10 per year).

In the following discussion, we discuss how behaviour and technology may address the four emerging barriers to energy efficiency among low-income households identified previously in chapter 4.2.

4.3.2 Addressing the identified barriers

This section explains how behavioural actions and technological improvements done by low-income households may only address two of the four emerging barriers identified in chapter 4.2. Behavioural actions and technological improvements may address the barriers to knowledge among low-income households by improving awareness of energy consumption. They may address the issue of poor housing conditions by equipping themselves with the right steps to improve building insulation. However, the barriers of landlord-tenant dilemma and energy policies might be difficult to address directly by the lower income households.

4.3.2.1 Addressing barriers to knowledge

In Chapter 4.2, the barriers of lack of knowledge among households in improving their energy consumption were discussed. In this section, we discuss how behavioural and technological actions may address the barriers to knowledge among low-income households.

While the energy crisis might have both exacerbated and improved the lack of knowledge among households to improve their energy efficiency, efforts to continue supporting and providing information on energy consumption among low-income households should continue as there will always be vulnerable people who will need help. Participant I01, who works withan energy advice institution added *"We always find that there are some tips that people don'tknow about and we always get people to do these things"* [Participant I01].

The Knowledge-Attitude-Behaviour model explains how knowledge is crucial in changing behaviour (Liu et al., 2016). In her study, Liu et al., (2016) used the awareness intervention for their haemodialysis patients which resulted in the patient's increased behavioural changes. This can be applied to energy efficiency as well. Setting up awareness interventions specifically on energy consumption might help people to change their behaviours. The model shows that knowledge is integral in changing one's behaviour.

In addition, another different but closely related Attitude-Behaviour-Context model suggests that certain behaviours and attitudes may be promoted by improving the context (conditions) required to promote these changes (Xu et al., 2017). Xu et al., (2017) found that promoting energy-saving behaviour in the workplace needs an improved interaction or discussion on energy between employees (Xu et al., 2017). This means the easier the task, the easier people can change their behaviour. In terms of low-income households, improving the

conditions needed for people to share their knowledge on behavioural change with each other would help to improve behavioural changes to save energy.

Another importance of consistently spreading awareness on energy consumption is the fact that the UK is rich in different cultures which might affect household energy consumption. International students who live in student university accommodation usually heats their homes differently. Students who are acclimated to warm countries may use their heat more frequently compared to local students who are used to colder climates and are aware of wearing thicker jackets indoor rather than increasing heating to save energy. Another example of how different cultures may affect behaviours was mentioned by Participant A03 in the interviews:

"people from different cultures that have recently arrived in the UK, they might need to adapt their culture to the energy costs. For example, in some cultures, it is common for women to be indoors a lot and to spend a lot of time in the kitchen, not necessarily voluntarily. And where they might have cooking habits, which involve basically cooking all day. Slow cooking and so on, these kinds of cultural practices are probably not suitable to the way power is priced in the UK, so they will need to adopt their cultural practices to the electricity prices. OK, so in those cases, behaviour change can be quite important"

[Participant A03]

Information technology such as smart meters may improve the knowledge of household energy consumption and has the potential to increase energy efficiency among low-income households (Brown et al., 2020). By using smart meters, consumers will be more aware of their potentialsavings.

"I would encourage people to get smart meters because they will notice that they will be able to visibly see the difference when they are doing these behavioural changes. Because sometimes the actual reduction is really small from these things" *[Participant I01]*

However, the implementation of technology is rendered useless if not paired with the right attitude (Batalla-Bejerano et al., 2020; Brown et al., 2020). The information obtained from smart meters would need to be paired with actions to improve energy efficiency. This is supported by participant IE02 which believes smart meters should come with better feedback: *" I would say that smart meters are far from smart…you need a whole bunch of good feedback and at the moment, people are not getting that"* *[Participant IE02]*

Smart meters should come with personalized feedback, which would maximize the impact of smart meters in saving energy. For example, the detection of high levels of energy consumption around 6 pm might suggest consumers reduce energy-related activities at peak hours such as taking long showers or cooking dinner right after work. Further personalized feedback may be to turn on notifications on smart meters when there are lower gas and electricity prices in order for people to do energy-related activities at those suggested times.

One of the suggestions for low-income households to improve energy efficiency is to implement the time-of-use tariff scheme such as the Octopus Energy Saving scheme. By reducing energy consumption at peak hours, households may save up to £100 per year (Table 7). However, these schemes can be discriminating as people struggling with different jobs might not be able to participate in these schemes.

"Sometimes these can discriminate against certain types of people depending on how you work. So obviously lots of people work 9-5 but quite a few people who are suffering fuel poverty, may do shift work, they may work multiple jobs within one day. They could be working overnight for instance. So they're not necessarily home within the time bandings or the time periods where they can benefit from receiving the savings of that." *[Participant I11]*

Other than that, people with disabilities and health conditions might also not be able to benefit from these time-of-use tariff schemes. Hence, the development of time-of-use tariff schemes should ensure that low-income households and people with disabilities and health conditions are protected and would not be discriminated.

4.3.2.2 Addressing housing conditions

In this subsection, we discuss how behavioural and technological actions by low-income households may contribute to improving housing conditions.

Interviews were conducted to ask about the technologies that should be prioritised for low-income households. Many of the participants highlight insulation as the main priority for low-income households. This is validated by the participants in this study.

"So yes, improvements to building services should absolutely be the first point of call, and it makes the most amount of sense" *[Participant I06]*

"Basically, insulating homes should be a priority for every household. But yes, if we talk about low-income, that (insulation) should be a priority" *[Participant I01]*

However, when looking at what could be done by the low-income households on the ground,the feasible actions without external support only cover no-cost behavioural actions and Do-It- Yourself draught proofing, Do-It-Yourself secondary glazing and insulating hot water cylinders (for homes that use hot water cylinder). Most of the improvements in building insulation are too expensive to be covered by the low-income households themselves. Without external support, there is not much that can be done by low-income households alone.

For technology, the best options are Do-It-Yourself actions such as draught-proofing, Do-It- Yourself secondary glazing and joining the time-of-use tariff schemes such as the Octopus Energy Saving Schemes.

The main risk associated with these DIY improvements on housing structures is that they may cause dampness, which may worsen the condition of the buildings (CSE, 2023). Other risks include poor insulation performance, damage to the visual characteristics of the building and create unwanted maintenance. (CSE, 2023). Hence, unless the improvements can be done at an affordable price with enough confidence and awareness of the risks and consequences**, it is suggested that households seek advice from professional retrofitting agencies** which will follow official guidelines by the government.

In the scope of actions that could be done directly by low-income households, the best optionsin terms of behaviour are to turn down the thermostat by 1-2ºC, turn down the boiler temperature to 60 °C and delay heating by a month at the start of winter from October to November (refer table 6).

The main actions in improving building efficiency are reducing anything related to heating such as reducing thermostat temperature and boiler temperature. This is because heating contributes to the most costs for energy bills.

What can be done by low-income households is **repair and maintenance** on the condition ofthe current house conditions. Many problems were reported by people not knowing what to do with the technology installed. For example, participant I15 shares their experience with tenants who already have heat pumps installed in their properties: *"I remember a lot of complaints because it hadn't been explained to them properly like how to use them or to use the technology correctly and in the end, it was very expensive for them to run." [Participant I15]*. Even with the latest technologies such as heat pumps which were supposed to improve energy efficiency, not knowing how to properly use these technologies or how to set the timers to best suit the consumer's consumption may increase energy bills paid by consumers.

Another example can be seen here as stated by Participant C04: *"In my experience, an installer of a meter or a boiler or anything else, they do not explain what goes on. …they just say it's all set up now goodbye."[Participant C04].* Installers who are knowledgeable in setting up specific technologies such as boilers for different houses, are not required to give further instructions or advice on using the technology. Having a short 10-minute conversation with the boiler installer on how to set timings for turning on and off heaters at specific times of the day could save hours of independent research online. What happens instead is that after installation, the installer will have done his responsibility and leave the property without the need to help set up the temperature timings. Households are left to explore the technologies themselves which might not be as impactful compared to advice from the installers themselves.

Households would need to improve their awareness of any signs of repairing or maintaining the technologies available at homes in the best conditions. What can be done by the people is establishing community groups that can help assess the quality of self-made retrofitting to make sure the retrofits have been installed correctly. This could be done by visual inspections or with the assistance of technologies such as thermal imaging.

4.3.2.3 How low-income households may influence policies

The previous discussion shows how behaviour and technology may address the two barriers to energy efficiency among low-income households, which were barriers to knowledge and housing conditions. However, behavioural and technological actions might not directly affect the energy policies and landlord-tenant dilemma. Hence, this chapter discusses how low-income households may affect policy decision-making, which is crucial in addressing the barriers of energy policies and landlord-tenant dilemmas.

Interviews with different stakeholders in the energy sector highlighted several ways low-income households can affect policies. The first step is for people to engage in political parties. This includes making sure to know the local candidate running for election in local areas, including their manifestos and goals from the political parties. " *as the general public, the best way in influencing the policy, one is by engaging in political parties. Doesn't matter what political party that you are involved. That is the first thing." [Participant C10].* Suggesting people to engage with their local candidates would require households to participate in community meetings and to be vocal about their needs. Families that voice out their problems would make it easier for local authorities to react in the best way possible.

Next is to be active in community structures. Interview with Participant C10, who has worked with the Bristol City Council for over 13 years, highlights how the council *"co-designed, co- facilitated, co-produced for everything that you do in the community"[Participant C10]*. By ensuring the collaboration between the councils and communities, the councils could best serve the needs of the communities. The latest Net Zero plans by the UK Department of Energy Security and Net Zero included Quarterly Net Zero forums and the establishment of 5 local Net Zero hubs with £5 million a year funding to improve energy efficiency and help reach Net Zero (UK.GOV, 2023a). *"The reason the forum was brought in was to provide like one touch pointso the local councils can have all of this government departments together in one place"[Participant IE13].* Lower-income communities could directly raise an issue to their local councils, which government officers can bring up in regular meetings. These programs show the improved commitment by the government to engage with local communities.

Implementing behavioural and technological actions might help gain data on the impacts ofenergy-saving measures. The government or organisations may use the data collected to improve further recommendations on energy saving for low-income households. Participant I11 recommends: *" So what behaviour and technology can provide is evidence…the (time-of-use tariff) schemes that Octopus Energy are doing, for instance, the evidence from that package can convince policymakers that that is the type of thing that needs to be happening in the energy industry." [Participant I11].* With the world moving towards improving energy demand flexibility to balance the energy grid with human energy consumption patterns, more data on the impact of these energy-saving technologies can enhance reliability and government trust in carrying out energy-saving programmes.

4.3 Key points:

- A general framework to assist low-income households to improve energy efficiency were summarized into 3 main steps which were 1) Behavioural actions, 2) Technological improvements and 3) To apply for government schemes (as shown in **Figure 13**)
- The most impactful behavioural actions are to turn down the thermostat temperature by 1-2°C, turn down the boiler temperature to 60°C and delay heating from October to November, which may potentially save up to £479 per year.
- The most impactful technological actions are to do DIY-draught proofing, DIY-secondary glazing and to make use of time-of-use tariffs which may potentially save up to may save up to £240 per year.
- The behaviour and technology might address two out of the four barriers to energy efficiency identified which is to 1) address the barriers to knowledge and 2) address housing conditions. Further recommendations were given on how low-income households may influence policies at a higher level.

Chapter 5 Conclusion and recommendations

This research sought to answer the research question of "*How can behaviour and technology assist low-income households in the UK in making energy savings?"*

This research achieved the objectives of this research which were:

1. To present an up-to-date context of the issues that led to the rise of energy poverty in the UK.
2. To present the importance of supporting low-income households in improving their household energy efficiency.
3. To highlight the key barriers faced by low-income households in the UK to improve their energy efficiency.
4. To create a framework, which is a list of recommendations based on their ease of implementation, for how behaviour and technology could improve energy efficiency in the UK.

To answer the first objective, a literature review was conducted on the current changing landscape of energy issues, eventually leading to the rise in energy prices in 2022. This was then followed by how the energy prices worse affect the energy poverty groups and low-income households. Then, a background study was done on the efforts to assist low-income households through the increased energy bills by improving energy efficiency. The research is then focused on the suggested actions that could be done by low-income households themselves which are by improving behaviours and technologies.

The method chosen in this research is semi-structured qualitative interviews with 15 high-level stakeholders in the energy industry from four separate categories, which were city councils, academics, industry experts and institutions. The interviews were transcribed, and a thematic analysis was done using NVIVO software.

The results and discussion in this research started with answering objective number 2, which discussed the importance of supporting low-income households in improving energy efficiency to reduce energy poverty and to reduce carbon emissions. While there were tensions identified in achieving the two goals of reducing energy poverty and reducing carbon emissions through energy efficiency, the study concluded that energy efficiency measures by low-income households could help to reduce energy poverty, improve comfort and, to an extent, contribute to a reduction in carbon emissions. Emphasis should be placed on reduction in poverty and

improvement in comfort for low-income people, as greater carbon reductions can be achieved by concentrating on higher-income consumers.

This is followed by a discussion of the emerging barriers to energy efficiency faced by low-income households in the UK which answers the third objective of this research. The barriers identified were barriers to knowledge, housing conditions, landlord-tenant dilemma and energy policies, which heavily impact low-income households in the UK. The barriers identified build upon the existing literature on barriers to energy efficiency among the fuel poor in the UK (Fylan et al., 2016) and in Europe (Kolokotsa & Santamouris, 2015; Ugarte et al., 2016), which puts a spotlight on the current significant challenges faced by the low-income households in 2022.

To answer the fourth objective, this research looks at how behavioural actions and technological improvements which low-income households could do to help improve energy efficiency at home. Behavioural actions such as turning down the thermostat by 2°C from 20°C to 18°C may potentially save up to £313 per year, while technological improvements such as DIY draught-proofing and secondary glazing, as well as time-of-use tariff, may save up to £240 a year. The research also came up with a framework which suggests the 3-level steps for low-income households in going through the energy crisis, which is by 1) changing behaviour to reduce heating conditions, 2) technological improvements such as DIY draught-proofing and time-of-use tariff schemes and finally 3) applying for government funding to get better support for insulation improvements. Applying these behavioural actions and technological improvements by low-income households may address the barriers of knowledge and housing conditions identified among low-income households but not directly address the problem of landlord-tenant dilemma and the issue of energy policies.

It is hoped that this research may contribute to helping low-income households improve energy efficiency and save energy while contributing to the UN's 7th Sustainable Development Goal of ensuring "affordable, reliable, sustainable and modern energy for all".

The limitations of this research were that it was based on the perspective of higher-level stakeholders in the energy industry instead of approaching low-income households directly because of ethical concerns. Other than that, the limited time constraints meant the number of participants interviewed was limited to 15 people for this study. Next, the discussion of the potential savings from behaviours and technology in Chapter 4.3 was based on limited

available data from the literature. Thus, the recommendation for further research is to directly approach low-income households with more interviews to understand better the struggles faced by them directly in an ethical manner. Finally, it would be interesting to do case studies on the actual savings, which could be done by implementing behavioural actions and technological improvements by different sizes of households and housing types as better guides for low-income households in the UK to improve their household energy efficiency.

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Appendices

Appendix 1: Glossary

Keyword	Definition
Energy poverty	Energy poverty is defined as people or households spending pending more than 10% of their income (after housing costs) on domestic energy (DESNZ, 2023).
Low-income households	Low-income households are people with a low monthly income that will need to pay a bigger portion of their income on energy bills compared to those of higher income groups. Hence, in this research, when addressing the issues of energy poverty, the main target group to be supported are the low-income households.
Net Zero/ Net Zero Carbon	Net Zero or Net Zero Carbon is a target to be achieved globally by reducing anthropogenic CO_2 until it is balanced with the cumulative anthropogenic CO_2 emissions (IPCC, 2022)
Behaviour	The definition of behaviour in this study is adapted from Gaspari et al., (2021) which refers to the repetitive actions that can be done at home to induce the habit of energy savings without including any technological improvements.. This includes actions such as reducing heater temperature, boiling water only as much as needed and using lower temperatures to wash clothes
Technology	Technology as defined by Brown (2020) are "materials and practice that require less energy to deliver a given service". Technology in this study includes housing improvement technologies such as structural repairs, information technology and renewable energy technologies that could help improve a household's energy efficiency.

Appendix 2: Interview questions

First round interview questions

Participants were given the Participant Information Sheet and Consent Form to be signed before the interview started.

Importance

1. How important is it to include low-income households in the energy transition towards net zero carbon.
2. What is your opinion on the role of energy savings in accelerating the energy transition?
3. Do you think it is relevant to impose energy saving/ energy efficiency actions on low-income households?

Barriers

4. In your opinion, what are the top three barriers for energy efficiency faced by low-income households in the UK?
5. If any, what are the other barriers to energy efficiency faced by low-income households that you can add to the list?
6. How limiting is the landlord-tenant dilemma to achieve energy efficiency for low-income households?

Behaviours

7. Which of these behaviours would best suit low-income households to promote energy savings?
8. How can we motivate behavioural changes among low-income people?

Technology

9. In your opinion, which of these technologies should be prioritised to support low-income households to save energy in the UK? Why?
10. What are other technologies that could benefit low-income households that could be added to the list?
11. How can we help households that still live in low temperatures even after energy efficiency retrofits?

Behaviour and technology

12. Is it important to incorporate human behaviour into technological advancements?
13. How can we ensure the technologies built to give maximum benefit to the users? (industry experts)
14. Do you consider behaviour in your technological developments? (industry experts)

Extra

15. Considering the latest increase in energy prices, what would be your key advice to low-income households to reduce their energy bills?

Second round interview questions

Participants were given the Participant Information Sheet and Consent Form to be signed before the interview started.

Importance

1. What are the importance of supporting low-income households in the community?
2. How does the energy efficiency portray the reality of reducing energy poverty and reaching net zero goals?

Barriers

3. From your experience, what are the main problems associated with housing conditions in the UK?
4. From your experience, what are the housing issues worst impacting low-income people?
5. How do you think the political changes affect the development of energy policies in the UK?
6. How did the Net Zero plan include improving energy efficiency for low-income houses?
7. In your opinion, does the rebound affect make it more difficult for energy efficiency improvements?
8. Do you think the Minimum Energy Efficiency Scheme- where landlords need to reach at least a minimum EPC level C to rent out buildings would work well to help tenants?

Behaviour and technology

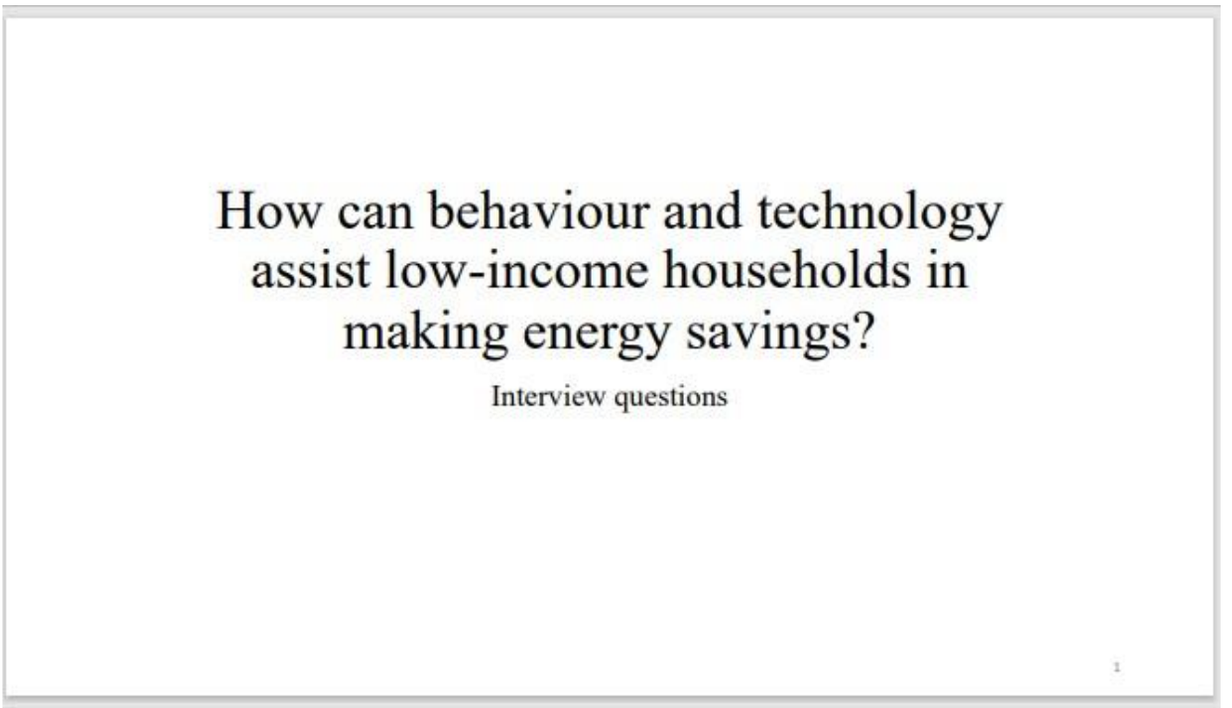
9. How can providing a general estimation of financial savings per action encourage people to improve their energy efficiency actions?
10. In what other ways can behaviour and technology help low-income people to improve their household energy efficiency?

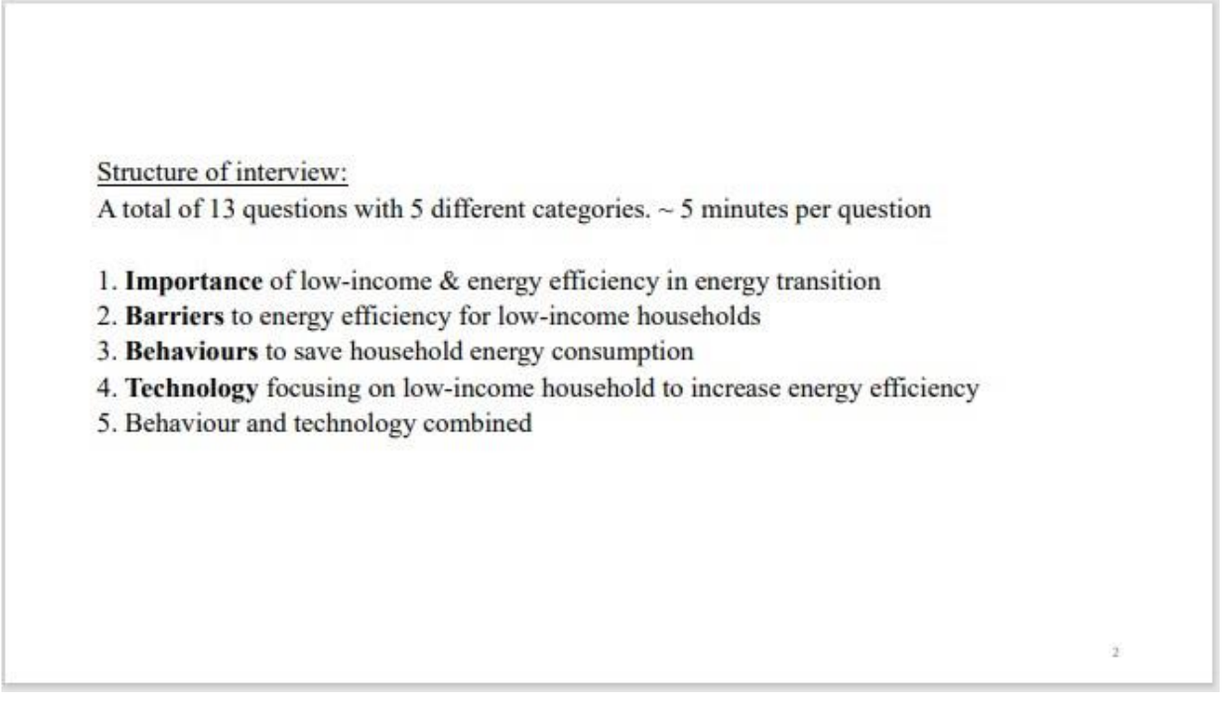
Addressing barriers

11. What are your thoughts on how the general public can influence policies (especially in energy).
12. How do you think behavioural actions can improve knowledge on energy consumption?
13. How does the central government collaborate with local councils (to include the low-income people's opinion) in deciding a policy?

Appendix 3: Interview slides

The interview questions which were written in a PowerPoint slide presentation is shared to provide an example of how the interviews were carried out.





Section1: Importance

Around 1.5m families will struggle to pay bills as UK set for recession – Niesr

Statement 1

1.5 million people in the UK will struggle to pay bills starting this year

(National Institute of Economic and Social Research, NIESR)

1. How *important* is it to include low-income households in the energy transition towards net zero carbon?

3

Importance

Statement 2

Energy transition is defined as any effort in achieving net zero carbon emissions. This includes the production of **electricity from clean renewable sources** and also **energy savings** to reduce carbon emissions.

2. What is your opinion on the *role of energy savings* in accelerating the energy transition?

4

Importance

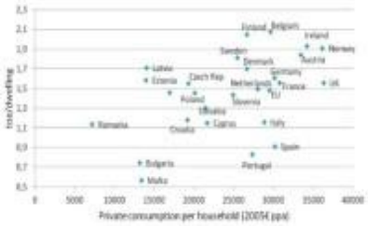


Fig. 7. Energy consumption per dwelling versus income per household in 2005.

Statement 3

In the EU, low income population use among the lowest levels of energy consumption (Kolokotsa and Santamouris 2015)

3. Do you think it is *relevant* to impose energy saving/ energy efficiency actions on low-income households in Bristol

5

Section 2: Barriers

Statement 4

Barriers to energy efficiency for low-income households in Europe (Ugarte et al 2016),(Brown,2020),(Rebecca 2019)

Types of barriers		Description
Behavioural		No general awareness on benefits of energy efficiency Tendency to procrastinate Copying other people Fear of regret to be wrong
Informational	Dwelling	• No knowledge about energy consumption • No knowledge on savings potential • Decision complexity
	External	• Lack of information about support programme/grants • Lack information on consultancy • Lack information on person-specific information
Economic	Financial	• Lack of savings • Low credit score
	Incentives	• Landlord tenant split incentive • Lack of subsidies on energy price
	Risk aversion	• Uncertain about future situation • Fear to acquire debt • High upfront cost with less obvious benefit
Building		• Poor housing conditions

6

Section 2: Barriers

4. In your opinion, what are the top ***three*** barriers for energy efficiency faced by low-income households **in the UK**?

7

Barriers

5. If any, what are the other barriers to energy efficiency faced by low-income households that you can add to the list?

8

Barriers

Statement 5

30% of people in the EU live as tenants, which are mostly categorized as low-income. Hence, a big issue about energy in low-income households is the **Landlord-Tenant dilemma**. (Ugarte et al 2016)

The landlord-tenant dilemma occurs when a landlord and tenant have difficulties in agreeing upon a common strategy for energy-efficiency improvement of a property. (Åstmarsson et al., 2013)

6. *How limiting* is the landlord-tenant dilemma to achieve energy efficiency for low-income households?

9

Behaviours

Statement 6

Behaviour actions in reducing household electricity and space heating energy consumption. (Martiskainen, 2014), (Centre for Sustainable Energy), (British Gas)

Examples

General
- Turning lights off when not in use
- Turning appliances off when not in use – Do not leave on standby
- Closing curtains at night to prevent heat loss

Kitchen
- Only boil as much water needed
- Defrosting freezer regularly
- Microwave> oven for reheating
- Get a slow cooker- better than stoves

Washing machine
- Clean dryer tumbler filter often
- Dry outside as much as possible
- Do not dry clothes on radiators
- Fully load washing machine
- Wash at 30°c (low temperature)
- Choose eco-friendly option if available

Behaviour type: Curtailment behaviours -Repetitive efforts-

Examples

Toilet
- Shorter showers (save energy to heat water)
- Use cold water over hot water
- Turn off heater when not in use

Living room
- Habit of wearing comfortable warm clothes inside
- Only turn on radiator when using it
- Turning off devices when not in use. Saves £5 annually according to Energy Saving Trust

10

Behaviours

7. Which of these behaviours would *best suit* low-income households to promote energy savings?

11

Behaviours

8. How can we *motivate* behavioural changes among low-income people?

12

Technology

9. In your opinion, which of these technology should be *prioritised* to support low-income households to save energy **in the UK**? Why?

13

Technology

Statement 7

Technology focusing on low-income household to increase energy efficiency (Kolokotsa & Santamouris, 2015), (Centre for Sustaina Energy), (Brown 2020), (British Gas)

Technological types	Example
Structural improvements	• Draught proof window& doors • Secondary glazing • Insulating hot water cylinder • Loft insulation • Cavity wall insulation • Solid wall insulation • Heat pumps

Technological types	Example
Information technology	• Company time of tariff schemes • Smart meters • Smartphone applications connected to smart thermostats • Installation of smart electrical appliances: smart lightings, smart thermostats, smart oven
Integration of renewable energy	• Solar rooftops • Microgrids in isolated regions. Community solar arrays + battery storage for off-grid consumers

14

Technology

10. What are other technologies that could benefit low-income households that could be added to the list?

15

Technology

Statement 8

(Critchley et al 2007) show that some of the houses that have performed energy efficiency retrofits in the UK still live in low temperature. This is because the systems may not be properly installed, or the retrofits done to most of the pre-1930 properties does not give significant impact despite major improvements

11. How can we help households that still live in low temperature even after energy efficiency retrofits?

16

Behaviour and technology

Statement 9

> Smart meter is a good example of encouraging behaviour with the use of energy information feedback. However, if users fail to demonstrate a pro-active attitude, they cannot hope to take advantage of the opportunities afforded by new technologies. (Batalla-Bejerano et al., 2020)

12. Is it important to *incorporate* human **behaviour into technological** advancements?

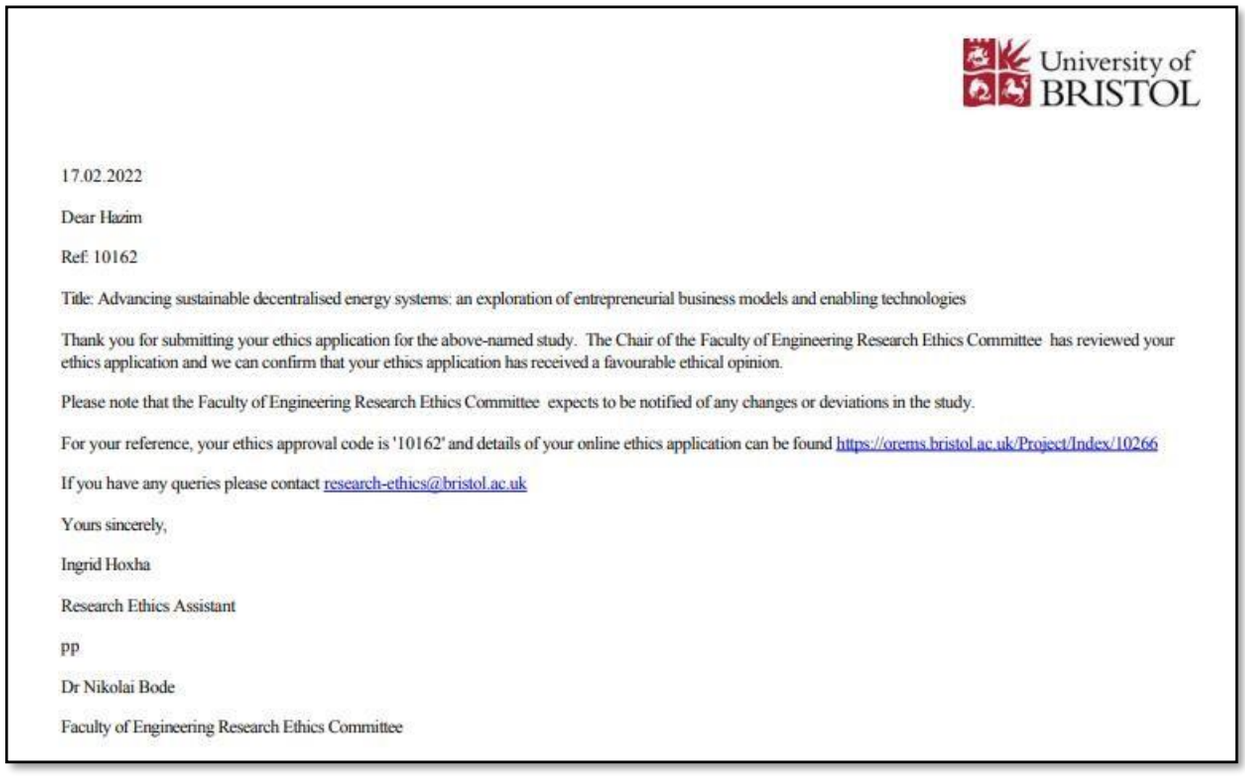
17

Extra

13. Considering the latest increase in energy prices, what would be your key advice to low-income households to reduce their energy bills?

18

Appendix 4: Ethical approval



University of BRISTOL

17.02.2022

Dear Hazim

Ref: 10162

Title: Advancing sustainable decentralised energy systems: an exploration of entrepreneurial business models and enabling technologies

Thank you for submitting your ethics application for the above-named study. The Chair of the Faculty of Engineering Research Ethics Committee has reviewed your ethics application and we can confirm that your ethics application has received a favourable ethical opinion.

Please note that the Faculty of Engineering Research Ethics Committee expects to be notified of any changes or deviations in the study.

For your reference, your ethics approval code is '10162' and details of your online ethics application can be found https://orems.bristol.ac.uk/Project/Index/10266

If you have any queries please contact research-ethics@bristol.ac.uk

Yours sincerely,

Ingrid Hoxha

Research Ethics Assistant

pp

Dr Nikolai Bode

Faculty of Engineering Research Ethics Committee

Appendix 5: NVIVO thematic analysis

Themes, subthemes and codes used in the NVIVO analysis

Themes

Theme	Subthemes
Importance	• Energy saving importance • Low-income importance
Barriers	• Energy policy • Housing conditions • Landlord-tenant dilemma • Barriers of knowledge
Behaviour	• Behaviours helpful • Behaviours not really helpful
Technology	• Insulation improvements • Sensors and controls • Integration of renewables

Subthemes

Files refer to the number of interviews cited for each subthemes, while references refer to the total number of codes for each subthemes.

Subthemes	Files	References
Energy saving importance	9	22
Low-income importance	11	38
Energy policy	12	55
Housing conditions	12	38
Landlord-tenant dilemma	12	40
Barriers of knowledge	9	21
Behaviours helpful	13	30
Behaviours not really helpful	5	8
Insulation improvements	9	31
Sensors and controls	8	17
Integration of renewables	9	29

Codes

The codes refer to the first level of data analysis, where the codes are then grouped into subthemes and finally into themes for results and discussion.

Codes	Subthemes
• Workplace • Value to customers • To concentrate on daily struggle • Shifting energy demand • Energy efficiency as root of energy poverty	Energy saving importance
• Staying warm • Overstated	Low-income importance

• Low-income low emission • Just transition • Imposing energy reduction on *LIH • Advantages of reducing energy for LIH • Breaking energy poverty	
• Misaligned policies • Lack of government support • Inconsistent policies • Energy UK a market failure	Energy policy
• Rebound effect • Poor housing • Minimum Energy Efficiency Scheme • Market challenges • Insulation barriers • Vulnerable groups	Housing conditions
• Stress of decision complexity • Split responsibility • Private landlord issue • Letting structure UK • Landlord-tenant dilemma • Landlord increasing rent • Landlord enforcement • Antagonistic landlord tenant	Landlord-tenant dilemma
• Trust issues • Lack information at organization level • Lack information at household level • Lack information at supplier level	Barriers of knowledge
• Standby awareness • Promote fun • Prepayment meters • No cost changes • Gender affect behaviour • Gaps in energy saving awareness • Culture affect behaviour • Behavioural advice	Behaviours helpful
• Only effective when excessive • LIH already use less • Government does not encourage • Frugality with money	Behaviours not really helpful
• Insulation • Council houses • Buy in bulks	Insulation improvements
• Variable tariff • Smart meter • LEDs • Heating controls	Sensors and controls

• Electric blankets • Data analytics	
• Renewables last thing to do • Microgrids • Install solar panels • Heat pumps • District heating	Integration of renewables

*LIH= Low-income households