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Whole-house retrofit: the role of new business models, finance mechanisms, and their implications for policy

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Abstract

The energy retrofit of homes is one of the most important and challenging issues for the decarbonisation of the global economy - having wider benefits for social welfare, economic development, energy security and public health. This thesis examines how new 'business models' and 'finance mechanisms', can promote a comprehensive 'whole-house' approach to retrofit - involving integrated energy efficiency measures to the building fabric, low carbon heat measures such as heat pumps, and electricity micro-generation such as solar photovoltaics (PV). In addition, it shows how policymakers can support these new business models and finance mechanisms through innovation intermediaries. To deliver these aims, this research involved thirty-eight semi-structured interviews, combined with information from documentary sources and is split into four original articles, with a primary focus on the United Kingdom (UK).

Article 1 shows how new business models can be a powerful tool for overcoming the challenges of whole-house retrofit. The article describes and compares five business model archetypes - ranging from the traditional, to highly innovative business models. These innovative models are characterised by: an emphasis on home improvement, aesthetics and comfort; industrialised processes and integrated supply chains; a holistic customer offering and single point of sale; long term energy-saving performance guarantees and integral project finance. Although the traditional model is suitable for the implementation of single energy-saving measures, it is argued business model innovation will be required to meet the UK's ambitious climate change targets.

Article 2 explores the challenges of financing this retrofit activity at scale. First, it develops a novel typology of finance mechanisms for residential retrofit - highlighting their key design features. The article then explores how these features influence the success of these mechanisms in different contexts. Three outcomes are shown to be especially important: a low cost of capital for retrofit finance; funding for non-energy measures such as general improvement works; and reduced complexity through a simple customer journey. Most importantly, the article outlines how finance alone is unlikely to be a *driver*

of demand and should be viewed as a necessary *enabler*, of much broader retrofit strategy.

Article 3 outlines how the adoption of ‘systemic innovations’, such as whole-house retrofit, may necessitate business model innovation. Through a case study of the innovative ‘Energiesprong’ retrofit business model it highlights the central role of an intermediary in this business model innovation. The article shows how Dutch policymakers sought to promote business model innovation through creation of this ‘market development team’: developing a novel framework combining the components of business models with the functions of intermediaries. The article further argues that policymakers might promote business model innovation through intermediaries in other sectors.

Article 4 outlines how recent policy initiatives in the UK, have failed to address four interrelated challenges that constrain demand for retrofits: 1) uncertain benefits and quality; 2) complexity, disruption and timing; 3) up-front capital cost and split incentives and 4) information, engagement and trust. Overcoming these challenges, will require a comprehensive and wide-reaching policy strategy - involving ambitious targets and regulations, and the creation and support of new finance mechanisms, business models and dedicated intermediary actors to support policy implementation.

This thesis therefore demonstrates how a focus on business models and financing provides an effective means of integrating the social and behavioural, organisational management and economic and financial challenges of retrofit. Thus, providing a coherent picture of how these problems fit together, as well as making a conceptual contribution. It further illustrates how policymakers can act to support business model innovation, through innovation intermediaries, and thus overcome many of the challenges facing the diffusion of whole-house retrofit.

Acknowledgements

Producing this thesis would not have been possible with the considerable time, effort and support given to me by my two supervisors Dr Paula Kivimaa and Prof. Steve Sorrell. I am heavily indebted and extremely grateful of their tireless support and forthcoming assistance, without which this work could have never been possible.

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I would also like to thank all my family whose support and endless supply of odd-jobs have kept me fed and clothed through the course of the PhD. Further a big thank you all my PhD peers who have made the 3 years a rich, entertaining and eye-opening experience.

Also thank you Anna for putting up with all of this.

“We shape our buildings; thereafter they shape us” - Winston Churchill

Preface

This PhD thesis is the product of three years of research undertaken at the Science Policy Research Unit (SPRU) at the University of Sussex, Brighton, UK. The thesis is the primary contribution towards the award of a Doctor of Philosophy in Science and Technology Policy at SPRU. This research was funded by the UK's Engineering and Physical Sciences Research Council (EPSRC) through a grant to the Centre on Innovation and Energy Demand (CIED), Ref. EP/K011790/1.

The CIED sits at the forefront of research on the transition to a sustainable economy, focussing on how different forms of innovation can transform how energy is used, to achieve substantial reductions in energy demand. As a PhD researcher within the CIED, the author was privileged to be part of an interdisciplinary community researching energy demand issues. This provided an invaluable experience which led to the collaboration on a number of projects across the centre, also facilitating collaboration on the four articles that make up this thesis by papers. Whilst Article 1 is solo authored, Articles 2 and 3 were co-authored by the thesis supervisors with Article 4 co-authored by several other CIED members. Alongside the work presented here, the author also contributed to several other papers, public consultations and policy briefs as well as attending multiple academic and industry events as a representative of SPRU and the CIED.

In producing this synthesis, a number of terms have been standardised across the four articles - to improve clarity and consistency. Therefore, the articles within this text vary slightly from their published counterparts in the following ways. Spellings are standardised to UK English throughout. The connecting chapters adopt the term whole-house retrofit which is preferred to 'comprehensive retrofit' from earlier published versions. The use of 'domestic' has been standardised to 'residential' throughout. The use of greenhouse gases has been standardised to carbon dioxide equivalents (CO₂e) throughout. The published version of Article 1 abbreviates business models to 'BMs', however in this document this abbreviation is removed. All other abbreviations are spelled out in each Article and in the Abbreviations section. In addition, a consolidated table of interviews is provided in Appendix A, which includes unique interview codes.

These codes have therefore been added to interview quotes across Articles 1, 2, 3 and 4. These Articles are provided in its published form in Appendix D. References are formatted in the style of SPRU's home journal, *Research Policy*.

Upon receiving examiners corrections, Article 3 has been modified from its published form to provide a re-organised Section 4.5, a new Section 4.6 and new text forming Section 4.6.2. Therefore, this section now differs from the published version in the SPRU Working Paper Series (SWPS) and Appendix C. Further, Article 4 has been modified from its published form to include footnotes with interview quotations as requested by examiners corrections.

Given that this is a papers style thesis, there is inevitably some repetition in the introductions to the four articles, as well as the literature reviewed. The aim of the connecting chapters (1, 6 and 7) is therefore to synthesise the findings across the articles such that they can be read as a 'stand-alone' contribution.

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Key terms and concepts

Concept	Definition
Business model	A description of the nature of value delivered to customers, how organisations and networks create that value and the means of capturing revenues from these activities.
Customer journey	Defined as the sequence of events that customers experience in order to learn about, purchase and interact with products and services (Norton et al., 2013).
Distributed Energy	Electricity generating plant that is connected to a distribution network, rather than the transmission network: including Combined Heat and Power (CHP) plants, wind farms, hydroelectric power, or solar photovoltaics.
Finance mechanism	The provision of capital through a combination of equity and/or debt that is repaid to the lender.
Net-zero energy	Where annual total household energy consumptions equals annual production of energy on-site through renewables (Energiesprong, 2014).
Regulated energy	Building energy consumption resulting from fixed building services and fittings, including space heating and cooling, hot water, ventilation and lighting (BRE, 2014a).
Retrofit	Involves the introduction of new materials, equipment and hardware into an existing building with the aim of reducing the energy consumption of that building (Baeli, 2013).
Sustainable energy	The provision of energy such that it meets the needs of the present, without compromising the ability of future generations to meet their own needs - having two key components: renewable energy and energy efficiency.
Systemic innovations	Systemic innovations require complementary changes in supporting technologies, technical skills, user competences, organisational practices and regulation (Midgley and Lindhult, 2015).
Whole-house retrofit	Whole-house energy efficiency retrofit involves combining improvements to optimise the performance of the building as a whole. Whilst this may still be implemented in stages, it differs from the current mainstream approach in that it promotes the interaction of multiple measures to be considered (e.g. fabric, ventilation, heating, lighting and microgeneration) at the earliest stages (Lewis and Smith, 2013).
Zero carbon	Zero carbon assumes a SAP rating of 100+, assuming that unregulated emissions are mitigated through onsite renewables or the low carbon content of grid electricity – thus cannot include fossil fuel heating sources such as gas boilers.

Abbreviations

BEIS - Business Energy and Industrial Strategy
 bn- Billion
 CBRP - CO₂ Building Rehabilitation Programme
 CCC – Committee on Climate Change
 CEWO - Clean Energy Works Oregon
 CO₂e – Carbon Dioxide Equivalents
 DfE - Department for Education
 DH - Department of Health
 DWP - Department for Work and Pensions
 EBRD - European Bank for Reconstruction and Development
 ECO – Energy Companies Obligation
 EE – Energy Efficiency
 ESA – Energy Service Agreement
 ESCO – Energy Service Company
 ESPC – Energy Saving Performance Contract
 FIT – Feed in Tariff
 GDP – Gross Domestic Product
 HEEPS - Home Energy Efficiency Programme for Scotland
 HES - Home Energy Scotland
 HMRC - Her Majesty's Revenue and Customs
 HMT - Her Majesties Treasury
 LA – Local Authority
 MESA – Managed Energy Service Agreement
 MHCLG - Ministry of Housing, Communities and Local Government
 NEP – Nottingham Energy Partnership
 NGOs – Non-Governmental Organisation
 NIC - National Infrastructure Commission
 OBF – On Bill Finance
 OBR – On Bill Recovery
 PACE – Property Assessed Clean Energy
 RHI – Renewable Heat Incentive
 SAP – Standard Assessment Procedure
 SME – Small to Medium Enterprise
 SO – Supplier Obligation
 SWI – Solid Wall Insulation
 £/tCO₂e – Pounds per tonne of Carbon Dioxide Equivalents

1. Introduction

1.1. Overview of the thesis

This thesis examines how new business models and finance mechanisms can reduce the energy consumption of residential buildings by promoting ‘whole-house retrofits’, and how public policy can support these outcomes. Although the insights are relevant to an international audience, the thesis focuses primarily upon the UK - considered to be an interesting case, due to the age of its housing stock and the perceived failure of recent retrofit policies.

The energy retrofit of homes presents one of the biggest challenges to decarbonising the global economy. In the UK, homes constitute around a fifth of total¹ greenhouse gas emissions – hereafter referred to as carbon dioxide equivalents (CO₂e) (CCC, 2016). The UK’s carbon reduction targets for homes imply a 24% reduction in direct² CO₂e from 1990 levels by 2030, with near-zero emissions needed by 2050 (CCC, 2018). Such retrofits are frequently cost-effective and can have important ancillary benefits for social welfare, economic development, energy security and public health (Washan et al., 2014). While the UK has made considerable progress in decarbonising electricity generation emissions, reductions from buildings have plateaued since 2012, and actually increased on a temperature-adjusted basis in 2016 and 2017 (CCC, 2018).

These emissions remain high due to an old and inefficient building stock - in which the majority of future energy and carbon savings must be found (CCC, 2018). The current housing stock will remain a major energy consumer in most advanced economies in 2050 (IPCC, 2014); where in the UK 80-85% of current homes will likely still be standing (Fylan et al., 2016). Significant progress has previously been made in the UK, through relatively cost-effective, single measures such as loft and cavity wall insulation. Although much of this ‘low hanging fruit’ has now been exploited (Rosenow and Galvin, 2013), there remains an annual potential to insulate 545,000 lofts by 2022 and 200,000 cavity walls by 2030 (CCC, 2018, p.94). Notwithstanding this potential, meeting internationally agreed

¹ This includes both direct emissions from fuels used for heating and hot water as well as indirect emissions from lighting and appliances

² Direct emissions exclude emissions from the generation of electricity supplied through the grid

emissions targets under the 2015 Paris agreement will require deeper emission reductions to a wider range of homes. This will necessitate a ‘whole-house’ approach to retrofit; including multiple energy efficiency improvements to the building fabric, low carbon heat measures such as heat pumps, and electricity microgeneration such as solar photovoltaics (PV).

This thesis aims to bring a fresh perspective to the retrofit challenge by investigating the potential contribution of new business models and financing mechanisms. Whilst a number of studies have explored how new business models can facilitate sustainability (Boons et al., 2013), there have been very few studies of business models for residential retrofit (Mlecnik et al., 2018). Similarly, while there is recognition of the importance of finance in the energy transition (Hall et al., 2015), there has been limited attention to financing residential retrofit, or indeed financing energy efficiency in general (Diaz-Rainey et al., 2017). Through a primarily qualitative approach involving thirty-eight semi-structured interviews and extensive documentary analysis, this thesis aims to provide practical insights into how the challenge of whole-house retrofits may be overcome, alongside theoretical contributions to the literatures on business models, finance and systemic innovation.

Previous studies have investigated the technical (Mcelroy and Rosenow, 2018), social and behavioural, (Walker et al., 2014), organisational (Mlecnik et al., 2012), and economic and financial (Bird and Hernández, 2012) challenges of retrofit, but this literature remains fragmented. By adopting a business model perspective, this thesis aims to synthesise and extend these perspectives and provide a coherent picture of how these different elements might fit together, to deliver successful retrofits on a large scale. The thesis also suggests how public policy can support business model and financial innovation, notably through encouraging ‘innovation intermediaries’. Broadening Kivimaa et al’s., (2018) definition, innovation intermediaries are defined as:

“Actors, networks and platforms that positively influence innovation processes by linking actors and activities, and their related skills and resources”

The thesis also provides a theoretical contribution. First, it develops a business model framework which draws together literature on the components of business models (Boons et al., 2013; Osterwalder and Pigneur, 2010) with the literature on organisational forms and governance (Eriksson, 2008; Hellström et al., 2015; Zott and Amit, 2010). Second, it outlines how the different features of finance mechanisms affect the cost of capital and consumer appeal. Third, it suggests how public policy can promote business model innovation, combining ideas from the literature on systemic innovation (Midgley and Lindhult, 2015), business model innovation (Massa and Tucci, 2013) and innovation intermediaries (Stewart and Hyysalo, 2008).

The remainder of the chapter is structured as follows. Section 1.2 introduces the research aims and questions, while Section 1.3 summarises the thesis structure. Section 1.4 describes the UK context for building energy use and climate change targets and indicates the contribution that whole-house retrofits can make to those targets. Section 1.5 reviews the literature on residential retrofit and shows how various challenges both reduce the demand for whole-house approaches and obstruct their delivery. It also summarises the concepts from the literature on business models and financing which are employed throughout the thesis. Section 1.6 summarises the methodology for the four original articles, while Section 1.7 summarises their content and results.

1.2. Research aims and research questions

Recent research has highlighted the potential role that innovative business models and financing may play in overcoming the challenges for sustainable innovation (Boons and Lüdeke-Freund, 2013; Mazzucato and Semieniuk, 2017). However, few studies have applied these concepts to the context of residential retrofit, with even fewer exploring their policy implications.

A limited number of studies have explored the role of new business models for retrofit (Mahapatra et al., 2013; Mlecnik et al., 2018; Moschetti and Brattebø, 2016), but these fail to reflect the diversity of business models or explain why different models are more

or less successful. Similarly, while a few studies discuss the importance of finance in the transition to sustainable energy systems (Blyth et al., 2015; Hall et al., 2016, 2015) there has been limited attention to the challenge of financing residential retrofit (Gouldson et al., 2015). Again, the existing literature fails to reflect the diversity of approaches to retrofit financing or explain their relative success. Further, there remains little or no literature on how public policy may encourage innovation in both business models and financing for retrofit, or indeed in wider contexts.

This thesis aims to fill these gaps in the literature by: first, demonstrating how the business model concept can provide fresh insights into the challenges of residential retrofit; second, by improving understanding of how different forms of finance can overcome these challenges; and third, by highlighting the role of policy in supporting new business models and financing mechanisms.

The thesis addresses the following overarching research question:

How can new business models and financing mechanisms encourage a greater uptake of whole-house retrofits and what are their policy implications?

This research is published in three academic journal articles and one book chapter. The author is the sole author of Article 1 and the first author of Articles 2-4. Articles 1-3 involve primary research and will be published in peer-reviewed journals. Article 4 is a synthesis of Articles 1-3 and are published in an edited book that was subject to internal peer review. The articles address the following subsidiary research questions in turn:

Article 1

1. How and why can new business models encourage the uptake of whole-house retrofit?

Article 2

2. How and why can new finance mechanisms encourage the uptake of whole-house retrofit?

Article 3

3. How can public policy encourage new business models for whole-house retrofit through intermediaries?

Article 4

4. How can the uptake of whole-house retrofit in the UK be accelerated by public policy?

1.3. Thesis structure

This thesis is structured as follows:

1. **Introduction** (This chapter) provides: the research aims, questions and structure; an overview of the empirical context; a review of the academic literature on residential retrofit, business models and finance mechanisms; a summary of the concepts employed; a description of the methodological approach; and finally, a summary of the four articles and their contribution to addressing the research questions.
2. **Article 1** develops a business model framework and then identifies five business model ‘archetypes’ for residential retrofit. Through a cross-sectional research design, it compares these business models and identifies the features that make them more or less successful in promoting whole-house retrofit.
3. **Article 2** identifies the key design features of finance mechanisms and constructs a typology of six finance mechanisms operating in the retrofit sector. Through a cross-sectional research design, it shows how these design features contribute to three key outcomes that are critical to the success of finance mechanisms in this sector.
4. **Article 3** provides an in-depth case study of an innovative business model for residential retrofit and contrasts this with the incumbent business model. The article highlights the critical role of an ‘innovation intermediary’, created by policymakers, which facilitated this innovation and discusses the wider implications for public policy.
5. **Article 4** identifies four key challenges that undermine demand and delivery of whole-house retrofits. This synthesises insights from the three previous articles and argues that a combination of the solutions advocated by each could

overcome these challenges. The article concludes with some concrete policy recommendations for the UK.

6. **Discussion** – this section reflects on the overall findings of the thesis. It discusses the methodological approach, theoretical insights, empirical findings and policy implications and the main contributions to knowledge.
7. **Conclusion** – this section answers the research questions, reflects upon the strengths and weaknesses of the research and suggests potential avenues for future research.

The following section outlines the UK empirical context for energy and climate change, the progress to date in reducing energy use in residential buildings and the role of residential retrofit - highlighting the lack of recent progress.

1.4. Empirical context: energy use in residential buildings

1.4.1. Climate change and the UK energy system

Recognising the threat of global climate change, many of the world's economies have agreed to reduce CO₂e emissions; to keep global average temperature increases below 2°C as part of the 2015 Paris Agreement. In its landmark Climate Change Act of 2008, the UK had previously committed to reduce its emissions of CO₂e by 80% below 1990 levels by 2050 (HM Government, 2008). This Act created an independent Committee on Climate Change (CCC) to oversee a series of five-year carbon budgets, to track progress towards the 2050 target. The UK is currently on track to outperform its second (2013-2017) and third (2018-2022) carbon budgets and has thus far (2017) reduced emissions by 43% compared to 1990 levels (CCC, 2018).

Much of the progress to date can be attributed to public policy, with approximately 75% of the savings since 2012 the result of decarbonising electricity generation. The UK's power generation mix in 2016 comprised 52% low carbon sources, including nuclear, wind, biomass and solar; with emissions from electricity generation falling by 59% between 2008 and 2017 (CCC, 2018). UK industry has seen emissions reductions of ~3%/year over the period 2009-2016 and a halving of emissions since 1990 - although partly a consequence of de-industrialisation and offshoring. Emissions from waste have also decreased by 70% since 1990 (CCC, 2018).

Other sectors of the UK economy have seen much slower progress. Some, such as agriculture, play a relatively small role, whilst emissions from transport constitute around 27% of UK total CO₂e emissions (CCC, 2018). However, a key sector where progress has stalled since 2012 is emissions from buildings. These trends are shown in

Figure 1.

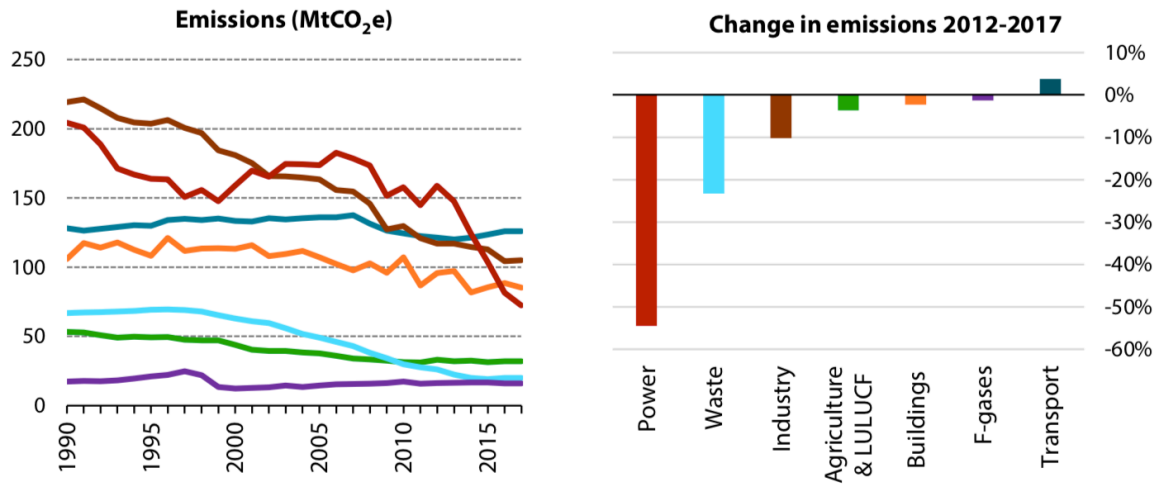


Figure 1 Changes in UK emissions by sector since 1990 and 2012. Source: (CCC, 2018)

1.4.2. The role of buildings and homes

CO₂e emissions from buildings are primarily a result of *direct* emissions from space and water heating, and *indirect* emissions from electricity consumption - a result of lighting, appliance use, ventilation and cooling. Taken together these emissions constitute approximately 30% of the UK's CO₂e emissions (CCC, 2018) and around 53% of its final energy consumption (Palmer et al., 2017). Adjusting for annual temperature changes, emissions from buildings actually increased by 1% in both 2016 and 2017 in the UK (CCC, 2018).

Homes are the most significant component of this energy consumption and CO₂e emissions. Direct emissions from space and water heating in homes account for 14% of the UK's CO₂e emissions with a further 6% arising indirectly from electricity consumption (CCC, 2018). Until recently these indirect emissions were much higher, reflecting the higher carbon content of grid electricity (Kelly et al., 2012). Energy consumption from the residential sector has risen by 12% since 1970, owing to population and income growth alongside demographic changes. This is despite significant improvements in the energy efficiency of buildings and appliances (BEIS, 2017).

The UK Government's standard assessment procedure (SAP) is a methodology to calculate the energy performance of homes (BRE, 2014b). SAP is rated from 0 to 100³ and informs the Energy Performance Certificate (EPC) system, with ratings from A-G - with an EPC A being an exemplary dwelling (SAP rating of 91+). Homes in the UK have seen a significant improvement in their average SAP rating, increasing from 18 in 1970 to 63 in 2016 (BEIS, 2017) as shown in Figure 2.

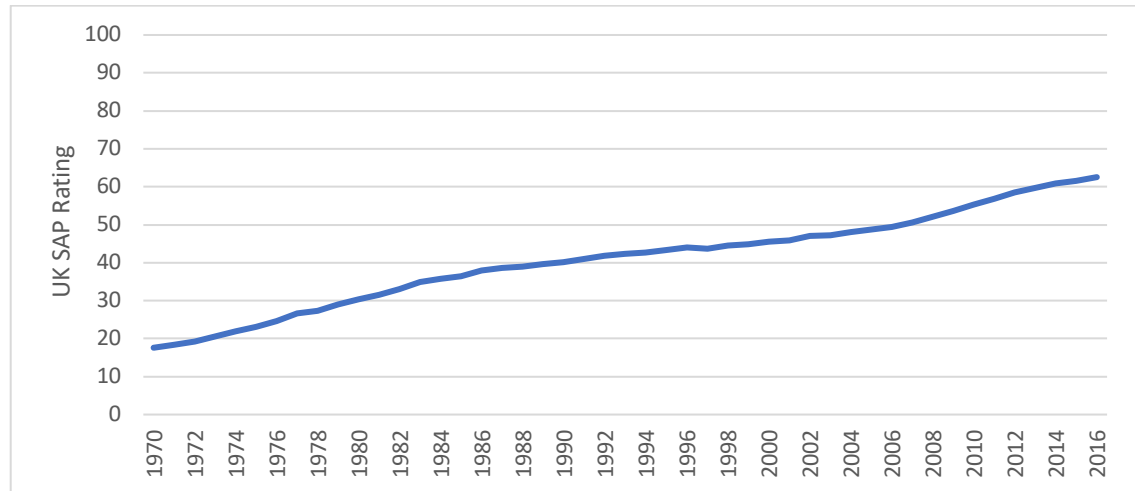


Figure 2 Average UK SAP rating 1970-2016. Adapted from: BEIS (2017)

Much of this improvement has been offset by the increased consumption of energy services such as heating and lighting, both in relative (per household) and absolute terms (BEIS, 2017). The widespread diffusion of central heating systems, rapid increases in appliance ownership and a proliferation of lighting use, have led to a take-back of many of these savings through increased electricity consumption and 'comfort taking' in homes. It is estimated that these direct 'rebound effects' amount to a significant portion of potential savings; although are thought to be no more than 30% in OECD countries (Sorrell et al., 2009). Despite this, energy efficiency savings from homes have mitigated a 46% increase in the number of households, an increase of 5.6°C in average internal temperatures and the rapid growth in appliance ownership – meaning per-household energy consumption has only increased by 7% in 45 years (Rosenow et al., 2018). These trends are summarised in Figure 3.

³ It is possible to achieve a score of over 100 for a 'zero carbon' home based on zero emissions. UK SAP is based on emissions from *regulated energy* sources; from fixed heating, cooling, lighting and ventilation systems, and therefore does not consider *un-regulated* emissions from appliances (BRE, 2014b)

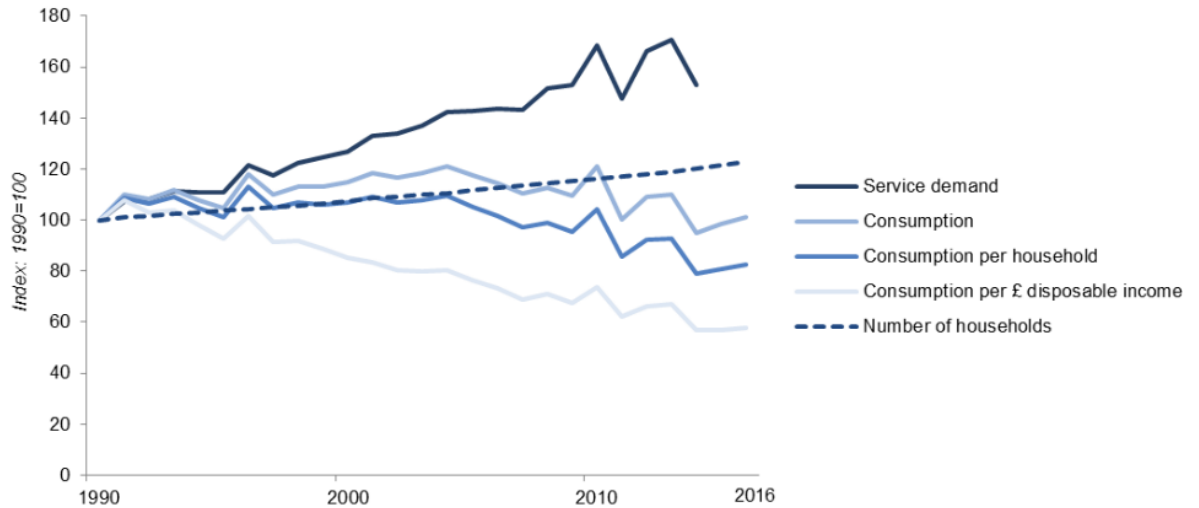


Figure 3 Factors impacting on residential energy consumption. Source: (BEIS, 2017)

1.4.3. Energy retrofit – what is it?

Energy retrofit or 'retrofit' for short is a term that is used throughout this thesis. Retrofit, as used here, involves the introduction of new materials, equipment and hardware into an existing building with the aim of reducing the energy consumption of that building (Baeli, 2013). Energy consumption in homes can also be reduced through the use of efficient appliances (Rosenow et al., 2018), behavioural changes (Risholt and Berker, 2013) and a shift towards less energy consuming social practices (Shove and Walker, 2014). However, this thesis is concerned with modifications to homes in terms of what UK SAP defines as *regulated energy* - that from fixed heating, cooling, lighting and ventilation systems (BRE, 2014b), and does not discuss these other issues in any detail. Energy efficient appliances and social and behavioural changes are in any case likely to be complementary to retrofit measures (Shove, 2017).

The retrofit of residential buildings involves three key types of measure: energy efficiency improvements to the *building fabric*; new *heating systems* and controls such as new boilers, thermostats, or heat pumps; and electricity *microgeneration* systems such as solar photovoltaics and battery storage. Retrofit as an area of empirical study, therefore encompasses other topics, such as *energy efficiency*, *low carbon heat* and *distributed energy*. Whilst these areas have traditionally been approached in isolation, only an

integrated approach which addresses them together is likely to be effective (Brown et al., 2018).

Figure 4 shows some of the main retrofit measures which can be installed in homes.

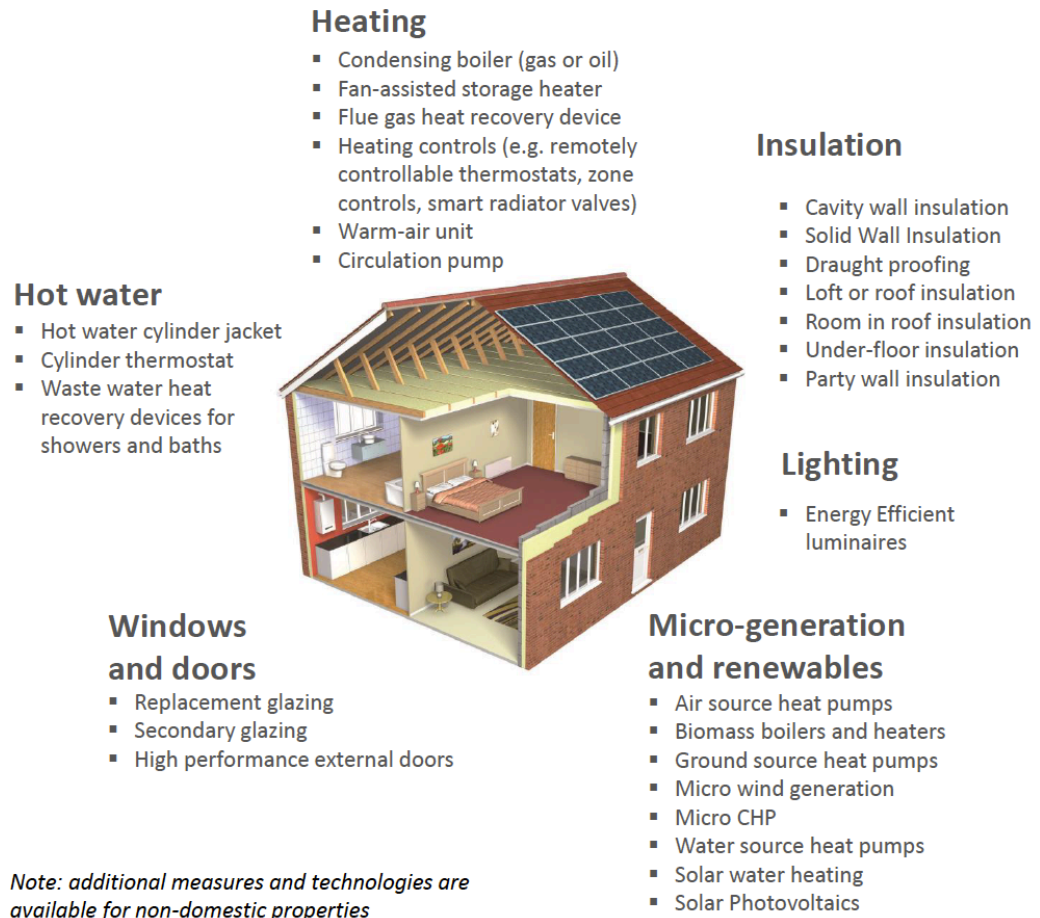


Figure 4 Key retrofit measures. Source: (DECC, 2012)

1.4.4. The benefits of retrofit

Meeting internationally agreed emissions reduction targets will necessitate significant progress in the retrofit of homes. Retrofit of residential buildings can significantly reduce CO₂e emissions (CCC, 2016), but can also contribute to reducing fuel poverty (Sovacool, 2015), improving occupant health and wellbeing (Willand et al., 2015) and increasing employment and economic growth (Washan et al., 2014).

In the CCC's central scenario, where building fabric measures and low carbon heat are deployed cost-effectively; direct emissions from all buildings are reduced to 32% below their 1990 levels in 2030 (CCC, 2018, p. 94). Despite historical progress, there remains an

un-tapped ‘cost-effective’⁴ potential⁵ of around one-quarter of the energy currently used in UK homes; an average saving of £270 per household per year (Rosenow et al., 2018). Rosenow et al., (2018) estimate that there is technical potential to reduce residential energy consumption by approximately one half⁵ (Rosenow et al., 2018), with further savings in CO₂e emissions available from renewable microgeneration such as rooftop PV panels (Reid and Wynn, 2015). Even more ambitious savings may be achievable with the net-zero-energy retrofits⁶ now being delivered in the UK and the Netherlands (Energiesprong, 2017). Indeed, it is expected that all homes will need to be net-zero-carbon by 2050 (CCC, 2018).

One in ten UK households are in fuel poverty⁷ (Sovacool, 2015); a product of income inequality, the poor condition of the UK housing stock, and rising energy prices in recent years (Rosenow et al., 2013b). Many households in fuel poverty are forced to choose between heating and other essential expenditures such as travel, clothing or even food (Fylan et al., 2016). This often leads to under-heating in winter, creating serious health problems particularly for young children and the elderly (Willand et al., 2015). It is estimated that of the 31,100 excess winter deaths in England and Wales in 2012/13, 30-50% were due to cold indoor temperatures (Washan et al., 2014). Improved winter warmth and lowered relative humidity have proven benefits for cardiovascular, respiratory, and mental health (Willand et al., 2015). Indeed for every £1 spent on retrofitting fuel poor homes an estimated £0.42 is saved in UK National Health Service spending (UKGBC, 2017).

Rosenow et al., (2018) develop a ‘cost-effective’ scenario for improvements in the energy efficiency of UK housing that includes all measures deployable to 2035⁸. The scenario uses a discount rate of 3.5% and places a monetary value on emission reductions,

⁴The CCC define the cost-effective path as “comprising measures that cost less than the projected carbon price across their lifetimes ... together with measures that may cost more than the projected carbon price, but are necessary in order to manage costs and risks of meeting the 2050 target” (2013, p. 27).

⁵ These figures include efficient appliances

⁶ A definition of net-zero energy is provided in the glossary of terms

⁷ The definition of fuel poverty in the UK, is where fuel costs that are above average (the national median level), and these fuel costs leave a residual income that is below the UK’s official poverty line (DECC, 2013b)

⁸ Estimated to be cost-effective according to criteria used by the UK government to appraise public policies (BEIS, 2018).

improvements in occupant comfort and improvements in air quality, in addition to the savings in energy costs. The scenario requires approximately £85.2bn of investment but would deliver discounted benefits of £92.7bn, giving a net present value (NPV) of £7.5bn (Rosenow et al., 2018). If allowance is also made for the additional benefits to human health, economic activity and the efficiency of the electricity system, the NPV could be as high as £47bn (Rosenow et al., 2018). Studies of the macroeconomic impacts complement this microeconomic evidence for the benefits of energy efficiency. For example, Washan et al.,(2014) estimate that raising every home in the UK to EPC level C or above would increase UK GDP by 0.6% by 2030 and deliver up to 108,000 jobs annually between 2020-2030.

Taken together these benefits provide a strong rationale for policy action.

1.4.5. Policies to promote retrofit and the UK policy gap

Retrofit has historically played a significant role in reducing the UK's energy use and CO₂e emissions. Total UK household energy use decreased by 19% between 2002 and 2016 on a temperature corrected basis. This is despite increases of 12% in the number of households and 10% in UK population over that period (BEIS, 2017). Per-household energy consumption fell by 37% between 1970 and 2015, with 29% of this occurring since 2004 as shown in Figure 3 (BEIS, 2017). Public policies to promote retrofit have been responsible for the bulk of these reductions in per-household energy consumption (BEIS, 2017; CCC, 2017; Odyssee, 2017; Thurlwell et al., 2011).

Since 1994, 'supplier obligations' have imposed energy and carbon saving targets on UK electricity and gas suppliers - allowing them to recover the costs through a levy on household energy bills. The first supplier obligation was the Energy Efficiency Standards of Performance (EESoP) running between 1994-1998, with successors, EESoP 2 and EESoP 3 running from 1998-2000 and 2000-2002 (Rosenow, 2012). These were replaced by the Energy Efficiency Commitment (EEC) 1 and 2 from 2002-2008, with a gradual ramping up of ambition, and the inclusion of a broader range of eligible measures and fuel types over this period (Rosenow, 2012). The most significant supplier obligation in

the UK to date - the Carbon Emissions Reduction Target (CERT) – ran from 2008-2012. Although the programme was designed to save CO₂ emissions, it is expected to deliver 500TWh of lifetime energy savings - mostly from loft and cavity wall insulation - around eighty times the ambition of the original EESoP (Rosenow, 2012) (Figure 5).

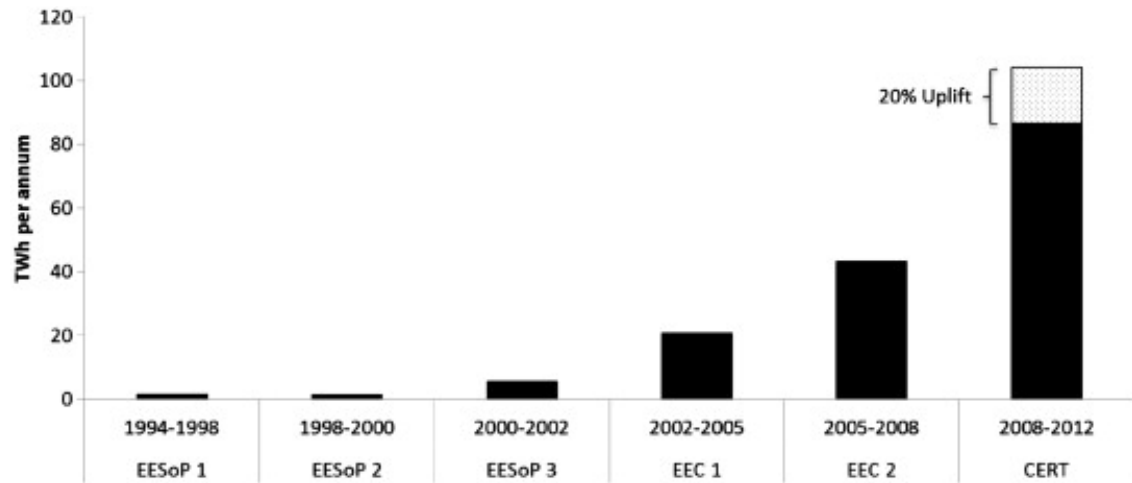


Figure 5 Changes to UK supplier obligation policy target. Source: (Rosenow, 2012)

Alongside the market based supplier obligations, dedicated grant programmes funded through general taxation have historically supported low-income households in ‘fuel poverty’ (Dowson et al., 2012). The most significant of these - ‘Warm Front’ ran from 2000-2013, with 2.3 million fuel poor homes receiving free insulation measures and boiler upgrades (Sovacool, 2015). Also important was the progressive tightening of EU standards on the energy efficiency of electrical appliances and the requirement for condensing boilers within the UK Building Regulations (Thurlwell et al., 2011).

However, there was a change in approach after 2013, contributing to a major reduction in investment in energy efficiency (Rosenow and Eyre, 2014). Previous supplier obligations primarily supported low-cost, single measures across all homes. The Energy Companies Obligation (ECO) introduced in 2013, was much smaller in scale and ambition than previous supplier obligations, and was reoriented to: first, focus upon low-income groups rather than so-called ‘able to pay’ households; and second, include more complex and invasive measures such as solid wall insulation (Rosenow and Eyre, 2014). It has since been argued that the ECO is a poorly targeted means of addressing fuel poverty, having

a regressive impact on wider fuel bills (Rosenow et al., 2013b) as well as lacking the social welfare focus of the Warm Front scheme (Sovacool, 2015). Equally, others have questioned the suitability of a supplier obligation based only on carbon savings for more complex and invasive measures (Rosenow and Eyre, 2014).

Parallel to ECO, the Green Deal was introduced in 2013 and was intended to trigger substantial private investment in multiple measures in ‘able to pay’ households. Unlike the supplier obligations, the Green Deal was a voluntary program based on a private sector finance mechanism, repaid on energy bills. While up to 2 million retrofits a year were anticipated under the Green Deal (DECC, 2014), an average of less than 6,000 were realised (DECC, 2015a). It has been argued this failure was due to its high interest rates, complex application process, and narrow funding criteria (Rosenow and Eyre, 2016, 2014). In 2015 the Green Deal was effectively terminated and funding provided through ECO has since been significantly reduced (Rosenow and Eyre, 2016) – partly due to concerns over the costs on energy bills (Kern et al., 2017). As a result, the rate of uptake of residential insulation measures has collapsed since 2012 (CCC, 2016), as shown in Figure 6.

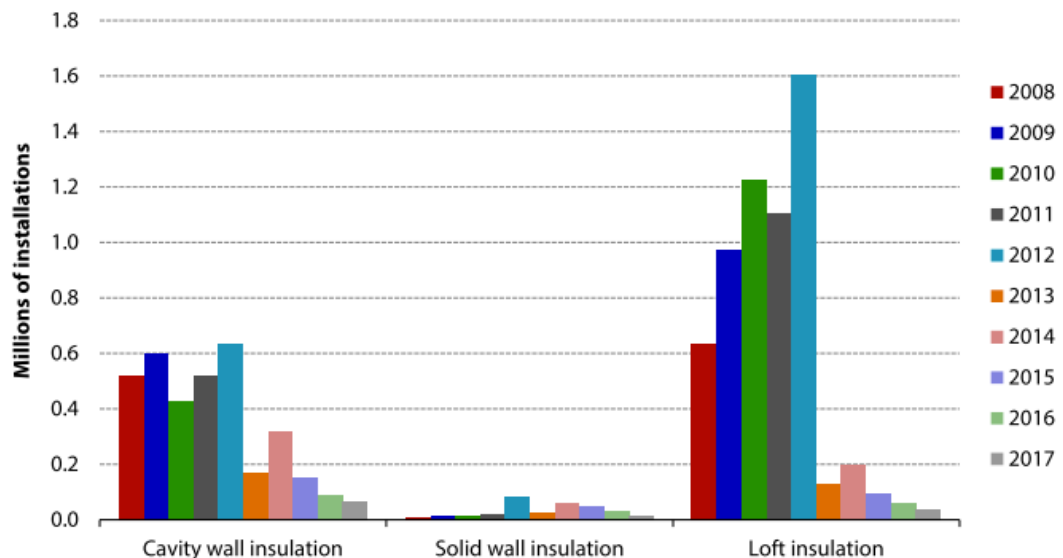


Figure 6 Recent trends in uptake of key insulation measures in UK (CCC, 2018)

Alongside these funding, obligation and standards policies, a range of intermediary organisations have facilitated the uptake of energy efficiency and retrofit measures in the UK. In 1993, the UK government created the Energy Saving Trust (EST), to promote energy efficiency in the UK's homes. In 2000, the EST contributed to the establishment of Energy Efficiency Partnership for Homes, and has been the key source of household advice, support and implementation to complement government energy efficient policies (Kivimaa and Martiskainen, 2018a). The EST's core government funding was cut in 2010, resulting in a significant curtailment of its activities (Kivimaa and Martiskainen, 2018a). The Building Research Establishment (BRE) is the UK's industry facing centre of excellence for buildings, developing standards and public policy on retrofit. Alongside the privatisation of the BRE in 1997, these cuts have weakened advocacy for the industry, providing less support for households, which are increasingly reliant on a diffuse network of charities and third sector intermediaries – lacking the policy influence of previous statutory bodies (Kivimaa and Martiskainen, 2018a).

The UK now has insufficient policies and capacity in place to deliver on its medium and long-term targets to reduce carbon emissions from buildings. Figure 7 shows a large gap between the CCC cost-effective scenario for all buildings and the projected emission trends. Achieving the cost-effective savings from the building sector is therefore based on policies that are at risk, policies that lack a basis beyond aspirational targets, or lack any policy commitment whatsoever. Others have argued that the CCC cost-effective scenario is itself overly conservative (Platt and Rosenow, 2014).

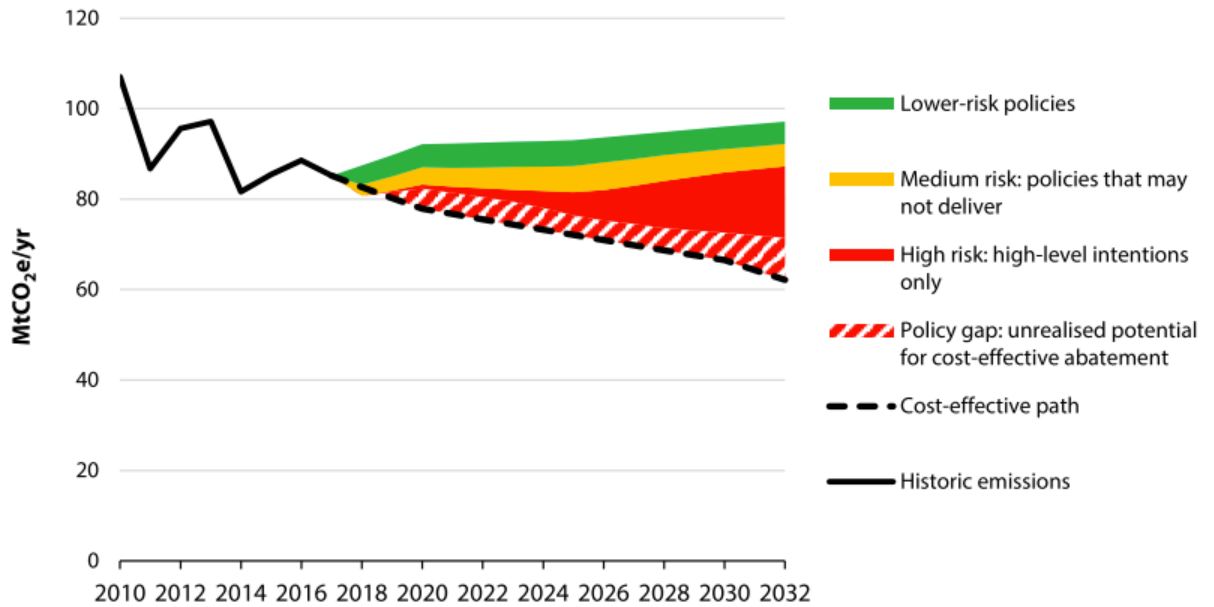


Figure 7 Risks around the delivery of buildings sector policies to meet the CCC cost-effective path (CCC, 2018)

The UK's 2017 Clean Growth Strategy outlines an aspirational target for all homes to reach EPC band C by 2035 and all fuel poor homes by 2030 (HM Government, 2017). The government has also recently introduced minimum energy efficiency standards (MEES) for the private rented sector. However, as shown in Figure 7 the current mix of policies is insufficient to deliver the near-term targets, and recent failures and cutbacks have highlighted the weaknesses of the current policy approach. The sheer scale of the task will now likely necessitate multiple measures to be installed at once, in a move towards 'whole-house retrofits' (Lewis and Smith, 2013).

1.4.6. The need for a comprehensive whole-house approach

Thus far, significant savings in the UK and European Union have mostly been achieved through single, incremental measures such as fluorescent light bulbs, loft insulation and efficient boilers (Rosenow et al., 2016). Whilst these measures have been implemented through existing supply chains, requiring limited changes in consumer and industry practices; it is increasingly recognised that with many of the 'low hanging fruit' now exploited, this approach will be insufficient to meeting the UK's emissions targets (Lewis and Smith, 2013).

Of particular importance to meeting the UK's climate change targets will be deeper⁹, measures such as solid wall insulation (SWI) and low carbon heating systems such as heat pumps (CCC, 2018). These measures require complementary consideration of draft proofing, moisture, ventilation as well as the suitability of existing heat emitters and controls (Bonfield, 2016). Research has shown that the single measures approach, incentivised by government policies such as ECO has in many cases led to damaging unintended consequences (Davies and Oreszczyn, 2012; Hansford, 2015; Milsom, 2016; STBA, 2012).

This piecemeal approach is problematised by cases where SWI is installed without consideration of moisture and ventilation implications (Milsom, 2016), or heat pumps are installed without appropriate assessment of existing pipework or heat emitters (Snape et al., 2015). Thus, a lack of attention to detail, insufficient consideration of building physics, cold bridges and airtightness, and poor heating system design (Gupta and Chandiwala, 2010; STBA, 2012), can create issues of mould growth, poor air quality and condensation (Hansford, 2015), low seasonal efficiencies, limited temperature control, excessive noise and heat pump breakdowns (Snape et al., 2015).

This has led to calls for a 'whole-house' approach to retrofit, particularly where measures such as SWI and heat pumps are involved (STBA, 2016). A report from the Energy Efficiency Partnership for Buildings provides the following definition:

"Whole-house energy efficiency retrofit involves combining improvements to optimise the performance of the building as a whole. Whilst this may still be implemented in stages, it differs from the current mainstream approach in that it promotes the interaction of multiple measures to be considered (e.g. fabric, ventilation, heating, lighting and microgeneration) at the earliest stages." (Lewis and Smith, 2013)

Thus, in a whole-house retrofit the building is treated as a *system* rather than as individual elements or measures. For example, a whole-house approach would: complement SWI with improved ventilation and moisture protection and elimination of cold bridging;

⁹ Occasionally referred to as deep retrofit such as Gupta and Gregg, (2016), however 'whole-house' is considered to better reflect the need for a holistic approach across multiple, related measures rather than a reflection of the depth of carbon savings

install new heat emitters and circuitry for a heat pump; consider PV panels when scaffolding is erected and integrate other non-energy repair works, such as roofing improvements alongside the retrofit. Each of these measures may interact and thus they would be considered holistically rather than in isolation.

Consequently, a whole-house approach involves the effective integration of multiple measures and consideration of their sometimes complex interaction; whether installed at once or over time (Fawcett, 2014). This strategy is likely to mitigate unintended consequences and achieve deeper reductions in emissions (Milsom, 2016).

These features call into question the suitability of supplier obligations for achieving whole-house retrofits. This is due to their narrow focus on costs of carbon saved (£/tCO₂e) from individual measures, rather than how multiple measures interact in a specific building (STBA, 2012). The adoption of whole-house retrofit may instead require changes in financing, supply chains and household practices (Wilson et al., 2015), requiring complementary policy and institutional changes to be fully and effectively realised (Brown et al., 2018). These multiple changes thus necessitate a *systemic* approach across multiple domains to enable the whole-house retrofit of millions of homes in a limited timeframe (Davies and Oreszczyn, 2012; Mlecnik, 2013). The required retrofit rate - amounting to '*1.4 homes a minute until 2050*' (BBC, 2017) - also emphasises the limitations of a strategy based on incremental installation of single measures, requiring multiple visits to a single home (Fawcett, 2014).

A successful retrofit strategy would therefore necessitate a significant uptake in both the rate and quality of residential retrofits, to meet its climate change targets as well as delivering on wider social policy and economic development goals. This would include meeting the UK's climate change committee's central scenario advocating a reduction in direct CO₂e emissions of at least 16% between 2017 and 2030 from the UK's buildings (CCC, 2018). And exploiting the remaining cost-effective potential of at least 25% energy savings from the UK's homes, or 140TWh per year, with further savings from electricity microgeneration (Rosenow et al., 2018). This level of retrofit will require an estimated £85.2bn of investment (Rosenow et al., 2017a), while necessitating improvement in the

quality of delivery and performance through a whole-house approach, to realise its wider benefits (Lewis and Smith, 2013).

Understanding how these challenges can be overcome is the primary focus of this thesis. Article 1 focusses on the delivery and quality of retrofit measures, whilst Article 2 elucidates the investment challenge. Article 3 emphasises the conditions required for the scale up of a retrofit strategy, whilst Article 4 draws together these findings into policy recommendations.

1.5. Literature review

This section first reviews the academic literature on the challenges for residential retrofit, particularly whole-house approaches. It then reviews the literature on business models and finance for sustainable innovation and briefly discusses how new approaches to both might promote the uptake of whole-house retrofit. This section synthesises the literature reviewed within the four articles and therefore repeats some of the arguments.

1.5.1. Literature on challenges for residential retrofit

The 'energy efficiency gap' - characterised as the limited uptake of apparently cost-effective energy efficiency measures (Jaffe and Stavins, 1994), remains the focus of much research (Kangas et al., 2018; Pelenur and Cruickshank, 2012; Rezessy and Bertoldi, 2010). Energy retrofit and its challenges are studied across many fields from architecture and engineering (Lowe, 2007), finance and economics (Hyland et al., 2013), sociology and psychology (Walker et al., 2014) energy policy (Rosenow, 2012) and innovation studies (Mlecnik, 2013). Understanding the challenges of promoting retrofit and how these challenges fit together, therefore, requires an interdisciplinary perspective, summarised in this section.

Much literature on energy efficiency adopts 'barriers' to uptake as the theoretical basis for understanding the energy efficiency gap (Kangas et al., 2018; Sorrell, 2007; Sorrell et al., 2004). However, the focus on 'barriers' characterises retrofit decision-making in terms of rational economic choices - downplaying social and contextual factors (Shove and Walker, 2014; Walker et al., 2014). This also assumes that there is a pre-existing

demand for retrofit once these barriers are removed (Wilson et al., 2015). This barriers framing has come to dominate the design of policy initiatives which also tend to emphasise the economic benefits of retrofit whilst ignoring others (Rosenow and Eyre, 2016). This framing is excessively narrow. A broader review of the literature highlights four interrelated challenges which are discussed below, including economic barriers, technical and skills issues, and wider social and cultural factors (Fylan et al., 2016)

First, many studies highlight a persistent lack of information, engagement and trust. A survey by Marchand et al., (2015) shows knowledge of the options and benefits of retrofit is widely lacking among UK households. Balcombe et al., (2014) also show that while many of the technologies and tools to retrofit existing buildings are known, their uptake is not widespread - due to a lack of household interest. Public engagement and marketing schemes have tried to generate demand, but tend to be top-down (Rosenow and Eyre, 2016), short-term, and focused upon specific subsidy schemes (Marchand et al., 2015). The complexity of policies, such as the UK's Green Deal, has also deterred household engagement with retrofit (Marchand et al., 2015). Owen et al., (2014) show how the conservatism of tradespeople towards retrofit solutions influences households decisions on technology choices and subsequent use. Thus, a lack of appropriate advice, concerns over post retrofit performance and the quality of workmanship have undermined trust with the wider public.

A second issue is the uncertain benefits and quality of retrofit improvements. Multiple studies show a 'performance gap' between modelled energy savings and actual energy performance outcomes (Gupta et al., 2015; Gupta and Gregg, 2016; Mcelroy and Rosenow, 2018; Webber et al., 2015). Studies cite several reasons for this, including a widespread lack of technical skills (Kangas et al., 2018), the complex design and engineering challenges of retrofit (Gupta and Gregg, 2016), and weaknesses in building performance evaluation methodologies such as the UK's SAP (Kelly et al., 2012). Wilson et al., (2015) and Walker et al., (2014) further emphasise how retrofit may be perceived to alter a buildings' existing features, affecting households' practices (washing, heating habits) and emotional attachments (aesthetics, familiarity) – creating resistance to change (Shove and Walker, 2014). Gram-Hanssen (2014) argue that the focus on barriers

has tended to side-line these more human dimensions. Thus, whilst government retrofit programs have emphasised the financial benefits of retrofit, households may value other factors above financial savings (Fawcett and Killip, 2014).

A third issue is the complexity, disruption and timing of retrofit projects. Davies and Oreszczyn (2012) outline the challenges of managing the multiple and overlapping activities carried out by several contractors and consultants in a retrofit project. Snape et al., (2015) also emphasise the significant disruption or the 'hassle factor' of major works as a deterrent to uptake. Whilst many households undertake extensive renovation work during wider home improvements, the timing of these decisions is rarely integrated with retrofit interventions (Maby and Owen, 2015; Wilson et al., 2015). Therefore, whole-house retrofit - if adopted, is typically done in a staged and piecemeal manner (Fawcett, 2014).

Fourthly, financial issues remain important. The high up-front capital cost, split incentives and long payback periods are important economic barriers to undertaking retrofit projects (Sorrell et al., 2004). Gouldson et al., (2015) emphasise whilst retrofits result in long-term energy savings, whole-house retrofits typically require long periods before the capital cost can be recovered in energy savings. Studies also show a lack of access to up-front capital as a key reason for not undertaking retrofits (Pettifor et al., 2015). 'Split incentives' occur where the benefits of an investment in terms of energy cost savings are not realised by the investor, such as when moving house or in a landlord-tenant situation (Sorrell et al., 2004). Bird and Hernández (2012) emphasise the pervasiveness of split incentives for low-income tenants and argue for a range of financing solutions to overcome them. Gouldson et al., (2015) further emphasise how the economics of long-term financing is extremely sensitive to interest rates, particularly if energy savings must exceed repayments (Rosenow and Eyre, 2016). Further, in a study of different financing mechanisms, Leventis et al., (2017) describe how the majority only fund energy measures - despite the need for funding of wider enabling measures and general repairs.

These challenges help to explain much of the low household demand for retrofits, and the limited success of recent policies to promote retrofit - particularly whole-house

approaches. This thesis therefore investigates how new business models, finance mechanism and supporting policy approaches may overcome these challenges.

1.5.2. Literature on business models

The concept of the ‘business model’ is increasingly adopted as a means of classifying different businesses, a theoretical lens for academic research, and as a practical tool for entrepreneurs and managers (Baden-Fuller and Morgan, 2010). As Teece (2010) argues, an effective business model is often more important than the relatively generic products and services an organisation provides. The business model is also critical for the diffusion of technological innovations (Baden-Fuller and Haefliger, 2013; Teece, 2010). Drawing on Hellström et al., (2015) and Teece (2010) a business model is defined here as¹⁰:

A description of the nature of value delivered to customers, how organisations and networks create that value and the means of capturing revenues from these activities.

The business model concept first became prevalent in the field of business and management during the late 1990s - a product of the profusion of new business models accompanying the emergence of the internet (Zott et al., 2011). Since then it has grown in significance in the field of technology and innovation studies (Lambert and Davidson, 2013), and more recently in the study of transitions to a sustainable economy (Wells, 2013).

Ritter and Lettl (2018) identify four perspectives on business models. In their most abstract form business models describe the underlying *logic* of an organisation, such as delivering sustainable buildings or low-cost air travel (Ritter and Lettl, 2018). In a less abstract form, business models are characterised by generic *archetypes* – involving idealised models such as the Gillette’s ‘razor and blade’ (Teece, 2010) or Rolls Royce’s ‘power-by-the-hour’ business model for aircraft engines (Teece, 2018).

¹⁰ A more detailed definition of the business model components is provided in Articles 1 and 3.

A more detailed perspective, which facilitates comparison between different business models, identifies the generic *components* common to all business models. Perhaps the most well-known is Osterwalder & Pigneur's (2010) framework which identifies nine components, simplified by Boons and Lüdeke-Freund (2013, p. 10) into four:

1. *Value proposition*: what value is embedded in the product/ service offered by the firm;
2. *Supply chain*: how are upstream relationships with suppliers structured and managed;
3. *Customer interface*: how are downstream relationships with customers structured and managed; and
4. *Financial model*: costs and benefits from 1), 2) and 3) and their distribution across business model stakeholders.

A final perspective provides a detailed description of the actors and networks involved in a business model (Amit and Zott, 2001). This view captures the networked and interdependent activities involved in the delivery of products and services - potentially across multiple organisations (Hellström et al., 2015; Zott and Amit, 2010). This shifts the focus from single firms towards the wider networks which deliver the value proposition. This perspective is therefore characterised here as business model *governance* - ranging from highly networked to hierarchical modes of governance (Bradach and Eccles, 1989).

Each of these perspectives has value depending on the area of interest and research questions deployed. This thesis draws on all four perspectives to answer the research questions. However, a drawback of these perspectives is their relatively static picture of business models (Foss and Saebi, 2018). Hence, it is useful to also consider the literature on business model innovation.

1.5.3. Business model innovation

The innovation studies literature has traditionally employed technological artefacts as the primary unit of analysis. However, there is growing attention to the role of business model innovation, particularly in the case of radical, path-breaking or systemic innovations (Chesbrough, 2010; Massa and Tucci, 2013; Teece, 2018). Massa and Tucci (2013) describe how business model innovation provides two important opportunities.

First, it allows organisations to reconfigure their existing business models towards more efficient or profitable practices (Zott and Amit, 2009). Second, it enables the adoption and diffusion of new innovations, which may currently have no route to market or be incompatible with existing business models (Baden-Fuller and Haefliger, 2013). The importance of business model innovation is emphasised by Teece (2010, p. 183):

“technological innovation does not guarantee business success - new product development efforts should be coupled with a business model defining their ‘go to market’ and ‘capturing value’ strategies”

Therefore, new business models have often been the critical means of commercialising now ubiquitous innovations; including the electric light bulb (Johnson and Suskewicz, 2009), smart phones (Mazzucato, 2015) and e-commerce (Teece, 2010). Further, the combination of a radical innovation with a new business model has revolutionised the business model of entire sectors in recent years; including taxis (Teece, 2018), printing (Chesbrough and Rosenbloom, 2002), and the music industry (Johnson, 2008). Consequently, business model innovation may also be crucial for transforming energy systems.

Business model innovation commonly involves new *value propositions*, such as a shift from product-based offerings like selling heating fuel, towards service-based offerings based on thermal comfort (Kindström and Ottosson, 2016). Business model innovation may also involve: *supply chain* innovations, such as process automation, integration and just-in-time logistics (Mlecnik, 2013; Mlecnik et al., 2012); new types of *customer interface* - utilising new forms of acquisition and engagement through information technologies and the internet (Shomali and Pinkse, 2016; Teece, 2018); or novel *financial models* like long-term leasing - such as Rolls-Royce’s ‘power-by-the-hour’ engine servicing model (Teece, 2018). Further, new approaches to business model *governance* may see firms ‘out-source’ or ‘in-house’ various components of their business model through mechanisms such as franchising (Hellström et al., 2015). Therefore, business model innovation is both enabled by technological innovation and also facilitates such innovation - explaining why general-purpose technologies such as the internet have had such a profound impact on organisational change (Osterwalder, 2004).

However, organisations face a range of internal (organisational) and external (socio-economic) barriers to business model innovation (Stubbs and Cocklin, 2008). These barriers may be structural, such as unfavourable regulations (Hannon et al., 2013) or cultural – relating to the ‘dominant logic’ within an firm or industry (Chesbrough, 2010). Organisations may therefore lack the complementary knowledge, capabilities or assets to innovate their existing business models or capture value from new business models (Teece, 2018, 2010, 1986). Firms are thus likely to under invest in business model innovation, due to market failures that also characterise technological innovation (Jaffe et al., 2005; Zott and Amit, 2010)

Bolton and Hannon (2016) argue that these barriers and benefits may provide a rationale for policy intervention – such as in the case of whole-house retrofit. However, few studies have explored how policymakers could promote business model innovation, despite an increasing focus on business models as a means of achieving sustainability policy objectives (OECD, 2015a).

1.5.4. Business models for sustainability

Most studies on business model innovation originate from the business and management literature (Massa and Tucci, 2013), although the concept is increasingly used to study the transition to a sustainable economy (Boons et al., 2013). The growing literature on business models for sustainability encompasses a range of empirical topics including energy and transport systems, industrial processes and waste, ecosystem management and social justice (Bocken et al., 2014).

Many authors therefore expect new business models to play an important role in creating a sustainable economy. Stubbs and Cocklin (2008) describe how incumbent business models, preoccupied with profitability and shareholder value, may be incompatible with long-term sustainability and planetary boundaries. Consequently, Bocken et al., (2014) identify a typology of eight archetypes of business models for sustainability which incorporate the ‘triple bottom line’ of economic, environmental and social sustainability.

Other authors emphasise the role of business model innovation in sustainable technological change (Massa and Tucci, 2013). For example, Richter (2012) argues that the incumbent energy utility business model is largely incompatible with distributed renewable energy systems¹¹. While the traditional business model can capture value from large scale renewable systems – such as offshore wind farms – distributed energy systems such as rooftop solar require a more fundamental shift towards ‘customer-side’ business models. Thus, requiring new revenue streams from energy services rather than units of power (Richter, 2013a, 2012). Budde Christensen et al., (2012) further describe how the adoption of electric vehicles may involve business models based on mobility services rather than ownership (Budde Christensen et al., 2012; Nykvist and Whitmarsh, 2008). Similarly, Roome and Louche (2016) argue that ‘circular economy’ business models will increasingly need to replace resource-intensive ‘open loop’ business models in many industries.

One area that has received particular attention is energy service business models (Duplessis et al., 2012; Hannon et al., 2015; Kindström and Ottosson, 2016; Labanca et al., 2014; Okkonen and Suhonen, 2010). These involve value propositions based on the energy service itself (heat, hot water, mobility) rather than the sale of energy commodities (gas, electricity, petroleum) (Steinberger et al., 2009). Consequently, these models create incentives to improve resource efficiency in the delivery of services such as mobility, thermal comfort, lighting and sanitation (Bertoldi et al., 2006; Roelich et al., 2015; Sorrell, 2007). Various studies have explored the potential for energy service business models in industry and non-residential buildings (Hannon and Bolton, 2015; Kindström and Ottosson, 2016; Okkonen and Suhonen, 2010), with examples of residential energy service business models also emerging (Irrek et al., 2013; Labanca et al., 2014).

However, there are few studies of business models for residential retrofit. Gauthier and Gilomen (2016) compare retrofit business models in two French case studies, but focus upon individual subcontractors rather than the overall business model. Several studies

¹¹ These involve smaller scale decentralised energy generation technologies, such as solar PV, small-scale wind, biomass or combined heat and power

identify the benefits of integrated retrofit business models, where multiple measures and finance are provided by one organisation (Mahapatra et al., 2013; Mlecnik, 2013; Mlecnik et al., 2018). Others highlight the potential of energy performance contracts in the residential sector (Winther and Gurigard, 2017), but do not present any operating examples. Hitherto, few studies contrast these innovative approaches with incumbent business models (Moschetti and Brattebø, 2016) and none explain why certain retrofit models are more or less successful. Moreover, no studies have investigated how policymakers can promote business model innovation in a retrofit or wider context.

This review of the business model literature therefore highlights two important gaps. First, there are no studies that compare the range of business models for residential retrofit or explain the reasons for their success or failure. Second, there are no studies that investigate how policymakers can promote innovative business models. Addressing these gaps would provide a valuable contribution to the literature.

1.5.5. Finance, the energy system and residential retrofit

There is increasing recognition of the importance of new forms of finance in the energy transition. Whilst the majority of UK sustainable energy investment (including residential retrofit) has come from the balance sheets of large energy suppliers, sufficient investment to meet the UK's carbon targets (estimated to be between £130-330bn by 2030) will likely require third-party capital (Blyth et al., 2015). The incumbent business model of the large energy suppliers is also poorly suited to funding retrofit - characterised by small-scale investments such as heat pumps and PV panels with complex revenue streams (Richter, 2013b, 2013a, 2012). This business model also lacks incentives to fund energy efficiency as is currently reliant on increasing sales of energy (Knoeri et al., 2016). Hall et al., (2015) therefore argue that '*institutional and structural constraints, behavioural routines, and fundamental uncertainties*' contribute to a 'finance gap' for sustainable energy (Hall et al., 2016; Masini and Menichetti, 2013, 2012). This is especially prevalent for small investments like retrofit where transaction costs can also be significant (Arnold and Yildiz, 2015).

Recent studies have emphasised the role of state investment banks in filling this investment gap (Mazzucato and Penna, 2016; Mazzucato and Semieniuk, 2018), whilst others have highlighted the importance of a local banking sector for funding smaller scale distributed energy systems – presently lacking in the UK (Hall et al., 2016). However, few studies have explored the challenges of financing energy efficiency retrofit (Gouldson et al., 2015) – with the mainstream finance journals largely ignoring energy issues altogether (Diaz-Rainey et al., 2017).

Investment in energy efficiency retrofit also faces particular barriers which are especially challenging for whole-house approaches. Often households lack access to capital, owing to limited savings or the unavailability of conventional financing solutions, such as secured and unsecured loans (Rezessy and Bertoldi, 2010). Further, most conventional forms of financing do not address the problem of split incentives (Bird and Hernández, 2012). The lower rates of return associated with deeper measures such as SWI are also especially sensitive to the cost of capital or the interest rates on loans (Gouldson et al., 2015). However, whilst these barriers have long been understood (Sorrell et al., 2004) the literature offers few insights into how these barriers might be overcome (Bird and Hernández, 2012; Gouldson et al., 2015).

A recent body of non-academic literature has highlighted the role of a range of *finance mechanisms* in overcoming these issues of access to capital, split incentives and long payback periods (EEFIG, 2015; Kim et al., 2012; Sweatman, 2013, 2012). A finance mechanism is considered distinct from targeted subsidies funded through taxation, energy supplier obligations (Leventis et al., 2017) or fiscal incentives such as variable property taxes (Rosenow et al., 2014). Instead, a finance mechanism is defined as:

The provision of capital through a combination of equity and/or debt that is repaid to the lender.

However, studies on retrofit finance mechanisms, together with their relationship to business models, are lacking from the academic literature. Whilst the majority of studies have focussed on government or supplier-funded grants (Rosenow et al., 2013b;

Rosenow and Galvin, 2013; Sovacool, 2015), most future investment will involve repayable financing for the ‘able-to-pay’ segment (Blyth et al., 2015; Rosenow et al., 2013b). Some authors have studied both the UK’s failed Green Deal (Rosenow and Eyre, 2016) and Germany’s successful KfW finance mechanisms (Rosenow, 2013), although provide limited insight to features that influenced their success and failure. New business models, such as those based on energy performance contracts (Winther and Gurigard, 2017), may also provide a means of delivering retrofit investment (Foxon et al., 2015); although these studies do not foreground the financial component of these models. Other work has highlighted how new finance mechanisms might overcome the split incentives barrier (Bird and Hernández, 2012; Gouldson et al., 2015). But taken together, this literature provides an incomplete picture of the range of financing mechanisms or a common conceptual basis for comparing them.

Consequently, research which identifies the features of alternative finance mechanisms, explains why different mechanisms are more or less successful, and explores the relationship between finance mechanisms and business models - would seem a timely addition to the academic literature.

1.6. Methodological approach

This section describes the methodological approach taken across the four articles. This begins with the *scope* of the research, clarifying the units of analysis, the concepts included, the assumptions employed and the choice of cases. Subsequently the key *conceptual* ideas used in the thesis are introduced. This is followed by the *research design* - describing the overall strategy to address the research questions. Subsequently, the methods of *data collection* are explained, and their strengths and weaknesses identified. Finally, the methods of *data analysis* are presented.

1.6.1. Research scope

This research concerns how new business models and finance mechanisms can help accelerate the uptake of whole-house retrofits, and how policymakers can promote these

new approaches. Therefore, the units of analysis are 1) business models for residential retrofit 2) finance mechanisms and 3) policy approaches to promote these.

The thesis is focussed on residential retrofit and does not consider the retrofit of industrial, public or commercial buildings. However, many of the business models and finance mechanisms operate in various guises in all three sectors. Although the focus is residential buildings, this includes all *forms*; from single family homes to multi-family apartment blocks; and all *tenure types*, from social housing, privately rented to owner-occupied homes. Section 6 discusses the challenges presented by these different forms and tenure types, and the suitability of different models and mechanisms for each. The primary focus is the UK, but Articles 1 & 3 include examples from France, Latvia, Belgium the Nordic countries and the Netherlands, while Article 2 includes examples from the USA.

The UK presents an interesting case for several reasons. Whilst having strong climate change legislation in the form of the Climate Change Act (HM Government, 2008), and having achieved considerable progress with electricity decarbonisation; the UK has one of the oldest and least energy efficient housing stocks in Europe (Fylan et al., 2016). Despite previous success installing single measures through its supplier obligation policies, two recent policies designed to promote deeper retrofits and multiple measures (the Green Deal and ECO) have delivered significantly less than anticipated (Rosenow and Eyre, 2016). The UK also has highly heterogeneous mix of buildings and tenure types (Gram-Hanssen, 2014). These factors create a challenging environment for retrofit policy, thus, the UK could provide important lessons for other national contexts.

1.6.2. Conceptual framework, archetypes and typologies

Building on the literature review, this thesis develops and applies several *conceptual frameworks, archetypes and typologies* to the context of whole-house retrofit.

A conceptual framework provides a means of making conceptual distinctions and organising ideas. It “*explains, either graphically or in narrative form, the main things to be*

studied—the key factors, concepts, or variables—and the presumed relationships among them”(Miles et al., 1994, p. 18). Articles 1-3 each develop a conceptual framework, with their relationship to each other, discussed in Section 6.1.

Article 1 develops a conceptual framework to describe the five generic components common to all business models. This builds on Boons and Lüdeke-Freund (2013) four key components of a business model, namely: the *value proposition*; *supply chain*; *customer interface*; and *financial model* and is supplemented with the *governance* component as described by Zott and Amit (2010). In Article 3, this framework is augmented with three key intermediation activities of *facilitating*, *configuring* and *brokering* (Stewart and Hyysalo, 2008).

For Article 2 on finance mechanisms, no equivalent conceptual framework could be identified from the literature. Therefore, the scoping research involved a grounded approach to theory development (Glaser and Strauss, 2017). Grounded theory is developed inductively during data collection such that it is ‘grounded’ in the evidence - entering the field with only a limited understanding of the important variables or how they relate to each other (Maxwell, 2012). Whilst some features of finance mechanisms could be determined from the literature and the researcher’s prior knowledge, it was only through this inductive process that an appropriate conceptual framework could be developed. This framework identifies seven generic features namely: the *source of capital*; the *financial instrument(s)*; the *project performance* requirements; the *point of sale*; the nature of the *security and underwriting*; *repayment channel* and the customer journey. These frameworks are used to explain why different business models and finance mechanisms are more or less successful, and how business model innovation can be supported.

The term archetype is used here to represent idealised examples of phenomena such as business models or finance mechanisms. Archetypes are intended to reduce the diversity of reality to a number of ‘ideal types’ - which can be differentiated by their key components. Article 1 develops five archetypes of business models, of which two are compared in Article 3. Similarly, Article 2 develops six archetypes of finance mechanisms.

A typology is a means of classifying a number of ideal types, usually to depict the diversity of examples within a given field of study: thus, a typology may be comprised from a number of archetypes. Article 1, therefore, identifies a typology of the key business model archetypes across the retrofit industry, whilst Article 2 identifies a typology of the main retrofit finance mechanisms currently in operation. Figure 8 shows how these three concepts link together.

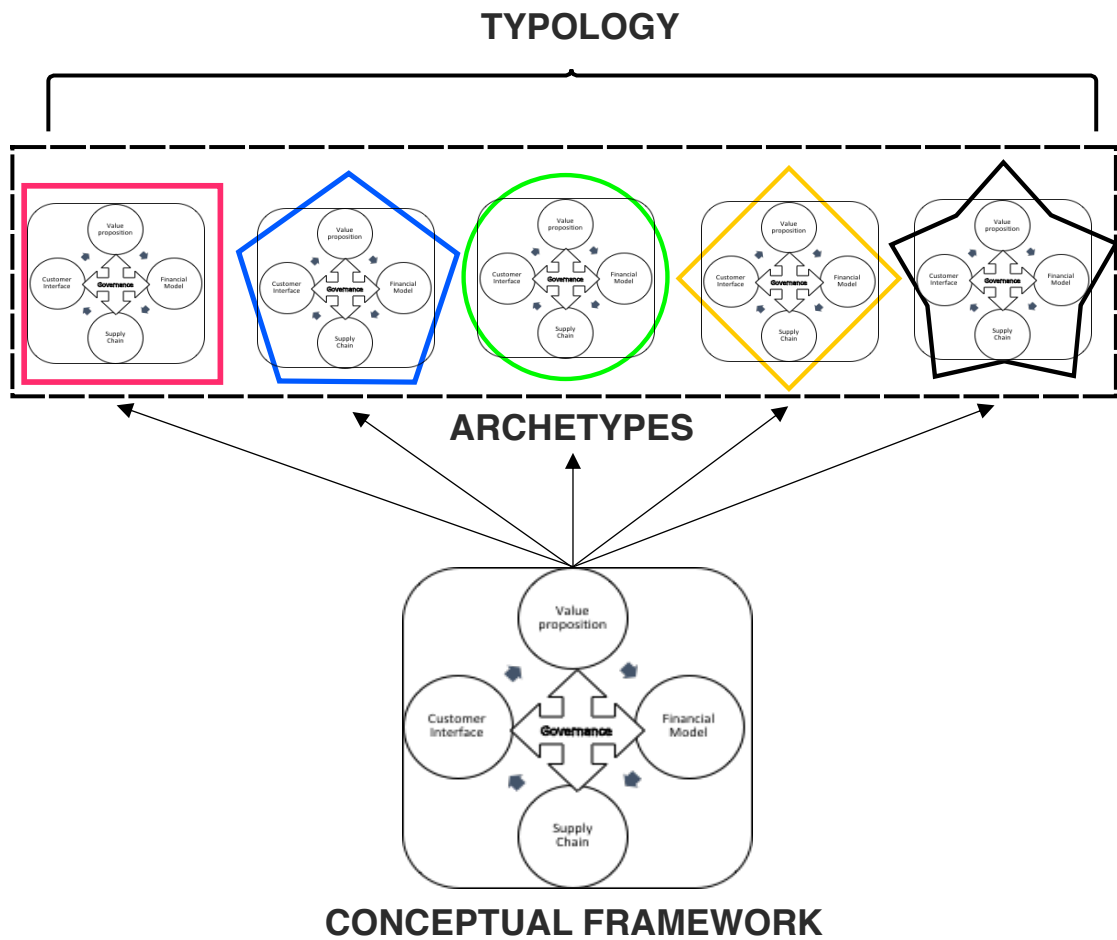


Figure 8 The relationship between conceptual frameworks, archetypes and typologies

1.6.3. Research design

The research design describes the overall plan for how the research questions are to be addressed. It provides *“the blueprint for the collection, measurement, and analysis of data”* (De Vaus, 2002). In this thesis, each article addresses each research question in

turn, generating cumulative insights for the subsequent stage of analysis. Thus, the research design was iterative, with research questions, conceptual framework, methodological approach, research methods and analysis revised reflexively throughout the project (Maxwell, 2012).

First, to identify the business models and financing mechanisms currently in operation and second to explain their relative success, data for Articles 1 and 2 was collected and analysed in two phases. Article 1 initially involved scoping research to investigate the diversity of business models within the UK and wider EU - developing archetypes guided by the business model conceptual framework. This led to the development of a typology of five business model archetypes considered to represent the diversity of models.

A complementary framework is developed in Article 2 to identify the generic features of finance mechanisms. This was developed through a grounded approach (described in Section 1.6.2 (Glaser and Strauss, 2017)). Subsequently, this led to the identification of a typology of six archetypes of finance mechanism; representing the diversity of approaches within the EU, although this time broadening the focus to include the USA.

Both papers then employed a cross-sectional study, to determine how the components of the business models and finance mechanisms impacted their success in different contexts. Cross-sectional research designs involve collecting data at one point in time, segregating the sample into a number of groups or types and analysing the extent to which variation in the outcome is linked to variation in these groups or types (De Vaus, 2002). These research designs usually involve the use or creation of a typology as in Articles 1 and 2.

Article 3 builds on Article 1 to explain why some archetypes are more successful than others. It compares two archetypes: one considered to be common practice, the other a highly novel and innovative business model – maximising the contrast between these cases. Whilst the research for Article 1 provided sufficient insight into the structure, operation and success of the common business model, an in-depth case study of the innovative model was deemed necessary. This was appropriate given the unique nature

of this case and its potential to be an exemplar for the wider retrofit sector (Flyvbjerg, 2006). Case study research also affords a greater depth of insight than a cross-sectional research design (Yin, 1994). Article 3 also draws upon insights from a project on Low Energy Housing Innovation Intermediaries (LEHII) undertaken by the primary PhD supervisor - providing background and context to the study (Kivimaa and Martiskainen, 2018; Martiskainen and Kivimaa, 2018).

The research for these three articles was qualitative throughout - considered appropriate given the need to develop an in-depth understanding of the operation of the business models and finance mechanisms, and to answer 'how' or 'why' questions regarding their relative success (Flyvbjerg, 2006; Yin, 1994). Qualitative research is also inherently flexible, allowing the research design, lines of enquiry and methodological approach to be developed iteratively (Maxwell, 2012). The primary data was supplemented by extensive analysis of secondary literature. This helped develop the researcher's understanding of the phenomena, as well as adding validity by triangulating data from the interviews. More detail on the approach to data collection is provided in each article.

Article 4 was developed for an edited book and aimed to synthesise the insights from Articles 1-3 and provide some policy recommendations for the UK. This involved supplementing the previous work with a review of the academic and grey literature on policy approaches for promoting residential retrofit. A summary of the research design and methods for the four articles is provided in Figure 9.

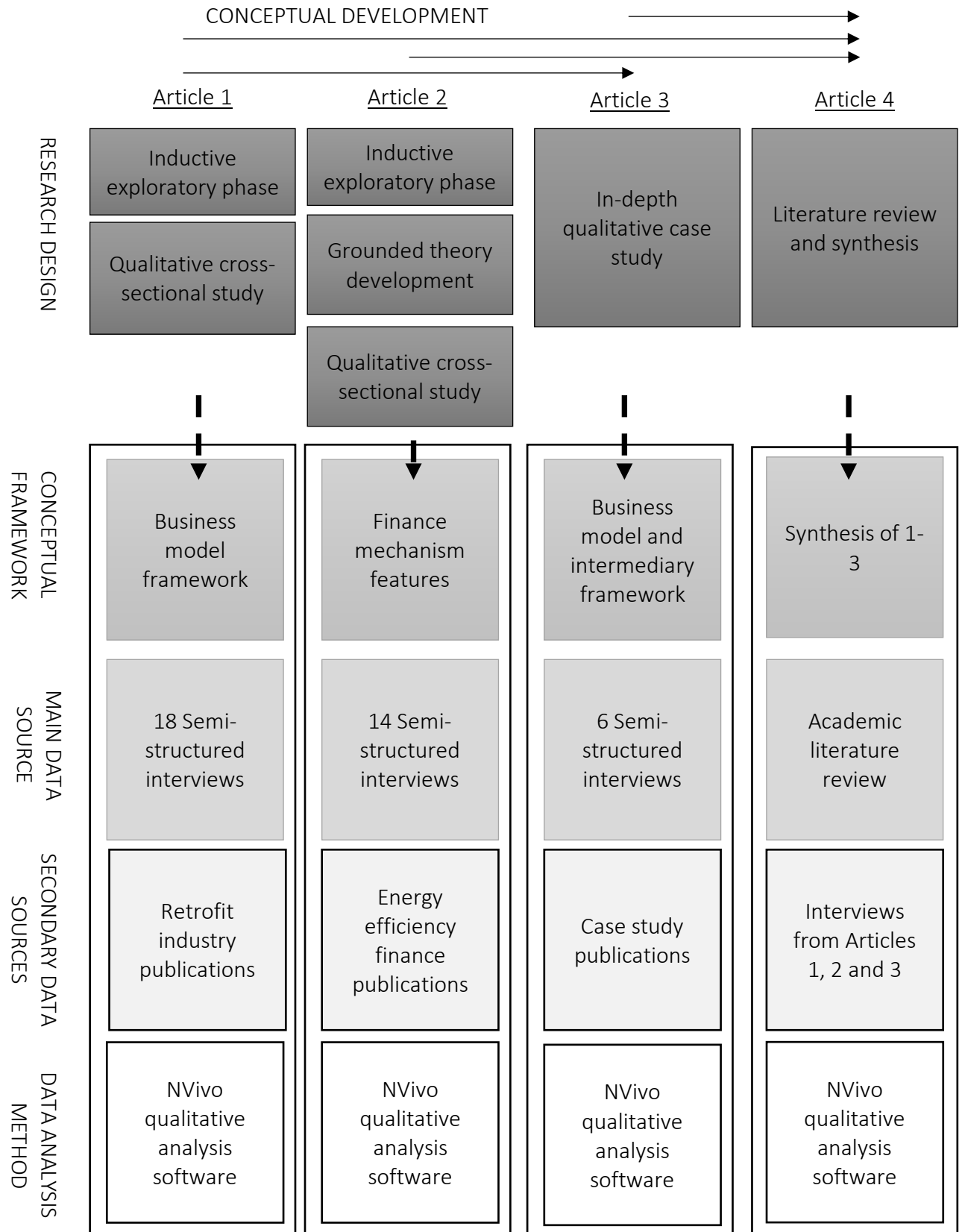


Figure 9 Overall research design

1.6.4. Data collection

Primary data collection involved a total of thirty-eight semi-structured interviews - including a mix of face to face and video conference interviews. This was supplemented by secondary analysis of a wide range of documents, described in each article. The interviews were conducted in three phases, each focussed on a research sub-question and each informing a separate article. Interviews in Articles 1 & 2 were subdivided into: a scoping phase to help develop the respective frameworks, archetypes and typologies; followed by a detailed investigation of the range of business models and finance mechanisms. Article 3 built upon the comparative investigation in Article 1 with an in-depth case study of an individual business model. A summary of the data collection process is provided in Table 1. More detail on the interviewees, including organisation and role, can be found in Appendices A and B.

Table 1 Summary of primary data collection

Article	Research question	Primary data: semi-structured interviews*	Date of collection
1	How and why can new business models encourage the uptake of whole-house retrofit?	8 scoping interviews with experts in residential retrofit and 10 with practitioners (18 in total)	November 2016 – March 2017
2	How and why can new finance mechanisms encourage the uptake of whole-house retrofit?	6 scoping interviews with experts in energy efficiency finance and 8 interviews with finance practitioners (14 in total) 4 interviews were re-used from Article 1	April – September 2017
3	How can public policy encourage new business models for whole-house retrofit through intermediaries?	6 case study interviews (one reused from Article 1) Interview data from Articles 1 & 2 was also reused	November 2016 – June 2018
4	How can the uptake of whole-house retrofit in the UK be accelerated by public policy?	Re-use of interview data from Articles 1, 2 & 3	N/A

*Each interview lasted approximately 1 hour

Semi-structured interviews combine planned questions with a more flexible and conversational approach (Kvale, 2008). This allowed the pursuit of unexpected lines of enquiry which produced unanticipated findings or contradicted initial assumptions (Grix, 2010). This approach was considered appropriate for the mix of inductive and deductive objectives of this project. Each interviewee was provided with a consent form and information sheet that allowed them to specify their anonymity and level of disclosure for the interview. Interviews were recorded using a smartphone and converted to mp3 files. Early interviews were transcribed by the author, but in the latter stages, an online transcription service was used. Interview transcripts are available on request, subject to confidentiality agreements.

1.6.5. Data analysis

Each interview transcript was coded using the NVivo 11 & 12™ software. This allowed common themes to be identified, along with areas for further investigation. Interviews were coded within a master file to allow coding links to be made across the data sets. This was especially beneficial for Article 3 which drew heavily on the insights from Article 1. The coding was structured to mirror the conceptual frameworks adopted in each article, thus guiding the data analysis. The coding structure (Figure 10) was divided into thematic nodes and case nodes. Whilst case nodes (red) describe discrete categories of information such as people, places or archetypes in a typology; thematic nodes (black) are more subjective and tend to contain more explanatory information such as *drivers* or *barriers*. The use of NVivo allowed a simple coding structure to be adopted with more precise relationships determined through the 'Query' function. This allows for the identification of overlapping coding and provides quick access to relationships in the data. For example, 'Good quotes' surrounding the 'Barriers' to a certain business model like the 'Energiesprong model'. This function also allowed searches for words or phrases of interest. Figure 10 summarises the NVivo coding structure across the three sets of interview data.

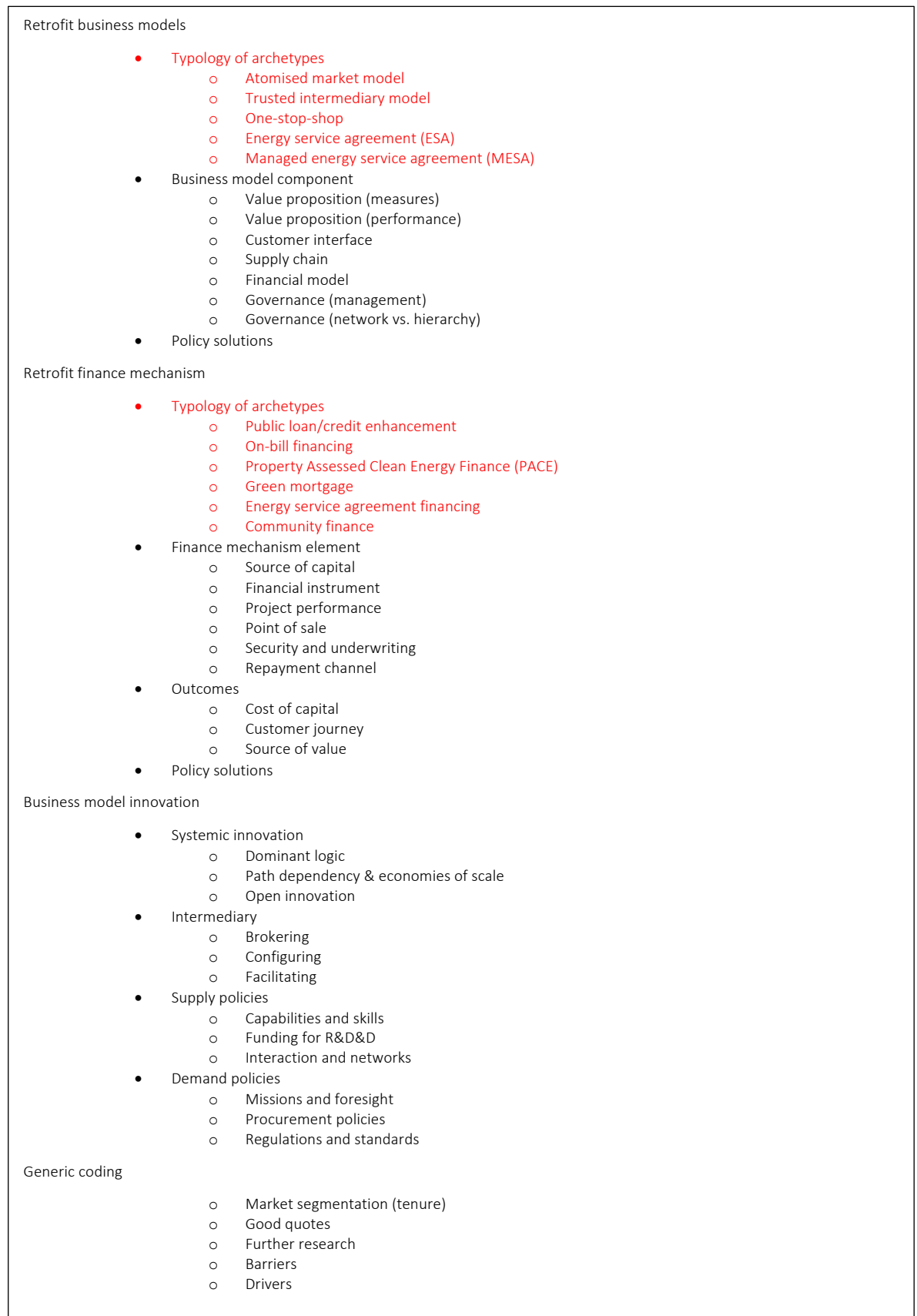


Figure 10 Coding structure across the interview data

1.7. Article summary

The following summarises the four articles and shows how they answer each of the research questions.

1. Business models for residential retrofit in the UK: a critical assessment of five key archetypes.

Article 1 shows how new business models can be a powerful means of overcoming the challenges of retrofit in residential buildings. The paper synthesises the contemporary literature on business models, combining the four components of a business model identified by Boons et al., (2013) with the additional concept of business model governance described by Zott and Amit, (2010). The paper then identifies five business model archetypes for residential retrofit, ranging from the traditional approach to innovative energy service contracts which are now being trialled in the EU.

By applying this framework, the paper identifies the core components of a business model that allow it to be both effective in delivering whole-house retrofits and appealing to consumers. These include: increasingly industrialised processes and integrated supply chains; a holistic customer offering and single point of contact; long-term energy saving performance contracts; and integral project finance. It is argued that whilst the traditional business model is suitable for the implementation of single or piecemeal retrofit measures, more innovative business models that embody each of these features will be required to meet the UK's ambitious climate change targets.

2. Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit.

Article 2 explores the challenges of financing this retrofit activity at scale. A literature review revealed that few studies investigate the features of alternative financing mechanisms. Therefore, the paper develops a conceptual framework to highlight the generic features of different finance mechanisms and to aid their comparison. These features include: the source of capital; the financial instrument(s); the project

performance requirements; the point of sale; the nature of the security and underwriting; repayment channel; and the customer journey.

The paper then explores how these features influence the success of the finance mechanisms in different contexts. It shows that: first, a low cost of capital is critical for the economic viability of deeper, whole-house retrofits; second, the inclusion of non-energy measures such as general improvement works can enable broader sources of value that are more highly prized by households; and third, mechanisms that reduce complexity by simplifying the customer journey are likely to achieve much higher levels of uptake.

The paper also argues that finance alone is unlikely to be a driver of demand and instead should be viewed as an enabler once demand is in place. This has important implications for the design of public policies to promote retrofit, which have too often foregrounded the financial barriers and benefits of retrofit and neglected wider considerations.

3. How intermediaries promote business model innovation: the case of ‘Energiesprong’ whole-house retrofits in the United Kingdom (UK) and the Netherlands.

Article 3 takes a more conceptual approach, arguing that systemic innovations - requiring complementary changes in supporting technologies, technical skills, user competences, organisational practices and regulation - may require new business models before they are widely adopted. The paper argues that whole-house retrofit is an archetypal example of a systemic innovation.

By comparing the incumbent ‘atomised market model’ with an in-depth case study of innovative the Dutch ‘Energiesprong’ retrofit initiative, the paper demonstrates the potential of business model innovation in this sector. The innovative business model is seen as a driver of consumer appeal but also technical and process innovation and a means of achieving economies of scale and cost reduction for whole-house retrofit.

By developing a novel framework, the paper also demonstrates the central role of an *innovation intermediary* in this business model innovation. It highlights how Dutch policymakers were able to promote business model innovation by funding and supporting this intermediary; providing lessons for how policymakers can foster business model and systemic innovation, which may be transferable to other sectors.

4. Overcoming the systemic challenges of retrofitting residential buildings in the United Kingdom, a Herculean task?

Article 4 is a chapter for a book on innovation and energy demand. It argues that the UK's historical retrofit policies have failed to address four systemic challenges that constrain uptake for whole-house retrofits, namely: lack of information, engagement and trust; the uncertain benefits and quality of retrofit work; the complexity, disruption and timing of the project; and high capital costs and split incentives that act as a financial barrier.

The chapter focuses on solutions to these challenges, drawing upon insights from the three previous articles in terms of the business model, financing and intermediaries. It argues that a more comprehensive policy approach will be needed to overcome these challenges and provides some specific recommendations.

Table 2 summarises the contribution of the main author to each of the articles.

Table 2 Main authors' contribution to the articles

Article title	Main author contribution	Co-author/supervisor contribution
Article title: Business models for residential retrofit in the UK: a critical assessment of five key archetypes. Authors: Donal Brown Journal: Energy Efficiency (2018) https://doi.org/10.1007/s12053-018-9629-5 Publication status: Published	Sole author	Supervisors advised on empirical data collection and provided proofreading and general feedback
Article title: Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit. Authors: Donal Brown, Steven Sorrell, Paula Kivimaa Journal: Energy Policy (2019) https://doi.org/10.1016/j.enpol.2018.12.033 Publication status: Published	Designed the study, undertook literature review, developed framework, undertook all 14 interviews and data analysis, wrote discussion and conclusions	Sorrell provided guidance on the literature and theoretical approach and undertook edits of the manuscript, for sense and readability. Kivimaa provided advice and comments on research design, interview structure, and undertook edits of the manuscript, for sense and readability.
Article title: How intermediaries promote business model innovation: the case of 'Energiesprong' whole-house retrofits in UK and the Netherlands. Authors: Donal Brown, Paula Kivimaa, Steven Sorrell Journal: SPRU Working Paper Series (SWPS) Publication status: Published	Designed the study, undertook literature review, developed framework, undertook all 6 interviews and data analysis, wrote discussion and conclusions	Kivimaa provided guidance on the literature and theoretical approach and undertook edits of the manuscript, including developing the literature review, framework and discussion as well as for sense and readability. Sorrell undertook edits of the manuscript, for sense and readability.
Article title: Overcoming the systemic challenges of retrofitting residential buildings in the United Kingdom, A herculean task? Authors: Donal Brown, Paula Kivimaa, Jan Rosenow, Mari Martiskainen Book: Jenkins, K and Hopkins, D. (2018) (Eds.) Transitions in Energy Efficiency and Demand: The emergence, diffusion and impact of low-carbon innovation. London, UK: Routledge https://doi.org/10.4324/9781351127264 Publication status: Published	Designed the study, undertook literature review, developed framework, wrote discussion and conclusions	Kivimaa provided the bulk of the text on intermediaries including developing the literature and theoretical approach and undertook edits of the manuscript for sense and readability. Rosenow provided the bulk of the text for subsection on UK policy on residential retrofit including reviewing the literature Martiskainen provided edits to the intermediaries section and undertook edits of the manuscript for sense and readability.

2. Article 1: Business models for residential retrofit in the UK: a critical assessment of five key archetypes

(Pre-print, published in Energy Efficiency)

Abstract

The whole-house retrofit of residential buildings has significant potential to reduce carbon emissions and provide additional health and economic benefits. However, in countries such as the UK much of this potential is yet to be realised. This paper shows how the concept of ‘business models’ can be a powerful tool for understanding the challenge of improving energy performance and reducing carbon emissions in residential buildings. Through a review of contemporary literature and eighteen semi-structured interviews; the paper describes and compares five distinct business model archetypes: the *atomised market model*; *market intermediation model*; *one-stop-shop*; *energy services agreement* and *managed energy services agreement*. These models range from the traditional approach to highly innovative energy service contracts. The paper further illustrates how the UK and EU market for retrofitting residential buildings is beginning to trial the more innovative business models. These emerging business models are characterised by increasingly industrialised processes and integrated supply chains, a holistic customer offering and single point of sale, long-term energy saving performance contracts (ESPC) and integral project finance. It is argued that whilst the traditional business model is suitable for the implementation of single or piecemeal energy-saving measures, business model innovation will be required to meet the UK’s ambitious climate change targets.

2.1. Introduction

The United Kingdom (UK) has an ambitious target to reduce greenhouse gas (CO₂e) emissions by 80% by 2050, relative to 1990 levels (Treasury, 2008). To this end, the UK government has set legally binding, five-year carbon budgets that include targets for reducing emissions in all sectors of the UK economy (CCC, 2013). In 2016, buildings were responsible for over a third of the UK’s CO₂e emissions, with 22% from the residential sector alone (CCC, 2016). Improving the energy efficiency of residential buildings can also improve occupant’s health (Willand et al., 2015) and reduce fuel poverty (Sovacool, 2015). In the UK, the energy performance of

residential buildings is measured using the ‘Standard Assessment Procedure’ (SAP)¹², where a SAP score of 100 equates to an exemplary dwelling. In 2012, the average SAP for UK homes was 59, compared to only 45 in 1996 (DECC, 2015b).

Progress in improving the energy performance of residential buildings has stalled since 2012 (CCC, 2016). The UK still has one of the oldest and least energy efficient housing stocks in Europe, and two thirds of the existing buildings are likely to exist in 2050 (Fylan et al., 2016). Older, solid walled properties constitute around 27% of the UK stock, and have a large energy saving potential (Element Energy, 2013), yet only around 4% have had solid wall insulation (SWI) installed (CCC, 2016). The UK also has a high proportion (67%) of owner occupied housing, with 19% in social housing and 14% in private rented sectors (CCC, 2016). The Committee on Climate Change (CCC, 2015a) estimates there is cost effective¹³ potential to reduce direct emissions¹⁴ from all buildings by 32% to 2030, with further savings available from the implementation of onsite microgeneration - with the need to achieve near-zero emissions from the sector by 2050 (CCC, 2016). A 2013 policy initiative to improve energy efficiency in this sector (the ‘Green Deal’) proved to be a high-profile failure, achieving only 15,000 installations (mostly new boilers) rather than the two million a year that were envisaged (Rosenow and Eyre, 2016). Since the remaining policies for energy efficiency in housing are relatively limited in ambition and scope, the carbon targets for this sector may not be achieved (Guertler and Rosenow, 2016).

Emissions from UK residential buildings largely derive from gas use for space and water heating, and electricity use for lighting and appliances. Alongside efficient appliances and behaviour changes, the majority of these emissions can be reduced by the *retrofit* of three types of measure (Mallaburn and Eyre, 2014): improving the *building fabric* of properties; adopting *low-carbon heat* technologies such as heat pumps; and building-integrated electricity

¹² SAP quantifies a dwelling’s performance in terms of: energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO₂ (the Environmental Impact Rating) (GOV.UK, 2017).

¹³ The CCC define the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes together with measures that may cost more than the projected carbon price, but are necessary in order to manage costs and risks of meeting the 2050 target (CCC, 2013).

¹⁴ Those that result from heating, ventilation and cooling systems as well as and hot water. This term excludes emissions from electricity consumption

microgeneration, such as solar PV (CCC, 2013). The CCC projections for 2030 include 2 million SWI and 2.5 million heat pump installations. This represents a 7-fold increase in properties with SWI and a massive upscaling in low carbon heat (CCC, 2016).

The improper installation of *deeper* single measures such as SWI have, however, the potential to cause damaging unintended consequences¹⁵ (Davies and Oreszczyn, 2012). A *whole-house residential retrofit*; where the entire building is treated as a system rather than as individual elements or measures, is likely to mitigate such issues and achieve greater reductions in emissions (Hansford, 2015). Such an approach typically involves multiple measures and strategies for insulation, draught proofing, ventilation and heating systems, and may also include microgeneration (Milsom, 2016). Consequently, if the UK is to meet its ambitious climate change targets, whole-house residential retrofit; involving multiple co-ordinated measures will need to become the norm (Lewis and Smith, 2013).

This paper argues that despite significant policy action in this area, a major reason for the slow progress is the limitations of the traditional *business model* through which energy efficiency measures are delivered. This model is characterised by a piecemeal offering; with a fragmented *supply chain*, a focus on single (rather than multiple, complementary) measures, and no guarantees on performance. Yet, research that identifies how alternative business models might be more effective in delivering whole-house retrofit, is largely absent from the literature.

This study addresses this gap. First, it uses the business model concept to better understand the challenge of residential retrofit; second, it identifies the range of business models currently used for delivering residential retrofit in the UK and the EU; and third, it evaluates how and why the characteristics of these business models influence their potential in delivering whole-house retrofits.

The study addresses the following research questions:

1. What insights does the business models concept offer for the challenge of residential retrofit?

¹⁵ Such as mould growth, poor air quality and interstitial condensation; due to poor detailing, and in-sufficient consideration of building physics, airtightness and ventilation (Milsom, 2016)

2. What business models are currently used for residential retrofit and how do they differ?
3. How and why do the characteristics of these alternative business models influence their potential for delivering whole-house residential retrofit?

Through a review of the academic literature on both business models and residential retrofit, together with semi-structured interviews with stakeholders from the residential retrofit industry, this paper explores how more innovative business models could enable greater uptake of whole-house retrofit. The paper is structured as follows. Section 2.2 summarises the theoretical literature on business models and the empirical literature on residential retrofit and outlines the value of using the former to understand the latter. Section 2.4 outlines the research methodology, while Section 2.5 describes five key business model archetypes for residential retrofit. Section 2.6 summarises the empirical results and highlights the implications for the successful delivery of whole-house residential retrofit. Section 2.7 places these findings in the context of the wider literature on business models and residential retrofit. Section 2.8 concludes and provides some suggestions for further research.

2.2. Literature on business models, energy services and residential retrofit

2.2.1. Literature on business models

Throughout history, the development of new business models has been instrumental in the diffusion of innovations, such as commercial aviation, modern customer electronics and the internet (Teece, 2010). Meeting the sustainability challenges of the 21st century, is likely to require a major transition in many sectors of the economy. This transition requires the development and rapid diffusion of multiple low carbon innovations throughout the housing sector. Thus, innovations such as distributed energy¹⁶ and whole-house residential retrofit may require novel business models before they are viable on a large scale; due to their incompatibility with existing industry practices (Hall and Roelich, 2016; Winther and Gurigard, 2017). Consequently, various scholars have identified how such *systemic innovations* may have specific characteristics that are more suitable to certain novel business models (Hall and

¹⁶ Defined as electricity generation feeding into the local distribution network (operating from 132kV down to 230V), as opposed to the regional or national transmission grid (which operates from 400kV and 275kV).

Roelich, 2016; Richter, 2012; Steinberger et al., 2009). In addition, new business models for *energy services* may also enable a whole-house approach to improving the energy performance of buildings (Kangas et al., 2018).

The business model is therefore increasingly adopted as a lens for evaluating firm strategies to address sustainability challenges (Boons et al., 2013). Yet, whilst a few key studies provide points of reference for characterising business models, the term remains contested; both in terms of the organisational components that are described (Osterwalder et al., 2005) and the system boundaries of individual firms or networks of firms (DaSilva and Trkman, 2014; Upward and Jones, 2015; Zott et al., 2011). Perhaps the most commonly used definition is from Osterwalder & Pigneur (2010) who identify four basic components; the *value proposition*, the *supply chain*, the *customer interface* and the *financial model* (Boons and Lüdeke-Freund, 2013). This characterisation provides a ‘meta-model’ of features that are generic to all business models, and can thus be applied in multiple contexts (Osterwalder et al., 2005). Business models therefore incorporate the nature of the value delivered to customers; the activities involved in delivering that value; and the means of capturing revenue from these activities (Boons et al., 2013).

However, the study of the business model of individual firms overlooks the interdependent and networked nature of the delivery of good and services (Hellström et al., 2015; Zott and Amit, 2010). Business models thus involve a range of activities that may span the boundaries of multiple organisations (Zott and Amit, 2010). This highlights the need for what has been termed a *systems perspective* on business models (Bolton and Hannon, 2016). This perspective emphasises the *governance* of business models, both in terms of the role of different actors and the chosen mode of governance; for example, from highly integrated to highly outsourced approaches (Amit and Zott, 2001).

2.2.2. Business models, energy services and residential retrofit

Several studies use the business model concept to describe how organisations provide *energy services* (Duplessis et al., 2012; Hannon et al., 2015; Kindström and Ottosson, 2016; Labanca et al., 2014; Okkonen and Suhonen, 2010). Energy service business models move beyond the

prevailing value proposition based on the sale of energy commodities (gas, electricity, fuel oil); towards an alternative value proposition based on the energy service itself (warmth, light, hot water) (Steinberger et al., 2009). This creates incentives for suppliers to reduce energy demand in order to minimise the energy cost of supplying the service (Bertoldi et al., 2006; Sorrell, 2007). Where these contracts include guaranteed reductions in energy consumption or costs for the client, they are termed Energy Savings Performance Contracts (ESPC), with the relevant supplier being termed an Energy Service Company (ESCO) (Kindström and Ottosson, 2016). The market for ESPCs is largely confined to industry and non-residential buildings (Hannon and Bolton, 2015; Kindström and Ottosson, 2016; Okkonen and Suhonen, 2010), since the transaction costs in the residential market are relatively high (Sorrell, 2007). However, Bleyl-Androschin and Schinnerl (2007) propose a number of models for ESPC's that could promote building envelope refurbishment. Indeed, several residential examples of ESPC's are now emerging across the EU (Irrek et al., 2013; Labanca et al., 2014).

Relatively few academic studies investigate business models for residential retrofit. Recent UK case studies focus on new models for distributed energy (Foxon et al., 2015; Hall and Roelich, 2016; Hannon and Bolton, 2015), but do not assess the specific challenges posed by residential retrofit. Gauthier and Gilomen (2016) compare two French case studies of residential retrofit business models, but focus on individual firms within the project, rather than the overall retrofit process. Mahapatra et al., (2013) evaluate the opportunities and barriers of *one-stop-shop* business models in Scandinavia for residential retrofit; where multiple services and finance are provided by one organisation. Winther & Gurigard (2017) explore a failed attempt to implement ESPC contracts in a Norwegian case study, whilst Moschetti and Brattembø (2016) map out possible alternative business models for residential buildings, yet provide limited empirical examples.

Cost effective energy efficiency measures face several barriers to their implementation (Sorrell et al., 2004). These barriers can be grouped into four categories: financial; social & behavioural; supplier competence; and performance risk (Fylan et al., 2016). The five components of the business model outlined in Section 2.1 correspond to each of these inter-related barriers. Studies identify problems with a value proposition focused on estimated, rather than guaranteed energy performance (Pettifor et al., 2015), and final energy services, such as

temperature and comfort (Roelich et al., 2015). Further barriers to uptake are identified as; a customer interface that is ineffective in engaging consumers (Owen et al., 2014; Wilson et al., 2015); poorly developed supply chains and retrofit performance gaps (where modelled savings are not realised) (Gupta and Chandiwalla, 2010; Kelly et al., 2012; Snape et al., 2015); and a lack of appeal in the financial model (Marchand et al., 2015). Other studies have identified the importance of *intermediary* actors in the governance of retrofit (Bleyle et al., 2013; Kivimaa and Martiskainen, 2018b), and as a means of reducing transaction costs for ESCO business models (Nolden et al., 2016). Thus, the five components of business models provide a comprehensive framework for understanding the solutions to these barriers.

2.3. Business model framework for residential retrofit

The following section describes how a business model framework can improve understanding of the challenges in delivering residential retrofit. This framework combines the four components of business models outlined by Boons and Lüdeke-Freund (2013) with the additional component of business model governance as described by Amit and Zott (2001; 2010). The components of a business model are therefore the value proposition, supply chain, customer interface, financial model and business model governance.

2.3.1. Value proposition

The value proposition refers to the value or utility from goods and services that an organisation provides to the customer (Boons and Lüdeke-Freund, 2013; Engelken et al., 2016). New business models do not necessarily provide a novel value proposition (Lopez et al., 2014), although a shift towards ESPCs may also create stronger incentives for energy efficiency improvements (Steinberger et al., 2009). Thus, the value proposition may constitute simply the implementation of energy-saving retrofit measures or a move towards some form of ESPC. Suppliers may also emphasise other sources of value for customers; such as improvements in aesthetics, comfort, health and wellbeing rather than energy cost savings alone (Knoeri et al., 2016). ESPC's may also enable more comprehensive residential retrofit projects (Kangas et al., 2018; Winther and Gurigard, 2017).

2.3.2. Supply chain

The supply chain is the upstream relationships between an organisation and its suppliers (Boons and Lüdeke-Freund, 2013). This comprises the logistical and technical elements that enable delivery of the value proposition (Osterwalder, 2004). In the context of residential retrofit, the supply chain includes the design and delivery of the retrofit; encompassing both the installation and the operational phases, potentially across multiple suppliers and consultants. Both integration of the supply chain and improvements in project management may enable more comprehensive residential retrofits (Mahapatra et al., 2013), increased material efficiency and quality control (Lopez et al., 2014) and industrialisation/automation of manufacturing processes and logistics; such as the use of offsite manufacture techniques (Energiesprong, 2014).

2.3.3. Customer interface

The customer interface covers all downstream, customer-related interactions (Boons and Lüdeke-Freund, 2013). This includes the relationship the customer has with the supplier organisations in terms of marketing, sales and distribution channels and the ongoing relationship with the product or service (Osterwalder and Pigneur, 2010). In a retrofit context, the customer may include homeowners, landlords or social housing providers. Where customers separately source retrofit measures, finance and energy audits; they may encounter multiple interfaces and points of sale.

2.3.4. Financial model

The financial model constitutes the combination of an organisation's capital and operational expenditures with its means of revenue generation from business activities (Osterwalder et al., 2005). Typically, the financial objective in energy retrofits is to recover the capital costs of the measures from the saving in energy bills, or from the revenues from onsite electricity generation. A range of *financing mechanisms* have thus been developed to overcome the initial capital cost; where the objective is typically to ensure that repayments are equal to or lower than the energy cost savings. A suitable finance mechanism is often the catalyst for a viable retrofit project, with the associated cost of capital being critical to the economic viability of many measures (Gouldson et al., 2015).

2.3.5. Business model governance

Business model governance involves both the control and management of the individual components (Zott and Amit, 2010) and the organisational form of the business model (Amit and Zott, 2001). As such, business models may involve a constellation of firms that interact to provide a service or product (Boons and Lüdeke-Freund, 2013), leading to interdependencies between various actors in the delivery of the value proposition (Zott and Amit, 2010). Consequently, the range of governance approaches lie along a continuum, with integrated, hierarchical firms at one end, and arm's-length, market-based, contractual relationships at the other (Treib et al., 2007). Where a hierarchical approach is adopted, the business model components are internal to a single organisation, whereas in a market-based approach, multiple organisations are likely to be involved. More common is a hybrid of these, with most business models employing varying degrees of market-based, hierarchical and trust-based governance; the latter involving recurrent relationships with trusted partners (Bradach and Eccles, 1989; Eriksson, 2008).

In residential retrofit, managers, intermediaries and government actors may each play important roles in governance (Bolton and Hannon, 2016). Governance (or lack of), becomes a particularly important consideration in highly networked arrangements where intermediaries (Bleyl et al., 2013; Kivimaa and Martiskainen, 2018b), such as community (Seyfang et al., 2013), municipal actors (Webb et al., 2016) work alongside private firms. In particular, innovative business models, may require these *system builders* to foster trust and co-ordinate the actions of multiple stakeholders (Bolton and Hannon, 2016).

2.4. Methods

This study began with a comprehensive review of the academic and grey literature on retrofit business models. The literature review identified a number of texts and reports¹⁷ that described the range of approaches to retrofit that are currently employed in the UK and EU

¹⁷ These texts were identified from Google, Google Scholar and Scopus using several search terms. Search terms included; retrofit business model, retrofit financial model, energy efficiency business model, retrofit intermediary, residential energy service contracts, community retrofit, co-operative retrofit, local authority retrofit, retrofit one stop shop, energy services agreement, residential energy performance contract, managed energy service agreement

(De Groote et al., 2016; Edrich et al., 2010; EST, 2011; Jankel, 2013; Kats et al., 2011; Kim et al., 2012; Koh et al., 2013; Mahapatra et al., 2013; Milin and Bullier, 2011; Straub, 2016; Sweatman and Managan, 2010; The Rockefeller Foundation and DB Climate Change Advisors, 2012). Five key *archetypes* of retrofit business models were subsequently identified, summarised in Table 3 and described in detail in Section 2.5. All these models currently exist in the EU, but some are much more widespread than others. The criteria for their differentiation were the five key business model components outlined in Section 2.3.

The literature review was followed by scoping interviews with eight prominent experts in the residential retrofit field (see ‘Expert scoping’ in Table A1 in Appendix A). The aim was to test the validity and representativeness of five archetypes and gain an overview of current practice in the UK and wider EU residential retrofit market. The selection of interviewees involved identification of the key organisations involved in the residential energy efficiency sector, including, academic, technical, advocacy and policy actors. Snowballing techniques were then used to develop contacts and source further interviewees (Kvale, 2008).

Building on the insights from the expert interviews, the business model framework was refined, and an interview protocol developed for practitioners from each of the business model archetypes, with the aim of including at least two representatives of each archetype (see ‘Practitioners’ in Table A1 in Appendix A). The sample was initially drawn from the UK but was expanded to include other EU Member States; including France, Latvia, and the Netherlands, to obtain representatives of the more innovative and less common archetypes. The interview questions were designed to develop a detailed understanding of the structure and operation of the business models and how this influenced their success in delivering residential retrofit. Both sets of interviews were supplemented by documentary analysis of publicly available reports, where available.

Each interview was recorded, transcribed, and coded using the NVivo 11™ software. This enabled detailed analysis of the responses, allowing common themes to be identified along with areas for further investigation. These methods were considered appropriate, given the need to develop a qualitative understanding of the role and importance of the different variables within the business model framework; as well to test the validity of the archetypes

through discussion with expert stakeholders (Kvale, 2008). The use of several case studies for each archetype allowed identification of their commonalities and to control for more idiosyncratic elements. It is recognised this method provides less granular detail than could be obtained from in-depth case studies and provides a less representative sample than could be obtained from a large survey. However, the chosen method is suitable for addressing the research questions given resource constraints.

2.5. Retrofit business models: five key archetypes

The following sections describe each of the five retrofit archetypes in turn. Each section provides examples of the archetype, identifies its distinguishing features and assesses how these characteristics influence the potential for delivering retrofits of residential buildings; particularly for whole-house approaches.

2.5.1. 'Atomised' market model

The *atomised market model* continues to be the primary model delivering residential retrofit in the UK. Through an offering based on estimated energy cost and carbon savings, this model involves individual retrofit measures and technologies installed by separate contractors. Customers source the individual measures, energy audits and finance separately, with the result that multiple customer interfaces, or points of contact are required for a whole-house retrofit. The offer of energy savings is based on modelled impacts of measures, and no guarantees are provided. Therefore, any finance package is based on estimated rather than guaranteed cost savings. The details of the model are illustrated in Figure 11.

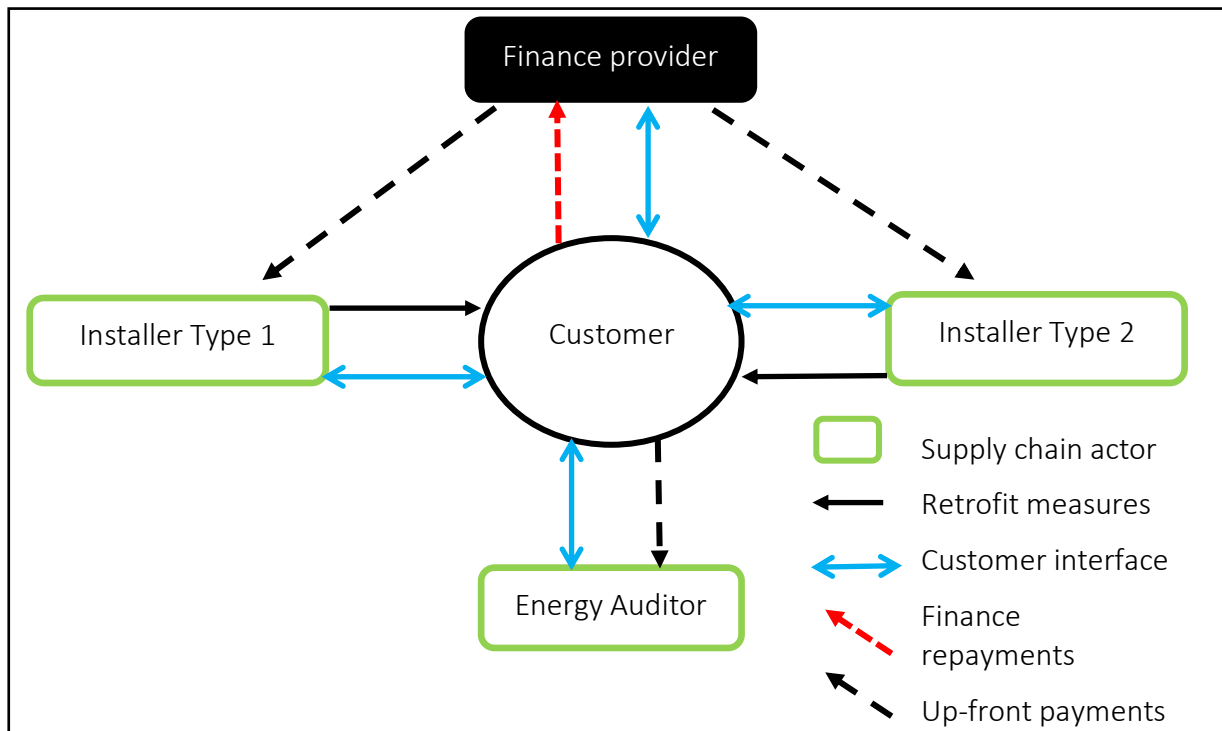


Figure 11 The 'Atomised' market model

Whilst a highly fragmented and market-based business model is the norm for many industries, interviewees agreed that this 'siloes' approach does not work well for whole-house residential retrofit.

"[Supply chain integration] is extremely poor; there has been a focus on single measures for the last 20/25 years. It is going to be hard to make the shift to a more comprehensive approach. Single measures have their place, but you want to have mechanisms to do more comprehensive residential retrofit." (Academic - energy efficiency policy-l#1)

This focus on single measures stems directly from the atomised and uncoordinated nature of the dominant model;

"what we've got in the UK is where the customer has to be this project manager...That's complex, it might work; for ringing somebody up when you boiler breaks down...[but] it's not the route for a....ramping up [of] energy efficiency measures" (Energy Saving Trust- l#3)

Such an approach has typified the delivery of the energy efficiency measures required and subsidised by UK policy; such as the supplier obligations and Green Deal, as well as the low carbon heat measures subsidised by the Renewable Heat Incentive (RHI), and microgeneration

Feed in Tariff (FIT). Thus, this approach has resulted in very few whole-house retrofits – instead tending to deliver a succession of piecemeal interventions at different times, linked to an ever-evolving policy landscape.

“We have tended to focus in the UK on subsidising installers, who do one thing; you can get a grant for doing x measures, get some carbon credits from the energy company...and that’s it. They don’t care about how it performs; they don’t care about how it actually impacts on the end user; they just go in and install one measure.” (Policy Advisor – UKGBC- I#2)

This model has not helped develop an effective supply chain for residential retrofit; particularly for SWI, which requires a more whole-house approach involving additional measures such as ventilation and draught-proofing.

“I’ve been around probably now over 3000 houses that have had external wall insulation and I haven’t seen any done right, and that is a fairly damning indictment of the industry...You have got industry-standard details which introduce cold bridging. There is no assessment of ventilation it is almost inevitable it’s going to go wrong.” (Director – BRE- I#4)

2.5.2. Market intermediation model

The *market intermediation model*, shown in Figure 12 is also a relatively common delivery model for residential retrofit in the UK and the EU. This model usually involves the implementation of government subsidy schemes, focused on single measures, and uses estimates of the associated energy cost and carbon savings from a basic energy audit. However, a key difference is the role of an intermediary organisation, who co-ordinate the supply chain and provide the customer interface through marketing activities and project management; thus, simplifying the *customer journey*. These schemes typically involve Local Authorities (LA) or NGOs who offer information, consultancy and procurement guidance to the client and may also offer a range of specialist services and financing assistance. If the intermediary is trusted by potential customers, their involvement can lower transaction costs, facilitate project implementation and help raise awareness of retrofit opportunities in the residential sector, building upon existing trusted relationships at the area or community level.

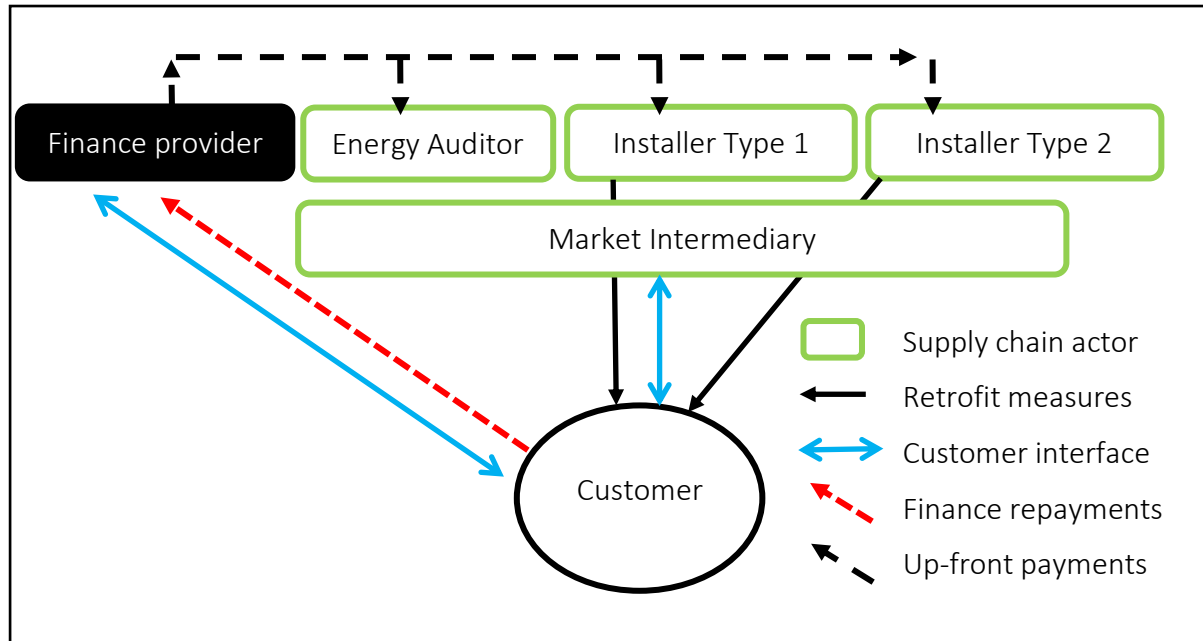


Figure 12 Market intermediary model

UK examples of this model include; the RE:NEW scheme implemented by the Greater London Authority (GLA); the Birmingham Energy Savers (BES) scheme, involving a partnership between Birmingham City Council and Carillion¹⁸ and the Nottingham Energy Partnership (NEP) an NGO initiative in Nottingham. These schemes commonly utilise relationships with local housing providers and LAs. The RE:NEW scheme has focussed on the social housing sector and has facilitated the retrofit of over 127,000 London homes, saving around 46k tonnes of carbon dioxide a year (GLA, 2017). The NEP scheme focuses on the privately owned and rented sector, with an emphasis on households in fuel poverty. Both these schemes owe their success to the trusted relationships between households and their housing provider, or council; *“working with the LA, it’s that trusted brand”* (Retrofit Intermediary- I#11).

By contrast the large-scale BES scheme was a major failure. This is in part attributed to the use of a multinational private sector partner for the marketing and delivery of measures to households, rather than using the councils branding and a local SME supply chain (Watson, 2014); *“There [was] a lot of installers who don’t deserve trust, I wouldn’t touch them with a bargepole”* (Sustainability Consultant – BES- I#12).

¹⁸ A large international construction firm, headquartered in the UK

RE:NEW have supported additional carbon savings above and beyond what would have otherwise occurred in the delivery of government and business-as-usual planned programs. *“The majority of organisations fed back [It’s been] faster, deeper and with less risk involved”* (Manager- RE:NEW – GLA- I#10).

However, these programs have done little to alter the underlying model of the industry and encourage the development of whole-house retrofit with an integrated supply chain; *“[in the end] it reverted to the piecemeal offer that we’ve identified is the problem”* (Sustainability Consultant – BES - I#12). The reliance on national subsidy schemes, where *“changes in policy mean that [the] model is ever changing”* (Retrofit Intermediary- I#11), also means that there is very little retrofit activity once these schemes have ended. This *stop-start* nature of funding is a key factor in the lack of a well-developed supply chain for whole-house retrofit in the UK. This may be changing, with schemes such as RE:NEW looking to support more novel value propositions and longer-term finance models (e.g. the Energiesprong approach discussed below). It was argued that, whilst future retrofit policy programs should recognise the importance of long-term industry led solutions, *“there is always going to be a role for intermediaries”* (Academic - energy efficiency policy- I#1) even where integrated business models are adopted.

2.5.3. One-stop-shop

The *one-stop-shop* business model (Figure 13) involves an integrated supply chain and customer interface that provides a single point of contact for the customer. The supplier offers a ‘holistic’ *design and build* including a comprehensive package of services, a more extensive modelling and design phase, the production of a comprehensive residential retrofit plan and the implementation of multiple complementary measures. Delivery of these is coordinated through either a single company or a well-integrated network of subcontractors. As shown in Figure 13, some business models also include finance as part of the offer, while several operate as co-operatives. The co-operative approach typically involves both suppliers and households as co-op members, who receive dividends on their equity investment in retrofit projects.

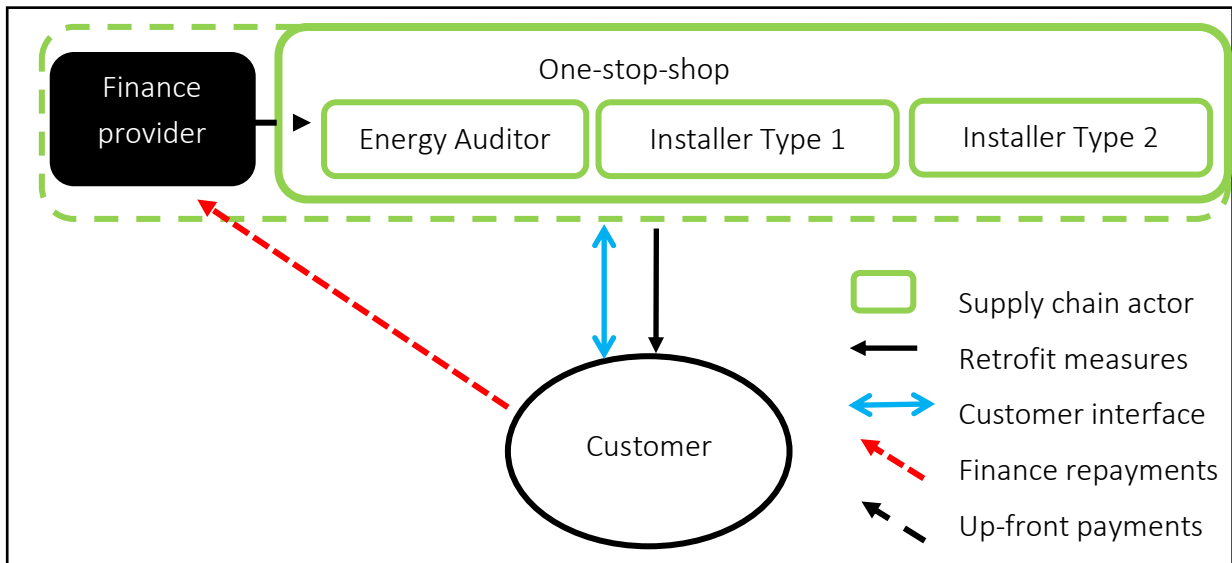


Figure 13 One-stop-shop

Although more established in Scandinavia (Mahapatra et al., 2013; Straub, 2016), the UK examples of this business model include the Retrofitworks project that utilises an online portal and co-operative approach to link suppliers to customers looking for retrofit, and home auditing services through its sister company Parity Projects. The Brighton and Hove Energy Services Co-op (BHESCo) also uses a co-operative approach and a low-cost financing offer based on issuing shares to the local community. A key emphasis in the business model is a focus on the needs of the client and a simplification of the customer journey. Segel AS - a consultancy providing specialist guidance on the implementation of one-stop-shops in continental Europe and Scandinavia, outline;

“The value proposition.....is a holistic retrofitting and single point of contact, easiness in the project, and project management...many of them also include help for the client in the application for grants...and confidence that the solutions chosen are right for [them]” (Segel AS - Business Consultant -I#14)

This approach typically facilitates whole-house retrofits and may be applied in conjunction with other forms of renovation. In several of the Scandinavian examples, local SMEs collaborate with a larger company such as Bravida¹⁹ or national hardware chains as a means of generating customers. In the case of Retrofitworks, the online portal is a key part of the customer interface

¹⁹ Bravida is an installation and service company with about 9000 employees at more than 160 locations in Sweden, Norway, Denmark and Finland.

where members of the co-operative can advertise works and have bids placed by the supply chain who are also co-operative members. Key to the success of these business models is the role of specialist *retrofit co-ordinators* or project managers;

“a person who understands what every element of the good retrofit looks like; isn't an expert in all of them but knows when they look dodgy or when an expert is needed to be brought in on certain things. So is about the genuine coordination...so I am a massive advocate of that and its built-in within...Retrofitworks.” (Retrofitworks/Parity Projects - I#13)

Whilst not all these examples offer financing, BHESCo combine their retrofit offering with a community share issue to provide a financing package to its customers.

“It's based on this virtuous circle, you become a member of the co-op,...you invest...,you get a 5% return on investment. We invest your money into...energy efficiency, the customer pays from the savings in their energy bill” (BHESCo -I#15)

At present the model is based on a hire purchase agreement²⁰ or what may be termed a *capital lease*, with the assumption that if the person moves they will see uplift in its value that will enable the lease to be paid off. However, offering competitive financing remains a challenge with considerable risk.

“Our...cost of capital is 5%, but we may have to consider whether we can offer that in the future... its very tricky and very difficult [to offer competitive finance]” (BHESCo - I#15)

2.5.4. Energy Services Agreement (ESA)

The ESA involves a form of ESPC, where building occupants are provided with an energy performance guarantee for specific energy services, usually over a period of 15 years or more. Instead of paying for units of heating fuel, occupants are guaranteed a level of performance such as a specified internal temperature (i.e. 21°C) and a certain volume of hot water at a specified temperature. Such an approach is synonymous with the ESCO model in that measures and the subsequent guarantee are provided by an ESCO, who are engaged as part of a long-

²⁰ Under an hire purchase agreement, the debtor hire the goods and then pay an agreed amount by instalments. While still making payments, the debtor isn't allowed to sell or dispose of the goods without the lender's permission.

term contract; with contractual penalties for under-performance. However, this model (Figure 13) differs from the more common examples in the public and municipal sectors (where the debt for the retrofit measures is taken on by the building occupants or tenant)²¹ as measures are financed directly by the ESCO, or upstream through a third party financier (The Rockefeller Foundation and DB Climate Change Advisors, 2012). These projects typically consist of an integrated offering; covering a whole-house retrofit of building fabric and heating measures, by a well-coordinated supply chain with *design, build and operate* phases under one contract. A whole-house retrofit is a likely pre-condition to offering a temperature guarantee, thus ensuring modelled savings are realised and energy consumption is controlled.

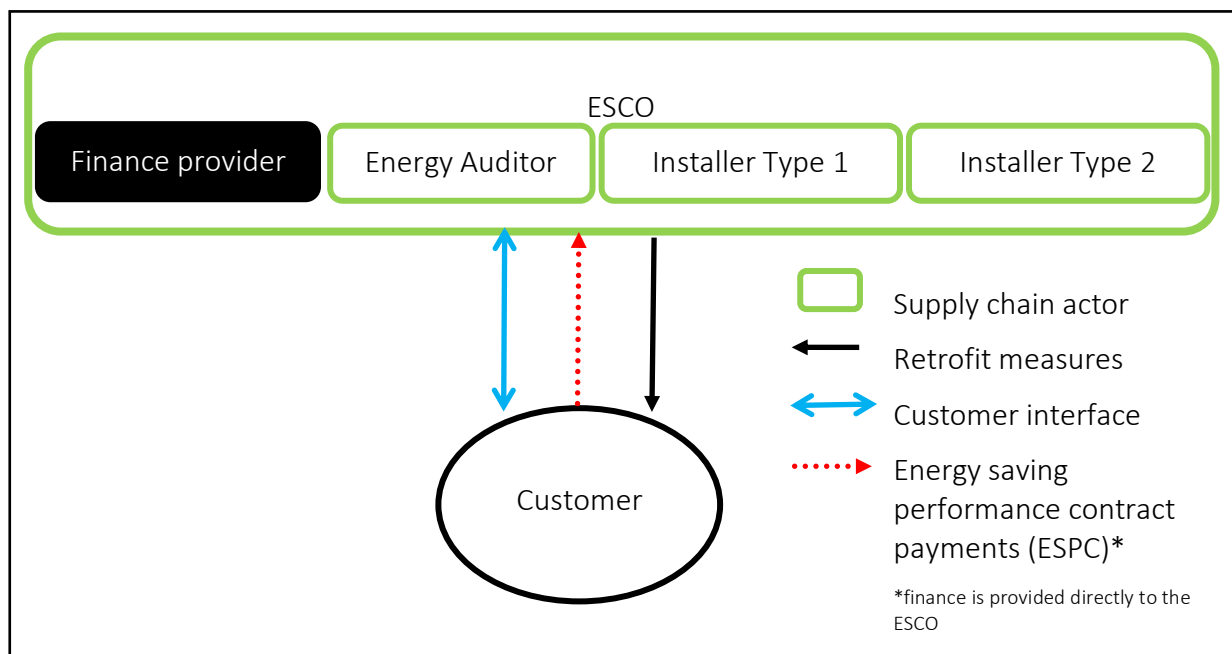


Figure 14 Energy Services Agreement (ESA)

The review did not identify any examples of ESA contracts for residential retrofit in the UK, but examples exist in France and Latvia. The French state-owned railway company SNCF also manages a significant number of social housing properties under its subsidiary; ICF Habitat. ICF have undertaken several schemes based on an ESA model, focused on medium-to-high-density multifamily buildings. The Energies POSIT'IF is an ESA model for privately owned or rented multifamily buildings in greater Paris. In addition, RENESCO is a social enterprise involved in

²¹ After significant desk based and interview research, the author could not find any examples of this business model in the UK or EU residential retrofit sector- thus it is excluded from the paper.

the retrofit of dilapidated multifamily buildings in former Soviet-era housing in Eastern Europe, particularly Latvia. The Latvian example is notable for its value proposition involving a focus on structural improvement as a selling point.

'We are not just conserving energy, our main task is conserving the building, we are protecting the building from the elements...about 15% of our total investment has nothing to do with energy efficiency' (RENESCO -I#17).

The risk of offering the ESPC is mitigated through a well-integrated business model *"This was possible because of one entity taking a decision and co-ordinating the investments [and works]"* (RENESCO-I#17). Such an approach means a single point of contact and recourse for the client: *"the main advantage of the [ESPC contract] is that we have only one firm to talk to"* (ICF Habitat-I#16). The successful co-ordination of the model therefore relies heavily on the design of effective contracts; *"we as a buyer have to make them talk together, so we have to design a process"* (ICF Habitat -I#16).

An important component of the ESA model is the *"bridge of finance and technology"* (RENESCO-I#17). Under the ICF Habitat model the capital is supplied by the housing provider, with the financial agreement upstream from the tenant. Whilst a large semi-public actor such as ICF can borrow at a relatively low cost of capital, RENESCO must source funds in private capital markets. RENESCO have chosen to use 'on balance sheet' finance, meaning the debt obligation is tied to the firm rather than the building owner. Based on their current cost of capital *"the renovation can be paid by the energy efficiency alone in 15 years"* (RENESCO-I#17). However, the economics of their offering are very sensitive to the financing terms, and the size of their portfolio. Therefore, RENESCO *"hope to sell off the cash-flows of the first 15 buildings"* (I#17) under a forfeiting scheme they are developing in collaboration with the European Bank for Reconstruction and Development (EBRD). This means that RENESCO can shift successful projects off their balance sheet, and sell them on to investors in secondary markets, improving their borrowing conditions.

"So, we get our equity back, we have our capital back, we can pay back the loan, we hopefully make a little bit of a profit" (RENESCO-I#17).

2.5.5. Managed Energy Services Agreement (MESA)

The MESA model (Figure 15) is like the ESA approach in that the ESCO provides guarantees for the energy performance of plant and building fabric measures, installed during a retrofit (Kim et al., 2012). However, in the MESA model the contracting organisation also takes on responsibility for the payment of the energy bill in an energy supply contract (ESC) upstream of the customer; to provide total energy management. This requires additional capability in energy supply and procurement. This also introduces a potential role for renewable electricity, storage and demand side management as part of the MESA. This level of integration also incentivises an integrated supply chain and represents a holistic energy services offering to the customer.

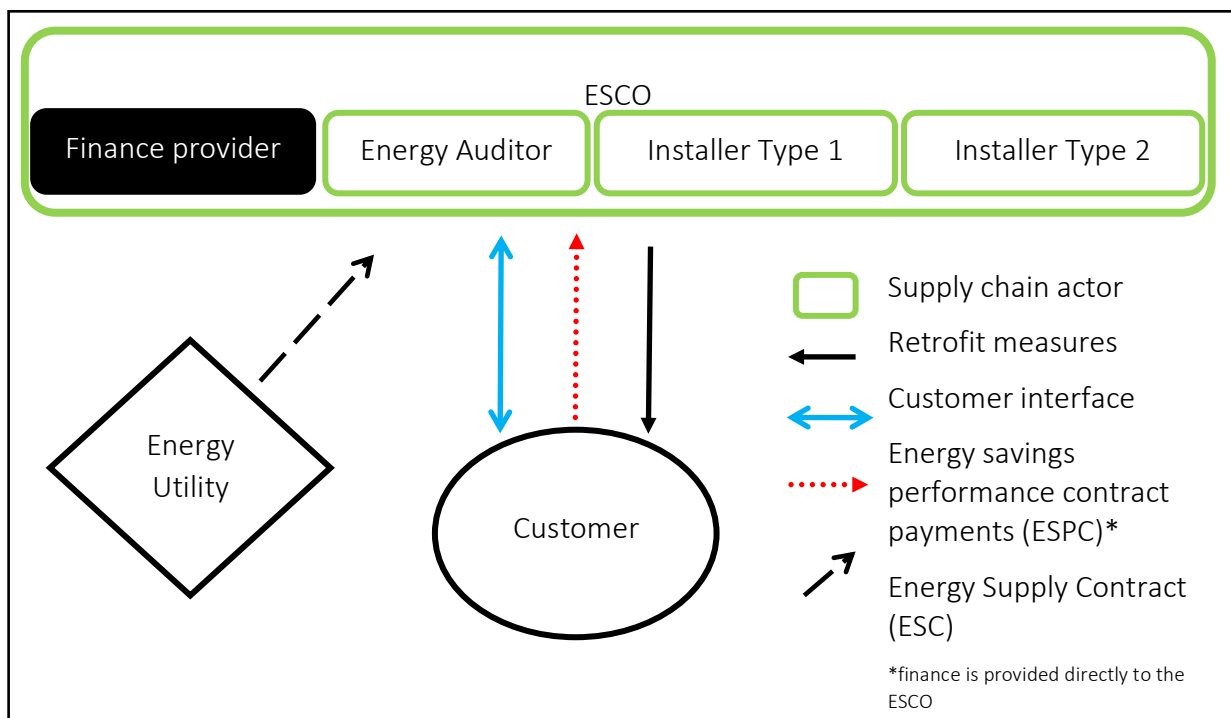


Figure 15 Managed Energy Services Agreement (MESA)

Whilst the MESA is more common in the commercial or public sector, the Dutch government has funded a large-scale trial of this approach in the social housing sector; known as the *Energiesprong* or 'energy leap' initiative (Energiesprong 2014). The scheme has thus far delivered approximately 1800 whole-house residential retrofits in the Netherlands; largely focusing on single family semi-detached or terraced units. At the time of writing the first UK

trial is about to commence in Nottingham (Energiesprong, 2017). This is the only known example of a MESA in the EU residential sector.

Energiesprong do not deliver the measures or the guarantee but instead their *market development team* acts as an intermediary between the client and contractor, providing technical assistance in implementation. Customers are offered a whole-house residential retrofit, based upon *net-zero energy* consumption. Typically, an Energiesprong retrofit involves the delivery of off-site manufactured, insulated facades, integrated with renewable heat systems and PV panels as well as lighting and controls. The contractor offers a 30-year energy performance guarantee for *net-zero* annual energy consumption, amortised over the calendar year. This is based on a guaranteed internal temperature of 21°C in living spaces, and a set allowance of hot water and electricity consumption; akin to a mobile phone contract with usage limits. A whole-house retrofit, with electricity microgeneration is a likely pre-condition to offering a net-zero energy guarantee, ensuring modelled savings are realised and heat and electricity consumption are controlled.

“The main premise of Energiesprong is an outcome-based procurement approach, specifying what it needs to do for the next 30 years; a long list of energy related measures; comfort, health and quality elements. So therefore, our approach is entirely technology agnostic” (Energiesprong UK-I#18)

Again, the value proposition emphasises the health, comfort and aesthetic benefits; ahead of energy cost savings.

“The quality of the design- the ‘kerbside appeal’ of the refurbished property...It is a complete envelope, so it gives an opportunity to redesign the property and uplift the value, not because of the energy efficiency economics, but the design improvements of the property” (Energiesprong UK-I#18)

The aim is to create demand through a desirable customer offering;

“it was new, it was exciting, and everybody looked at it. You had owner occupiers knocking on the door and saying, “Can I buy one of those?” So, it is really being able to see, to display the product, which is a brand new refurbished house” (Energiesprong UK-I#18)

The Energiesprong model requires significant process innovation, in the form of developing entire insulated facades using offsite manufacture techniques, to enable an installation time of less than one week. This process of mass production and industrialisation is key to enabling ESPCs for single family dwellings. Such an *industrialised* approach also drives down costs for SWI, which would otherwise be prohibitively expensive.

“So therefore, it is a challenge given to industry...because there is no technical specification, but an outcome-based specification it is more [like] a product design approach in industry; akin to automotive and other sectors.” (Energiesprong UK-I#18)

The Energiesprong MESA has thus far been applied in the social housing sector, and *“the financing model therefore is a combination...of maintenance, major repair works. And the additional revenue stream for thirty years from the energy plan that comes with the property.”* (Energiesprong UK-I#18). However, at present the net-zero energy retrofit is too expensive to enable a payback within the 30-year contract. *“The [current] market price for a 3-bed terraced property of 80 m² we would be looking at £70k. As a starting point, maybe a trajectory to £40k, £35k [is needed]”*(I#18). The Energiesprong UK team are hoping to build up a large order-book that would enable industrialisation of the supply chain and economies of scale. Currently the model is reliant on several sources of grant funding including the EU Interreg scheme. However, for long term economic viability, a cost of capital at <2% is also likely to be required.

2.6. Summary of findings

A summary of the five archetypes and how they differ in terms of the business model components is provided in Table 3. The results of the empirical study have provided insights into the characteristics of successful retrofit business models, including some generalisable findings that draw lessons from all five archetypes, summarised in Table 4.

Table 3 Business model archetypes and business model components

	'Atomised' market model	Market intermediation model	One-stop-shop	Energy services agreement (ESA)	Managed energy services agreement (MESA)
Value proposition The bundle of products and services that create value for a specific customer segment	Single measures Emphasis on energy cost savings Savings are estimated rather than guaranteed	As for 'atomised' market model	Multiple measures or whole-house residential retrofit common Emphasis on energy cost savings Savings are estimated rather than guaranteed Additional emphasis on home improvement and comfort	Multiple measures or whole-house residential retrofit required Emphasis on energy services of temperature and hot water volume Energy savings performance contract (ESPC) including performance guarantee for heat and hot water Additional emphasis on home improvement and comfort	As for ESA but with: Additional energy services of lighting and appliances, (ESPC) including performance guarantee for electricity consumption Energy supply contract (ESC) (gas, electricity)
Customer interface How are downstream relationships with customers structured and managed	Largely left to the market to promote and engage customers, with responsibility for the marketing and engagement for the different components (i.e. measures, finance) of the retrofit typically separated	One point of contact for the promotion, marketing and sales typically provided by an intermediary whom has no direct involvement in the retrofit itself Additional interface for finance	One point of contact for the promotion, marketing and sales of the full package necessary to achieve the retrofit, typically provided by the host company offering the retrofit package as a one-stop-shop	As for one-stop-shop	As for one-stop-shop and ESA but with: Potential for customer engagement through traditional energy supply retail channels

	'Atomised' market model	Market intermediation model	One-stop-shop	Energy services agreement (ESA)	Managed energy services agreement (MESA)
Supply chain How are upstream relationships with suppliers structured and managed	Largely 'siloed' relationship with traditional separated trades installing the retrofit measures in sequence with limited co-ordination	Greater co-ordination of overall installation, through quality assurance vetting and scheduling by the intermediary	Highly integrated package of measures, provided in house or through trusted subcontractors, greater scope for whole-house solutions Supply chain may require legal and finance skillsets	As for one-stop-shop but with: Additional contractor requirement for performance guarantee reducing likelihood of performance gap Supply chain requires legal and finance skillsets	As for ESA but with: Additional supply chain for energy supply required, can be through fully licensed supplier model or through a white label scheme
Financial Model How the retrofit is funded, by whom and how this is repaid to the lender	Finance is arranged via third party with little involvement in the retrofit process	As for 'atomised' market model	Finance may be provided and arranged by the retrofit provider, even where this is part of an upstream scheme	Lender developer / investor firms seeking to use ESPC/ESA structure to fund retrofits Lender captures energy savings and charges back to property owner based on historic consumption	As for ESA but: Supplier assumes responsibility for payment of energy bill
Governance Are the components of the business model provided by a single organisation, or a network, how is this co-ordinated and by whom	Highly networked arrangement of suppliers with little co-ordination between the various elements – this is largely left to the customer to manage	A network of separate suppliers, although the intermediary provides some co-ordination. Customer typically left to arrange finance and may engage in multiple contracts	The elements of the business model are delivered by a single organisation, who take responsibility for project delivery. Finance packages may also be offered by the supplier	As for one-stop-shop but finance is included upstream within the ESPC	As for ESA but also integrated energy procurement

Table 4 Main findings and application of business model framework

Business model component	Key findings
Value proposition: what value is embedded in the product/ service offered by the firm	<ul style="list-style-type: none"> Value proposition should place less on emphasis on carbon and energy cost savings. Focus instead on comfort, health benefits, aesthetics, building longevity and uplift in value Energy performance guarantees can be more attractive to customers and can help reduce performance gaps, although they add risk and cost for contractors
Supply chain: how are upstream relationships with suppliers, structured and managed	<ul style="list-style-type: none"> Integrated supply chains can improve quality and reduce unintended consequences, but the required holistic skillset is lacking in the UK due to highly 'siloesd' disciplines The role of a <i>retrofit coordinator</i> may therefore be an essential component for the successful delivery of whole-house residential retrofit
Customer interface: how are downstream relationships with customers, structured and managed	<ul style="list-style-type: none"> A single and trusted point of contact is very important, particularly for single family schemes Co-operative and community-based approaches offer a key means of customer engagement for retrofit Integrated supply chain or one-stop-shops can help but general lack of awareness of retrofit and customer engagement at all levels
Financial model: the nature of operational expenditures, and the means of revenue generation from the business activities	<ul style="list-style-type: none"> Low cost of capital is essential for the viability of long-term whole-house approaches due to the low rates of return Energy performance guarantees can reduce perceived risk for investors, and thereby lower cost of capital An integrated financing package provided with the retrofit is also likely to encourage customer demand
Governance: co-ordinating the business model may involve a multi actor network; spanning multiple organisations.	<ul style="list-style-type: none"> Successful retrofits involve the coordination of the various elements of the business model; this helps both suppliers and customers Networked approaches such as the 'atomised' market model are only suitable for single measures. Whole-house retrofit is better delivered through <i>integrated business models</i>; where the supply chain, customer interface and financial model are brought together as a co-ordinated offering The role of intermediary organisations i.e. municipalities or co-operatives likely to be crucial; particularly for novel business models

2.7. Discussion

The preceding sections have identified five business models for the delivery of residential retrofit and evaluated the potential of these models based on recent cases in the UK and EU. Previous studies discuss the emergence of one-stop-shop business models for single family homes (Mahapatra et al., 2013), and the potential of ESCO models in this sector (Moschetti and Brattebø, 2016; Winther and Gurigard, 2017), but have provided few empirical examples. This study builds on this work through identifying the Energy service agreement (ESA) and Managed energy service agreement (MESA) models involving residential ESPCs, along with the market intermediation model. These are contrasted with the incumbent ‘atomised’ market model that typifies most residential retrofits in the UK, and EU. The study thus contributes to the literature on residential retrofit by identifying and evaluating the broader range of business models in this area.

The findings in Table 4 support the argument that ESPC’s have a significant potential for energy saving in residential buildings (Steinberger et al., 2009). In addition, the study demonstrates the importance of an emphasis on comfort, health and wellbeing and the improved condition of the property as per the value proposition (Pätäri and Sinkkonen, 2014; Sunikka-Blank and Galvin, 2016). Supply chain integration (where multiple measures and design services are provided by a single organisation) is shown as critical for the delivery of whole-house residential retrofit; particularly for single family houses. This supports previous literature on one-stop-shop retrofit business models (Mahapatra et al., 2013; Mlecnik et al., 2012). Through this more integrated approach, performance gaps (Dowson et al., 2012) and negative unintended consequences; such as mould and poor air quality can also be minimised (Hansford, 2015). In turn this can strengthen the reputation of the industry and further simplify the customer journey. This contrasts with the highly fragmented and ‘siloed’ supply chains that have characterised most residential retrofit delivery to date.

The inclusion of financing options as part of the retrofit package may also be a critical driver. Whilst many UK suppliers are unable to provide financing, the more integrated businesses models; such as BHESCo and the ESA and MESA models include long term finance packages to cover the up-

front cost of measures. However, the associated cost of capital is critical in determining the economic viability of whole-house residential retrofit measures such as SWI (Gouldson et al., 2015). Indeed, the Energiesprong model is currently reliant on several forms of grant funding for its economic viability. While the existence of an ESPC is likely to reduce the perceived risk for investors, several other factors will also be important (Donovan and Corbishley, 2016).

Low customer demand is perhaps the biggest challenge for the upscaling of whole-house retrofit. A lack of visibility and knowledge of retrofit measures can be a key barrier (Marchand et al., 2015), as well as the hassle for the occupants (Snape et al., 2015). Indeed, retrofit interventions may also affect current practices in the home (such as heating behaviour), the inherent qualities of the property, and other competing needs and desires (Gram-Hanssen, 2014; Wilson et al., 2015). Retrofit measures are not typically differentiated from other renovation decisions (Wilson et al., 2015). Thus other renovations (such as bathroom replacement) may present opportunities for retrofit at certain points in a properties' life cycle (Achtnicht and Madlener, 2014). Occupants may also balance potential economic benefits of retrofits against building heritage and aesthetic concerns (Sunikka-Blank and Galvin, 2016).

This study shows that a business model with a simplified customer interface, with one point of contact for the retrofit process, reduces this complexity and may address barriers to uptake (Mahapatra et al., 2013). Examples, such as the Energiesprong scheme, utilise industrialised processes to reduce retrofit timescales and the visual upgrade of external facades, and could drive increased demand through 'kerbside appeal'. The role of intermediaries, or facilitators may be particularly important in promoting the uptake of novel business models (Bleyle et al., 2013); involving coordinated marketing efforts, capacity and trust building with energy agencies, supply chains, LAs, and the media (Long et al., 2015; Stieb et al., 2013).

If the business model is characterised as the network through which the product or service is delivered, the governance of this network becomes critical. This builds on other work that identifies the role of network governance in delivering energy service business models (Hellström

et al., 2015). The findings suggest that integrated business models are likely to be most suitable for whole-house residential retrofit, where the individual components of the business model are co-ordinated by a single actor to provide a simple and holistic offering to the customer.

At present these innovative business models are relatively rare, with the ESA and MESA models largely being trialled in multifamily buildings and social housing. With the UK's large share of private rented, owner occupier and single family housing (Element Energy, 2013), a significant challenge remains to scale up these models to impact the wider residential market. In the MESA example in this study, the ESPC is included into the rental agreement. In the owner occupier sector, this would supplant the energy supply contract, and would therefore require alterations to UK legislation surrounding the energy switching rights of consumers (Ofgem, 2016). The Dutch *Energiesprong* policy aimed to address the retrofit challenge and produce *business model innovation* (Energiesprong, 2017). This included a range of regulatory changes, public funding commitments and the establishment of a 'market development team', to promote a radical shift in industry practice (Energiesprong, 2017). Highlighting that a mix of policy solutions may be required to overcome the multifaceted challenges of whole-house residential retrofit and promote business model innovation.

This paper described the breadth of business models adopted for residential retrofit, including novel and innovative examples, using desk-based research and qualitative interviews. While this approach enabled a detailed understanding of each archetype, the smaller number of participants involved means the results are harder to generalise than quantitative results. The pre-testing of the framework with 'experts' was intended to prevent key approaches and elements being missed, although it is acknowledged this could introduce selection bias in the choice of interviewees. Equally, the use of in-depth case studies would have provided greater depth of understanding for specific approaches, at the expense of breadth. However, acknowledging these weaknesses, the approach adopted provides a balance between these factors, and is deemed appropriate for the research aims.

2.8. Conclusions

This paper has demonstrated how business models can be a useful framework for understanding the challenges posed by residential retrofit. The paper has identified five archetypes that are currently being used for residential retrofit within the EU, compared them in terms of their value proposition, supply chain, customer interface and financial model, and overall business model governance and showed how differences in these elements can help explain their relative potential in delivering whole-house retrofit.

The paper has shown how more innovative business models could expand the market for whole-house residential retrofits in the UK. Elements of a successful business model include:

- a value proposition focussed primarily upon aesthetics, comfort, health and wellbeing and includes guaranteed rather than estimated energy performance savings;
- an integrated and industrialised supply chain providing a whole-house approach;
- a simplified customer interface with a single expert point of contact;
- a financial model that includes a low-cost financing mechanism integral to the offering and;
- co-ordinated governance of these four components through an integrated business model

This is in stark contrast to the highly ‘atomised’, market-oriented approach adopted as the primary UK delivery model to date.

Two issues in particular, merit further research. First, the nature of the finance mechanism remains a key challenge, so further research should aim to identify how alternative mechanisms could enable long-term finance with a low cost of capital. Second, future work should identify the challenges of business model innovation in the sector, the barriers to such innovation and how both industry and policymakers can respond to these challenges.

There are multiple gains from whole-house residential retrofit, including health and economic benefits that go beyond energy and carbon savings. This paper has shown how viewing this

challenge through the lens of business models, can provide valuable new insights. What is clear is that the incumbent approach is not delivering the scale of change needed; which necessitates the rapid growth in comprehensive whole-house retrofit in a short period. Meeting ambitious carbon targets requires a sea change in the industry and the diffusion of innovative business models, such as those outlined in this paper. Achieving this will require new ways of thinking in both industry and policy.

3. Article 2: Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit.

(Pre-print published in Energy Policy)

Abstract

Improving energy efficiency, de-carbonising heating and cooling, and increasing renewable microgeneration in existing residential buildings, is crucial for meeting social and climate policy objectives. This paper explores the challenges of financing this ‘retrofit’ activity. First, it develops a typology of *finance mechanisms* for residential retrofit highlighting their key design features, including: the *source of capital*; the *financial instrument(s)*; the *project performance* requirements; the *point of sale*; the nature of the *security and underwriting* the *repayment channel* and *customer journey*. Combining information from interviews and documentary sources, the paper explores how these design features influence the success of the finance mechanisms in different contexts. First, it is shown that a low *cost of capital* for retrofit finance is critical to the economic viability of whole-house retrofits. Second, by funding non-energy measures such as general improvement works, finance mechanisms can enable broader *sources of value* that are more highly prized by households. Thirdly, mechanisms that reduce complexity by simplifying the *customer journey* are likely to achieve much higher levels of uptake. Most importantly we discuss how finance alone is unlikely to be a driver of demand for whole-house retrofit, and so instead should be viewed as a necessary component of a much broader retrofit strategy.

3.1. Introduction

CO₂ emissions from energy used in residential buildings result from space and water heating, and electricity used for cooling, lighting and appliances. These emissions constitute a significant proportion of total emissions in advanced economies (IPCC, 2014). Aside from more efficient appliances and behavioural changes, emissions from the existing building stock can be reduced by the *retrofit* of three main types of measure: improving the energy efficiency (EE) of the building fabric; adopting low carbon heating, ventilation and cooling technologies (HVAC); and building

integrated electricity microgeneration, such as solar photovoltaics (PV) (CCC, 2013). Thus, in this paper ‘retrofit’ finance potentially includes funding for all three types of intervention.

The Intergovernmental Panel on Climate Change have set ambitious goals for the retrofit of buildings (50% energy reduction from 2050 baseline scenario (IPCC, 2014)), to keep global temperature rises below 2°C as part of the 2015 Paris agreement. Since 1970 emissions from all buildings have more than doubled and in 2010 constituted around 19% of global carbon emissions (IPCC, 2014). Many retrofit measures deliver net cost savings or are cost effective²², when compared to other climate mitigation measures (CCC, 2018; IEA, 2017). However, delivering these ambitious targets, will necessitate increasingly comprehensive ‘whole-house’ retrofits, involving multiple integrated building fabric, HVAC, and microgeneration measures (Brown, 2018).

Delivering the 2°C scenario will require an estimated \$31Tn of investment in buildings globally over the next four decades (IEA, 2013). A significant proportion of historical energy efficiency measures has involved self-financing by firms and households (IEA, 2017; Webber et al., 2015). However, an important source of EE investment in recent years in both Europe and North America (12% of total) has come from market based instruments such as supplier obligation policies, paid for by a levy on electricity and gas bills (IEA, 2017). These policies have typically delivered single home retrofit measures (Rosenow, 2012).

Achieving sufficient ‘whole-house’ retrofits through supplier obligations alone could lead to significant increases in household energy bills (Kern et al., 2017), thus having a negative impact on low income households who do not undertake retrofit measures (Rosenow et al., 2013b). Whilst ‘fuel poverty’²³ objectives could be better achieved through general taxation (Rosenow et al.,

²² The UK’s Committee on Climate Change define the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes together with measures that may cost more than the projected carbon price, but are necessary in order to manage costs and risks of meeting the 2050 target (CCC, 2013)

²³ The definition of fuel poverty in the UK, is where fuel costs that are above average (the national median level), and these fuel costs leave a residual income that is below the UK’s official poverty line (DECC, 2013b)

2013b), there is a need for effective, repayable *finance mechanisms* for the ‘able-to-pay’ segments (Freehling and Stickles, 2016).

In this paper, finance mechanisms are considered distinct from targeted subsidies, supplier obligations (IEA, 2017), or fiscal incentive schemes such as property tax breaks (Rosenow et al., 2014). A finance mechanism is thus defined as the provision of capital for retrofit measures through equity and/or debt that is repaid to the lender (Leventis et al., 2017). A range of retrofit finance mechanisms have been developed, in the European Union (EU) and USA. The features of and reasons for success of these alternative approaches are the main focus of this study.

A comprehensive study of finance mechanisms for domestic retrofit is largely absent from the academic literature - with most studies published being non-academic, having limited consideration for the specific issues of residential buildings, or involving a different unit of analysis, such as supplier obligations (Rosenow, 2012). Further, an empirical investigation of factors that contribute to household appeal and the cost of capital is presently lacking. The role of different types of financing and their impact on projects remains somewhat of a ‘black box’ in the energy studies field more generally. This paper aims to open up the features of alternative finance mechanisms, and to understand the extent to which they can promote the uptake of whole-house retrofit -drawing on selected examples in Europe and North America.

This paper is structured as follows. Section 3.2 provides background to the context of residential retrofit and reviews the literature on retrofit finance. Section 3.3 introduces the conceptual framework for the features of finance mechanisms along with the cost of capital. Section 3.4 outlines the methodology. Section 3.5 introduces a new typology of retrofit finance mechanisms, while Section 3.6 describes how these mechanisms differ according to the framework. Section 3.7 discusses the findings. Section 3.8 concludes and provides recommendations for policy and research. A glossary of key financial terminology used in the paper is provided in Table B1 in the Appendix.

3.2. Background on finance, energy efficiency and residential retrofit

Residential retrofit produces a range of environmental, social and economic benefits, making it an important area for academic and policy research (Kerr et al., 2017). Energy savings from residential retrofit and a shift away from fossil fuel-based heating and cooling have the potential to significantly mitigate anthropogenic climate change. The IPCC (2014) estimate that, through improved EE, energy use from buildings could be stabilised by mid-century, compared to a current baseline where this is set to double. Thus, the EU has set a target of 27% improvement in EE by 2030 (EC, 2014) and the revised Directive for the Energy Performance of Buildings has set a near zero-energy aspiration for the existing building stock (EC, 2018). Residential retrofits have also been shown to improve occupant health and wellbeing (Curl et al., 2015; Willand et al., 2015), reduce fuel poverty (Sovacool, 2015) and lead to job creation and economic growth (EEFIG, 2015; Washan et al., 2014). Retrofit may also produce private benefits to households, including increased property value (Brounen and Kok, 2011; Fuerst et al., 2015), significant savings in energy bills and improved thermal comfort (Aravena et al., 2016; Gillingham et al., 2009). However, much of this potential remains unexploited.

The lack of investment in seemingly cost effective EE measures, is commonly termed the 'energy efficiency gap' (Jaffe and Stavins, 1994). Firms, public sector actors and households are seen to underinvest in EE, due to multiple 'barriers' that constrain uptake (Kangas et al., 2018; Sorrell et al., 2004). Although many factors that contribute to a low demand for EE are likely to be outside of what financing alone can achieve (Wilson et al., 2015), tailored financing solutions can make an important contribution to the uptake of retrofit measures (Rezessy and Bertoldi, 2010), particularly in the residential sector (Freehling and Stickles, 2016).

Historically, a large proportion of global investment in residential retrofit has involved either self-financing or energy supplier obligations (IEA, 2017). However, meeting the 2°C target will likely require third-party sources of finance (EEFIG, 2015), particularly as energy suppliers see their

market capitalisation shrink and attempt to de-leverage²⁴ their balance sheets due to declining revenues and market share (Blyth et al., 2015; Bolton and Foxon, 2015). Incumbent energy suppliers also lack incentives to fund EE investments, as their current business model relies on increasing throughput sales of energy (Knoeri et al., 2016). Existing financial institutions, such as banks and institutional investors, also remain reticent towards such investment due to an unfamiliarity with the technologies, regulatory risk, short investment horizons, high transaction costs and a lack of suitable finance mechanisms (Bolton and Foxon, 2015; Hall et al., 2015; Stone, 2014).

The United Kingdom's (UK) 'Green Deal' policy provides an interesting case of an innovative finance mechanism, intended to deliver approximately 2 million retrofit installations per year and leverage billions of pounds of investment. The scheme was based on private sector lending to households, paid back through a levy on energy bills—known as 'On-bill repayment' (OBR). However, the scheme only achieved a fraction of its target, and resulted in a significant loss to UK taxpayers before its premature scrappage in 2015 (Rosenow and Eyre, 2016).

A range of more successful retrofit finance mechanisms, however, provide some important lessons (EEFIG, 2015). Examples include the USA's Property Assisted Clean Energy finance (PACE) programmes (Kim et al., 2012); low cost loans delivered by the German KfW state bank (Schröder et al., 2011); other forms of On-bill-financing and repayment (On-bill) (Zimring et al., 2014a); green mortgages (Ecology Building Society, 2017); and state-backed guarantee funds (Borgeson et al., 2013). In addition, energy service agreements (ESA), where finance for measures is procured upstream by an Energy Service Company (ESCO) as part of an energy saving performance contract have been used in multi-family housing and commercial buildings (Labanca et al., 2014).

Yet, academic studies on alternative approaches to EE finance are largely absent from the energy and climate journals, with leading finance journals largely silent on energy issues in general (Diaz-

²⁴ Leverage involves the use of borrowed money: typically, the use of various forms of debt. Firms or projects may be considered over leveraged when their balance sheets excessive levels of debt compared to equity.

Rainey et al., 2017). The literature on ‘green finance’ has tended to focus on high level flows of energy finance (Mazzucato and Semieniuk, 2018), or the challenges of funding large renewable energy projects (Blyth et al., 2015). Hall et al. (2016) also highlight the challenges of financing distributed energy systems, where differing national institutional contexts influence the financial solutions available.

A handful studies have discussed the potential of alternative retrofit finance mechanisms, including potential revolving retrofit funds (Gouldson et al., 2015), the UK’s Green Deal (Marchand et al., 2015; Rosenow and Eyre, 2016), and the successful German KfW programme (Rosenow et al., 2013a). Others have explored how energy performance contracts could finance residential retrofit (Winther and Gurigard, 2017) but have not foregrounded the financial component of such models. Bergman and Foxon (Bergman and Foxon, 2017) discussed the challenges for reorienting finance towards EE in the UK and argue for a re-framing of EE as infrastructure financing. Previous work has also discussed the potential of novel financing solutions for overcoming the *split incentive* barrier (Bird and Hernández, 2012). But taken together, these studies provide only limited insights into what the features of a successful finance mechanism might be. This paper seeks to address this gap in the literature.

3.3. Features of a finance mechanism and the cost of capital

Access to capital and *split incentives* are a significant barrier to residential retrofit. Often household savings or conventional financing solutions, such as secured and unsecured loans may be unavailable, or unsuitable (Rezessy and Bertoldi, 2010). Many also face split incentives - where the benefits of an investment do not fully accrue to the investor (Bird and Hernández, 2012). The classic example is the pervasive ‘landlord tenant dilemma’, where energy savings accrue to the tenant, with the landlord making the investment. Homeowners may also face split incentives if they move out before their initial investment has been recovered and if the value of that

investment cannot be capitalised in the sale price. Thus, many conventional forms of financing²⁵ do not address split incentives (Bird and Hernández, 2012). In response, a range of retrofit finance mechanisms have been developed to overcome these barriers (EEFIG, 2015). Figure 16 summarises the conceptual framework of key design features of finance mechanisms, which are described in detail in Table 5.

²⁵ Conventional forms of financing such as home equity, credit cards, bank loans or conventional mortgages are excluded from this study. Whilst these approaches may be used to fund retrofit measures they are considered distinct from mechanisms designed to fund energy efficiency specifically - as the latter are designed to utilise the savings generated from the retrofit measures and in many cases to overcome specific barriers such as split incentives.

3.3.1. The features of a finance mechanism

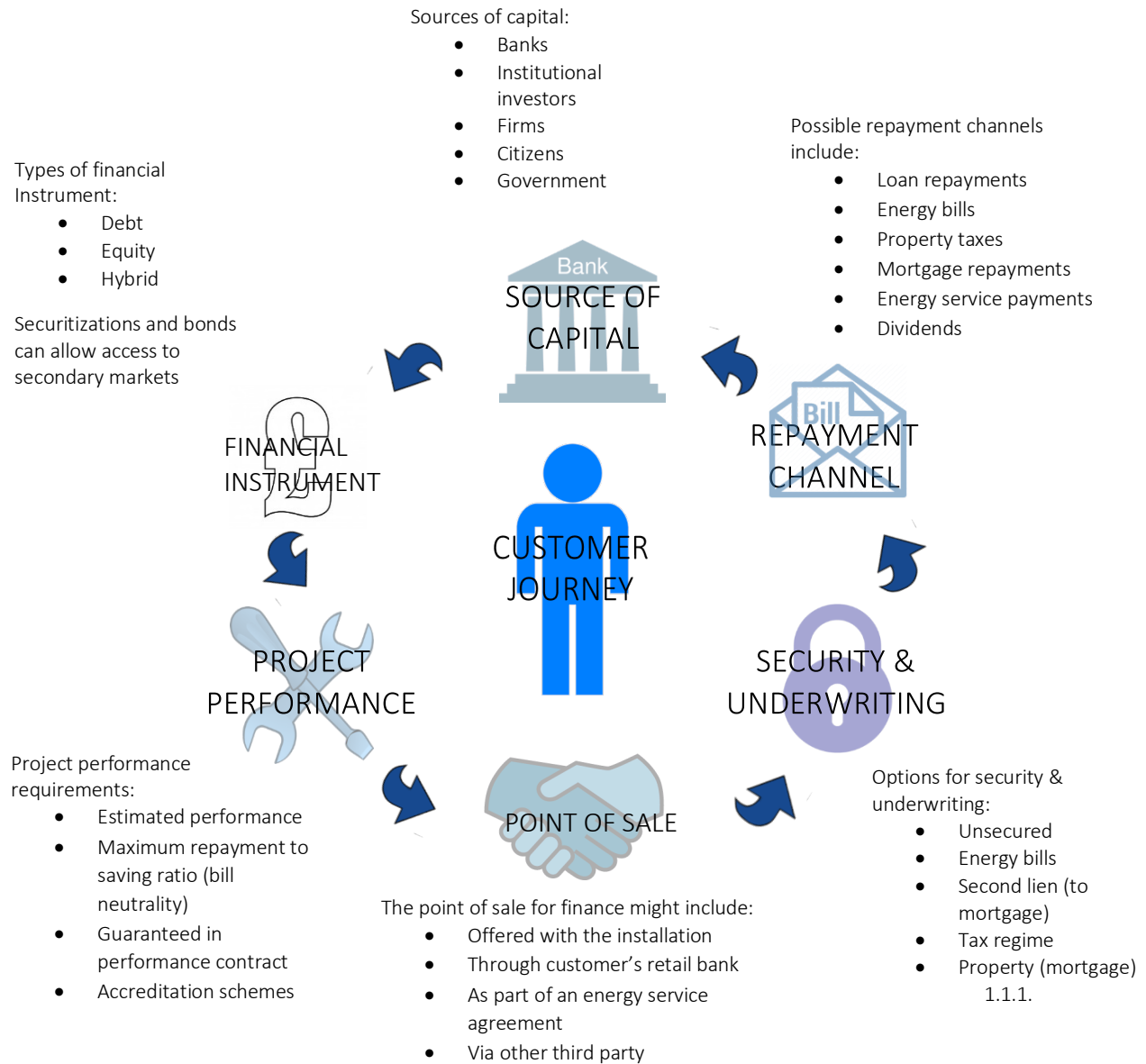


Figure 16 Process diagram of an EE finance mechanism

Table 5 The key design features of finance mechanisms

<i>Feature</i>	<i>Description</i>
Source of capital	<ul style="list-style-type: none"> Investment in EE may come from single or multiple sources. Banks, institutional investors, firms, governments or even citizens may provide financing. Debt is typically provided by banks and institutional investors, whilst other non-financial corporations may also provide loans (Buchner et al., 2015b). Equity providers tend to be different (although there is often overlap) and can include project developers, ESCOs, co-operatives, private investors/citizens and venture capital funds (Buchner et al., 2015a). Public bodies may provide all of the capital, or provide <i>credit enhancements</i>²⁶ including: junior²⁷ (high risk) debt with private finance providers providing the senior (low risk) debt (EEFIG, 2015); interest rate reductions (Gouldson et al., 2015); or credit guarantee funds – all with the aim of reducing risk, the cost of capital and leveraging private funding (Zimring, 2014a).
Financial instrument	<ul style="list-style-type: none"> Finance may take the form of debt or equity, or a combination of the two.²⁸ Debt finance typically consists of loans provided by financial institutions or equipment providers in the form of leases (Sorrell, 2005). Debt may be issued directly to the homeowner or upstream to energy suppliers, ESCOs or to a special purpose vehicle (SPV)²⁹ (Rezessy and Bertoldi, 2010). Securitisation³⁰ involves aggregating loans into tradeable ‘securities’, thus drawing in sources of capital who would normally only invest in larger projects (OECD, 2015b). Small scale loans to households can be aggregated and <i>securitised</i> and sold into secondary markets³¹, often in the form of bonds (Borgeson et al., 2013). Equity takes the form of part ownership or share issues. Stakeholder models such as cooperatives adopt largely equity based approaches (Walker, 2008),

²⁶ Credit enhancements are a set of approaches usually offered by public actors, which reduce lender or investor risk by providing some form of protection or guarantee in the event of default, bankruptcy or delinquency.

²⁷ Junior Debt is a loan or security that ranks below other loans or securities with regard to claims on assets or earnings. Junior debt is also known as a ‘Subordinated debt’ or subordinated loan. In the case of borrower default, creditors who own subordinated debt won't be paid out until after senior debtholders are paid in full.

²⁸ Many retrofit programmes may be partly based on grants or other public subsidies, however the focus of this study is to analyse the dynamics of the finance mechanisms, rather than the influence of grants or subsidy instruments on the underlying economic viability of retrofit measures.

²⁹ A special purpose vehicle (SPV) is a company with a specific and often short-term purpose, with a structure and legal status that allows the SPV to fail or go bankrupt without bringing down the wider organisations involved the transaction. They are designed isolate risk and allow organisations to finance projects ‘off balance sheet’.

³⁰ Securitization is a form of financial engineering where groups of illiquid assets are bundled together, often by aggregating multiple smaller securities, and transforming them into a tradable security in secondary markets.

³¹ A secondary market allows for securities (such as loans) to be resold, often in aggregation and are thus second hand.

	<p>although in commercial finance equity tends to be costlier³² than debt (Tapia, 2012), despite its theoretical equivalence (Modigliani and Miller, 1958). The majority of domestic retrofit schemes are debt-financed, although ESCOs may use their own equity to finance projects, as part of energy performance contracts (Leventis et al., 2017).</p>
<i>Project performance</i>	<ul style="list-style-type: none"> • The post intervention performance of EE retrofits is of critical importance to both financiers and building occupants. Evaluating the potential of a retrofit is likely to require an energy model and audit and ideally data on past energy consumption (Rezessy and Bertoldi, 2010). • Financiers may place a range of requirements on project performance. This may include requirements that measures are ‘cash-flow positive’ meaning that finance repayments are less than or equal to energy bill savings – often referred to as <i>energy bill neutrality</i> (Borgeson et al., 2013). • Savings-backed arrangements such as energy performance contracts include requirements for <i>actual</i> energy performance outcomes, such as kWh savings, guaranteed cost reductions or even guaranteed temperatures (Sorrell, 2005). • Financiers may also require projects to be standardised to best practice guidelines (Investor Confidence Project, 2015) or be accredited to industry quality standards (Bonfield, 2016). Alternatively, funders may place less strict requirements on energy performance outcomes, or enable wider non-energy measures to be funded (Borgeson et al., 2013).
<i>Point of sale</i>	<ul style="list-style-type: none"> • The point of sale is the interface through which the customer accesses finance. The nature of this interface has important implications for the <i>customer journey</i>³³ (Norton et al., 2013) for a retrofit project. • In many cases, finance has a separate point of sale from the contractor providing the retrofit measures. This may include the use of the customer’s existing bank (Schröder et al., 2011), a special mortgage product (Ecology Building Society, 2017) or an additional third party provider. In other cases the retrofit provider may offer an integrated finance package as part of the retrofit, or as part of an energy performance contract (Borgeson et al., 2013). • Previous studies have shown that the uptake of retrofit schemes is strongly influenced by how information is presented (Hoicka et al., 2014; Long et al., 2015); the nature of the financial rewards (upfront payments or long term savings) (Collins et al., 2018); and the channels through which the scheme is promoted (Mahapatra et al., 2013; Mlecnik et al., 2011).

³² Debt is senior to equity, so in a bankruptcy, the debt holders get paid before the equity holders. Therefore, equity providers (shareholders) require dividends that tend to reflect these higher risks with higher associated rewards and are often linked to project profitability.

³³ The customer journey is defined as the sequence of events that customers experience in order to learn about, purchase and interact with products and services (Norton et al., 2013).

<i>Security and Underwriting</i>	<ul style="list-style-type: none"> • Mortgages are secured by the financial institution's ability to repossess the home should a customer default on their loan (Borgeson et al., 2013). Other forms of security include property taxes or energy bills, meaning the threat of court proceedings or disconnection can be applied (Zimring, 2014b). • The <i>underwriting</i> process is how financiers determine the underlying credit-worthiness of the asset or borrower. Underwriting may be focussed upon the asset to which finance is secured (i.e. the historic repayments of property taxes or energy bills), or upon the borrower through metrics such as personal credit ratings (Leventis et al., 2017). Publicly funded programmes may place less emphasis on security and underwriting, particularly if they are targeting low-income households (EEFIG, 2015).
<i>Repayment channel</i>	<ul style="list-style-type: none"> • The repayment channel is how funds are repaid to the creditor or shareholders. A range of repayment channels exist for EE projects and are an important area for new policy and legal frameworks (EEFIG, 2015). • Repayments can be made through conventional personal or corporate loan repayments, through energy bills, service charges, collected via property taxes or through rent or mortgage repayments. • Equity returns are then distributed through dividends, although these may be contingent on the performance of the asset or company (EEFIG, 2015). Further, equity release models may only require payment once the property is sold (Scottish Government, 2017). Where repayments are linked to the underlying asset such as with property taxes or energy bills, this can enable transferability of the retrofit finance from one occupant to the next, thereby addressing split incentive problems (Borgeson et al., 2013).
<i>Customer Journey</i>	<ul style="list-style-type: none"> • The customer journey is defined as the sequence of events that customers experience to learn about, purchase and interact with products and services (Norton et al., 2013). Although individual elements of a finance mechanism influence the customer journey, the concept summarizes the household's experience of how these elements are integrated. • Complex or lengthy customer journeys have been shown to negatively impact the uptake of residential retrofit finance (O'Keeffe et al., 2016). Specific issues include poor integration with the timing of wider renovations (Fawcett, 2014), complex applications and limited information (Marchand et al., 2015), low trust in the provider (Risholt and Berker, 2013), and a lack of co-ordination with the supply chain (Brown, 2018).

3.3.2. The cost of capital

The cost of capital is of critical importance for determining the economics of capital-intensive investments, such as retrofit (Donovan and Corbishley, 2016). The cost of capital consists of the weighted average cost of debt (e.g. the interest rates attached to a bank loan) and equity (e.g. the

returns required by shareholders). Due to the effects of compound interest, the cost of capital has increasing significance for long term, capital-intensive investments (Donovan and Corbishley, 2016).

Figure 17 provides a simple illustration. Assuming a fixed repayment of £100/month and a loan maturity of 20 years, the figure shows the total amount that can be borrowed at 0%, 5% and 10% interest rates respectively. Whilst a household could borrow £24,000 (the principal) at 0%, this reduces to £14,954.65 at 5%, and only £10,216.27 at 10% - where at 10% the total interest is higher than the principal. Consequently, assuming fixed payments and loan term, the cost of capital limits the amount that can be borrowed and in turn the extent of the retrofit measures funded.

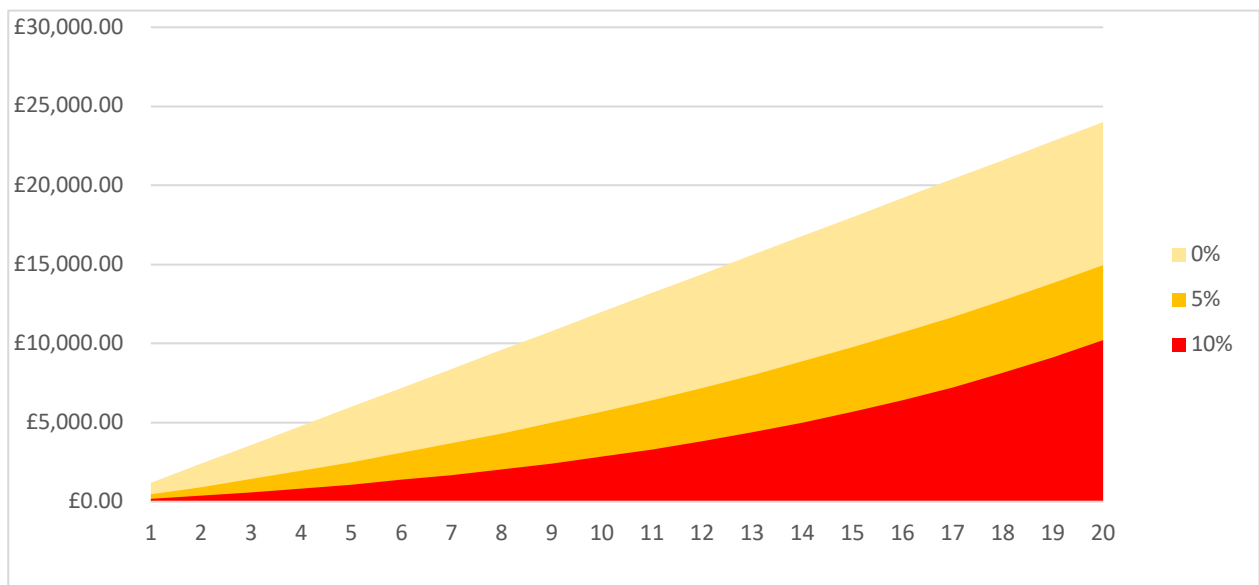


Figure 17 The impact of the interest rate on borrowing potential, assuming a fixed repayment and term

Previous studies show that the interest rates on loans can limit the appeal of retrofit finance mechanisms such as the UK's Green Deal (Marchand et al., 2015; Rosenow and Eyre, 2016), whilst low interest rates were an important success factor in Germany's KfW scheme (Rosenow et al., 2013a; Schröder et al., 2011). This high cost of capital is also likely to significantly limit the feasible range of retrofit measures that can be funded (UKGBC, 2014). However, Borgesson (2014)

question the extent to which the cost of capital is a barrier, emphasising how high interest credit card financing for retrofit remains prevalent in the USA.

3.4. Methods

This study takes a qualitative approach, involving analysis of interviews and secondary data, including a comprehensive review of the ‘grey literature’ on EE finance. Whilst there are few academic studies on the topic, numerous policy briefs, publicly commissioned studies and consultancy reports exist from a range of public, private and third sector sources. This review identified several texts with recurring descriptions of the key approaches to retrofit finance in both domestic and commercial buildings (EEFIG, 2015; EST, 2011; Investor Confidence Project, 2015; Kats et al., 2011; Kim et al., 2012; Sweatman, 2012; Sweatman and Managan, 2010; The Rockefeller Foundation and DB Climate Change Advisors, 2012; Zimring, 2014b). Examination of this literature led to the development of a typology of six *archetypes* of finance mechanisms used to fund residential retrofit in the EU and USA. For simplicity, some archetypes, such as public guarantee funds and state bank loans were aggregated under a single heading, whilst others, such as leasing, were excluded due to limited examples being available in the residential sector. This typology is summarised in Table 6 and described in detail in Section 3.5.

Subsequently, eighteen semi structured interviews were carried out, split into two phases: ‘expert scoping’ and ‘practitioner’ interviews. During Spring/Summer 2017, eight prominent experts (Appendix Table A1) in the EE finance community were interviewed. Several interviewees were authors in the key texts described above, notably the European Commission funded Energy Efficiency Finance Group report (EEFIG, 2015), whilst others were selected through personal contacts and snowballing techniques (Yin, 1994). The aim was to understand the key drivers and barriers for residential EE financing; which design features of a finance mechanism are most important; and why certain approaches are more effective. Information was also sought on how the policy and institutional context shapes the preference for and viability of different approaches.

Building on the insights from the expert interviews, a protocol was developed to interview







practitioners pertaining to each of the six finance mechanisms in the proposed typology. The aim was to include at least two representatives of each type, with the sample drawn from the EU and the USA. Many of the mechanisms under study, such as PACE, have only been adopted in certain USA states, notably California. Understanding both the mechanism's features and the policy and institutional context in which they operate is therefore important. Questions were designed to probe each of the design features of finance mechanisms (described in Section 3.3), and the drivers and barriers to the adoption of those mechanisms, including broader contextual factors. During Summer/Autumn 2017, ten semi-structured practitioner interviews (Appendix Table A1) were conducted.

Interviews were coded using the NVivo 11™ software, allowing common themes to be identified along with areas for further investigation. This qualitative approach was considered appropriate, given the need to develop a rich understanding of the role and importance of different features of finance mechanisms, and their broader contextual setting (Yin, 1994). The pre-testing of the framework with 'experts' was intended to prevent key approaches and elements being missed, although it is acknowledged this could introduce bias in the selection of interviewees.

3.5. Typology of retrofit finance mechanisms

Building on the review of grey literature, a number of distinct finance mechanisms can be identified. These approaches are distinguished by variations in the key features identified in Section 3.3. The range of approaches to financing residential retrofit was discussed during the expert scoping interviews, leading to the development of a typology of six archetypes of finance mechanism, namely, *public loan/credit enhancement*, *On-bill finance and repayment*, *property assessed clean energy financing*, *green mortgages*, *energy service agreement financing*, and *community financing*. The typology is described in this section and summarised in Table 6. The following types are drawn from prominent contemporary examples and their nomenclature reflects common terminology within the industry. The typology is ordered from the more widespread publicly funded approaches, to the more niche community financing. Some overlap exists between the different archetypes, with the possibility that hybrid forms may emerge.

Table 6 The key features of six archetypes of finance mechanism for residential retrofit

TYPE OF FINANCE MECHANISM	EXAMPLE SCHEMES	FEATURE OF FINANCE MECHANISM					
		SOURCE OF CAPITAL 	FINANCIAL INSTRUMENT 	PROJECT PERFORMANCE 	POINT OF SALE 	SECURITY AND UNDERWRITING 	REPAYMENT CHANNEL 
PUBLIC LOAN/ CREDIT ENHANCEMENT	HES and HEEPS equity loan (Scotland)	Government spending	Debt	Minimum saving CO ₂	Third party finance provider	No security - basic credit check	Unsecured Loan/ equity release
	KfW CBRP (Germany)	Public Bank	Debt (bonds)		Retail bank	No security - basic credit check	Unsecured Loan
	JESSICA-> LEEF (EU-> London, UK)	Hybrid – EIB, LEEF & Private lender	Debt		Housing provider	Varies	Revolving phase then full repayment
ON BILL FINANCING/ ON BILL REPAYMENT	UK (OBR) Green Deal	Third party private Sector	Debt	Bill neutrality (Golden rule)	Third party finance provider	Energy meter & bill history	Energy Bills
	USA & Canada (OBF) schemes	Energy Utility & public/ credit enhancements	Debt (some securitised examples)	Often Bill neutrality	Energy utility		
PROPERTY ASSESSED CLEAN ENERGY (PACE)	RE:NEW Financial (US)	Municipal bond -> private capital	Debt (bonds)	None - approved contractor schemes	Contractor	Lien on property & tax bill-based underwriting	Property taxes
GREEN MORTGAGE	EMF Green mortgage project (EU)	Covered Bond market	Mortgage (equity & debt)	EPC improvement	Mortgage provider	Detailed credit check	Mortgage payments
	Ecology Building society (UK)	Member deposits	Equity				
ENERGY SERVICES AGREEMENT	RENESCO (Latvia)	ESCO -> Public Bank	Debt & Equity	Energy Performance Guarantee	Contractor	Based on ESCO	Energy performance contract
	SEA (Italy)	ESCO -> Institutional investor				Based on ESCO & bill payment history	
COMMUNITY FINANCING	BHESCo (Brighton, UK)	Member share issue	Equity	None	Contractor	Credit check	Hire Purchase agreement-> dividends

3.5.1. Public loan/ credit enhancement

Public retrofit finance mechanisms typically involve low cost loans provided by governments, but may also include a range of credit enhancements to be blended with private capital (EEFIG, 2015). The most prominent example is Germany's CO₂ Building Rehabilitation Programme (CBRP). Germany's state bank, the KfW, provides loans to households arranged through commercial banks. Funds are raised on capital markets³⁴, and offered at very low rates of interest (>2%) (Rosenow et al., 2013a). The bank is able to offer these low rates primarily due to its AAA rating; a product of its public status, with additional state funding to further subsidise interest rates (Schröder et al., 2011). In 2007, the CBRP issued €5bn in loans, and the programme is estimated to have reduced carbon emissions from the existing building stock by 24% between 1990 and 2006, with an average of a 59% reduction per property in 2006 (Schröder et al., 2011).

Less well-known schemes are the Home Energy Scotland (HES) loan and Home Energy Efficiency Programme for Scotland (HEEPS) equity loans, funded by the Scottish government. Both programmes offer 0%³⁵ interest loans. The HEEPS equity loan is repaid upon the sale of the property. However, it is more common for public funded programmes, such as the HES and KfW loans, to be unsecured and linked to the individual rather than the property (Zimring et al., 2014a). Both the CBRP and the HEEPS equity loan schemes allow funding for wider renovation measures (Schröder et al., 2011), with the HEEPS equity loan allowing 45% of the maximum £40,000 to be spent on non-efficiency measures (EST, 2017).

Credit enhancements blend public money with private capital in a single fund. For example, the Joint European Support for Sustainable Investment in City Areas (JESSICA) programme, administered by the European Investment Bank, mobilises grants from European structural funds³⁶ (Rezessy and Bertoldi, 2010). Such mechanisms typically involve the low cost public

³⁴ Generally, these markets involve the trading of longer-term debt and equity instruments, typically with a maturity of a year or more.

³⁵ A small administration fee and inflation index linking is applied

³⁶ The European Structural Funds are a set of financial tools designed to address inequalities in income, wealth and economic opportunities within the Member states of the European Union.

capital occupying the junior (high risk) tranche³⁷ of a fund, which is then blended with private sources (Zimring, 2014b). This reduces risk for the private providers, with the public money absorbing the first losses should customers default. A prominent example is the London & Mayors EE Funds (LEEF & MEEF) (LEEF, 2012). Such schemes aim to leverage high ratios of private to public capital for EE investments with LEEF and MEEF raising £100m (50:50 private/public ratio) and £1bn respectively (70:30 private/public ratio) (Amber Infrastructure - £25). Other examples may include loan loss reserve funds and guarantees³⁸ or direct interest rate subsidies (Zimring, 2014a).

3.5.2. On-bill finance and repayment (On-bill)

On-bill mechanisms involve the repayment of loans via the energy bill (electricity, gas or dual-fuel). The investment is typically secured by the right to disconnect supply, if left unpaid (Zimring et al., 2014a). These approaches are divided into two types, with different sources of capital. On-bill financing (OBF) involves energy bill-payer or public funds, whilst On-bill repayment (OBR) refers to the use of third party, private capital (Zimring, 2014b). In the USA, UK and Canada over 20 On-bill programmes have provided over \$1.05Bn of financing to households for EE improvements, delivering \$76m in 2014 alone (Zimring et al., 2014a).

The UK's Green Deal is probably the most well-known example of OBR and included requirements for *energy bill neutrality* as part of its 'Golden rule', meaning savings had to be equal to or greater than loan repayments. The Green Deal also precluded non-energy measures from financing (7-11% interest rate). The scheme had very limited uptake. Of the 614,383 assessments undertaken, only 15,138 households adopted a Green Deal plan by October 2015 (DECC, 2015a), far less than the millions of installations that were hoped for (Rosenow and Eyre, 2016). However, in many cases these assessments may have led to self-financing (Webber et al., 2015).

³⁷ Tranches are different portions of debt within the capital structure of a fund or project finance structure that are designed to divide risk or group different characteristics such as rewards, maturity and size in ways that are marketable to various classes of investor. This typically includes equity components, junior and senior debt but may also include mezzanine and other hybrid forms of finance.

³⁸ A loan loss reserve or guarantee sets aside a limited pool of funds from which financial institutions can recover a portion of their losses in the event of borrower defaults. Several examples exist in the US including the Michigan Saves single family loan loss reserve scheme (Zimring, 2014a)

A range of other On-bill programmes in North America have been more successful. Manitoba Hydro's public OBF scheme has funded almost \$300m in efficiency improvements in single-family residences since 2001, although 95 percent of the loans have funded single-measure window, door or furnace replacements (Zimring et al., 2014a). Some smaller scale programmes, such as Clean Energy Works Oregon (CEWO) OBR private finance, have funded whole-house retrofits with loans of up-to \$30,000 (Zimring et al., 2014b). Several of these programmes offer reduced interest rates (0-5%) through public funds and credit enhancements, and have very low rates of default (0-3%) (Zimring et al., 2014a).

3.5.3. Property assessed clean energy (PACE)

PACE was developed in 2007 and allows municipalities in the USA to fund home and commercial retrofit using land-secured special improvement districts (Kim et al., 2012). These are debt instruments linked to a specific geographical area and secured by land or property. Traditionally they are a means of funding municipal infrastructure investments, through an additional charge on the property tax bill, common in the USA. The assessment districts were devised by Benjamin Franklin in the 17th century as a means to fund improvements that meet a 'valid public purpose'. (Energy Pro-I#23). Originally in PACE, local governments funded retrofit measures and attached a tax lien³⁹ (a form of security that allows claims on tax payments) to properties that benefit from the improvement works. Most PACE funding now comes from the private sector, although still uses the bond issuance and tax collection powers of municipal or local governments (Kim et al., 2012). The PACE financing is secured as a senior lien on the property and is re-paid along with other municipal charges and assessments, on the property tax bill - which provides investors with robust repayment security⁴⁰ (DOE, 2016).

³⁹ A lien is a legal right granted by the owner of property to a creditor to claim rights to or seize an asset that is the subject of the lien. The lien guarantees the underlying obligation to repay the creditor, such as claims against residential property for repayment of a loan.

⁴⁰ "Subject to the structure of a state's PACE statute...the PACE obligation may result in a property tax lien on the property. If applicable...the failure to pay property taxes, including PACE assessments, could trigger foreclosure and property loss even if the property owner is current on other mortgage lien(s)" (DOE, 2016)

Most residential PACE projects have been concentrated in California, with private providers such as RENEW Financial securitising PACE debt for re-sale to capital markets (RENEW Financial-I#30). Residential PACE financing has risen dramatically in recent years, facilitating more than \$4 billion in clean energy investments (Leventis et al., 2017), with RENEW Financial achieving an average 28-27% reduction in home energy use on their projects (RENEW Financial). There is currently no national or state requirement for energy bill neutrality within PACE schemes.

3.5.4. Green mortgages

Mortgage or home equity financing provides the mainstay of extension and renovation funding to existing homes, usually through a mortgage-extension or re-mortgage. Loans are secured to the property and typically have a duration of 25 years or more. However, some mortgage providers offer a range of Green or EE mortgage products designed to provide lending specifically for retrofit.

Mortgage underwriting is based on the applicant's ability to repay. Whilst a significant proportion of outgoings relate to energy costs, current underwriting methods use arbitrary techniques to determine these costs. Initiatives including the UK LENDERS (2017) and EU EeMAP (2017) projects are seeking to promote actual energy usage data in these underwriting calculations. Thus, lenders may provide increased lending for more efficient properties at reduced interest rates—as the higher disposable income reduces the risk of default (EeMAP, 2017). The LENDERS project estimates that monthly savings equivalent to two Energy Performance Certificate (EPC)⁴¹ bands, could equate to around £4,000 in additional mortgage finance (LENDERS, 2017). Eventually this may create a modest 'green premium', increasing property values for the most efficient properties (EeMAP, 2017), also providing additional borrowing for retrofit measures.

Whilst mainstream European mortgage lenders are yet to offer EE mortgage products, some

⁴¹ EPCs are a measure of a buildings energy efficiency and running costs, based on a standardised assessment procedure. Most EU member states employ some form of EPC and they are typically rated from A to G, with A being an exemplary dwelling.

specialist lenders such as the UK's Ecology Building Society offer both additional lending for retrofit projects and also interest rate discounts of 0.25% for each EPC improvement level (Ecology Building Society, 2017). In the USA, the Fannie Mae mortgage company's Green financing for multi-family buildings reached \$3.6 billion in 2016, involving preferential interest rates and additional borrowing for energy and water efficiency property improvements (Leventis et al., 2017). The UK government is now looking to promote 'innovative green mortgage products' as part of its Clean Growth Plan (HM Government, 2017).

3.5.5. Energy Service Agreement (ESA) financing

Energy service agreements (ESAs) are a form of financing to fund energy performance contracts. In a traditional energy performance contract⁴², the ESCO implements a retrofit and provides an energy performance guarantee and a commitment to maintain the assets under the contract for a given period. Energy performance contracts have been most common in the public sector, where public actors can access cheap capital and, thus, ESCOs typically provide engineering services without any financial component (Nolden and Sorrell, 2016). Recently energy performance contract and ESCO models have been growing in the small commercial and residential sectors (Labanca et al., 2014). Under an ESA, a finance provider will arrange financing directly with the ESCO or SPV (typically 7-10% interest), with the end user or household paying for measured performance improvements - usually derived from a baseline of past consumption (Kim et al., 2012). This effectively shifts the financing upstream from the household to provide an integrated offer of finance and measures through an energy service charge. In some models the ESCO will initially use its own funds and then sell on the cash flows or 'receivables' of proven projects to a third-party financier in a process known as 'factoring'⁴³ (EEFIG, 2015). In a pure ESA, the third-party financier will fund projects from the beginning, usually via an SPV, where projects are aggregated and sold into secondary markets to institutional investors (SUSI Partners, 2017).

⁴² In an energy performance contract without a financing package from the ESCO, the client will need to find other forms of capital to fund the retrofit. Therefore, this model is not considered a standalone finance mechanism and is not included in the study.

⁴³ Invoice Factoring involves the sale of project accounts and revenues (receivables) to a third party at a discount. This allows the issuing company to shift these projects with corresponding debt and future cash flows off their balance sheet - enabling them to deleverage and take on additional projects

Although in 2014, over \$150m of USA ESCO revenues were generated through projects in public housing, most this was funded using working capital from the housing provider rather than an ESA structure. However, since 2011 PosiGen have offered an ESA for residential solar and EE and completed 8,400 projects in the USA (Leventis et al., 2017). The model has also been gaining traction in Europe in the multi-family sector. RENESCO provide an ESA for the deep retrofit and renovation of dilapidated eastern European housing, while Servizi Energia Ambiente (SEA) offers ESAs and energy performance contracts to the Italian multi-family market. RENESCO have invested over €4m in 15 Soviet-era blocks and are developing a factoring fund with the European Bank for Reconstruction and Development (EBRD) (RENESCO 2015). SEA are currently negotiating to refinance several projects, with financing partners (SUSI Partners, 2017). Several large investment funds are now beginning to become involved in the ESA market, including the UK's Green Investment Group (2017).

3.5.6. Community Financing

Community financing mechanisms use equity capital from multiple individuals, each providing a small component of funding for a project. Often this involves groups organised around a local geographical area, adopting 'co-operative type' legal structures. Typically the number of shares (and votes) an individual can hold is limited (Yildiz, 2014). Projects are funded through a share issue. However, often these shares cannot be easily sold on, requiring long term commitment from project investors, who may value wider community benefits (Yildiz, 2014).

Community finance mechanisms are common for renewable energy, where in Germany, over 500 energy co-operatives with 80,000+ members have invested up to €800 million in solar PV (EEFIG, 2015). Yet, there are a growing number of examples of this being used to fund residential EE projects. The Brighton and Hove Energy Services Co-op (BHESCo) in the UK use a co-operative approach and a low-cost financing offer (5%) to fund retrofits, based on issuing shares to the local community with an annual return of 5% (BHESCo-l#15). A number of examples also exist in Germany (EEFIG, 2015).

3.6. Key features of retrofit finance mechanisms

The following section outlines the key findings from both sets of stakeholder interviews in relation to the features of these finance mechanisms as outlined in Section 3.3. The discussion draws upon insights from each of the archetypes of finance mechanisms described in the previous section, with the aim of identifying some more generalizable findings. A summary of relevant interview quotes for each feature of is provided in Table B2 in the Appendix.

3.6.1. Source of capital

Two interviewees felt that government should be the primary source of capital for residential retrofit. It was argued that the multiple social and environmental benefits of retrofits are ‘public goods’, justifying state financing. Equally, government bodies typically have the lowest cost of borrowing and are able to offer the longest term, lowest interest loans to the widest range of customers. It was emphasised that governments already absorbed significant risk in other areas, providing credit guarantees and low-cost loans for a range of sectors from infrastructure to first time house purchases.

However, most interviewees (eleven out of eighteen) considered that the required investment (~\$1.3 trillion to 2035 in the EU (EEFIG, 2015)) could not be met from public sources alone. Indeed, whilst many small publicly funded programmes utilised day-to-day government spending, (such as the HES and HEEPS loans in Scotland), scaling this up could be a challenge. Therefore, many stressed the need to bring in low-cost institutional capital⁴⁴. The only scheme to have achieved this at significant scale has been PACE in California, with ESA models being better developed in the commercial sector. Crucial to accessing these sources of capital is project standardisation and the use of aggregation or securitisation techniques discussed in the following sections.

Aside from PACE, leveraging significant private capital for residential retrofit has involved public co-financing and credit enhancement approaches. Programmes such as LEEF/MEEF and

⁴⁴ Institutional investors are a class of investor who trade in securities of sufficient scale and quantity that they qualify for preferential treatment and lower commissions. Typical institutional investors include pension funds and life insurance companies.

some On-bill schemes in the USA use public money to reduce risk for private investors. Through provision of the 'at risk' or junior tranche of a fund or project finance structure, these approaches are able to leverage significant sums of private capital and achieve high ratios of private to public investment.

Germany's CBRP programme is able to overcome the constraints on day-to-day public spending through the use of the borrowing powers of the KfW state bank. Thus, the programme is able to access large amounts of low-cost funding via the capital markets. However, five interviewees described how this approach owes a lot to the specific institutional context in Germany and similar approaches would require significant institutional change in countries such as the USA or UK, where no equivalent banks exist.

3.6.2. Financial instruments & secondary markets

Most of those interviewed agreed that the long term, low yield nature of retrofit investments lends itself to debt financing. However, BHESCo co-operative (I#15) emphasised that community equity finance mechanisms could also play an important role in empowering citizens to engage in retrofit at a local level. Community shareholders may also accept lower returns in exchange for local community and environmental benefits.

EnergyPro (I#23) in particular emphasised that accessing institutional investor capital is likely to require aggregated financial instruments, such as bonds enabling small loans to be pooled and traded in capital markets. Unlike central governments, state banks such as KfW are less constrained by national fiscal policy and deficit reduction as they are able to issue bonds directly into capital markets (Schröder et al., 2011). Equally EE mortgages can utilise the well-established 'covered bonds'⁴⁵ markets, which are used for trading mortgage securities (European Mortgage Federation-I#32). Private sector PACE programmes in the USA, have successfully aggregated multiple retrofit loans through securitisation and sold them as PACE bonds into the asset-backed securities market (RENEW Financial-I#30).

⁴⁵ Covered bonds are backed both by the issuer -usually a bank and the portfolio of projects -typically mortgages. Unlike asset backed securities they remain on the balance sheet of the issuer and are thus considered very secure.

Achieving sufficient *scale* was described by six respondents as the key challenge in accessing these secondary markets. Most institutional investors require minimum investments of at least £2m. Several examples of the ESA/energy performance contract approach have successfully sold on project receivables, often by aggregating several projects once the revenue streams or cash flows had been proven. Therefore, ESA models are an attractive means of bringing in institutional investors, although these models have so far only been used for the non-residential and multi-family markets. To appeal to institutional investors, achieving standardised projects, that can be aggregated and securitised was identified a key challenge by both Energy Pro (I#23) and the European Mortgage Federation (I#32). Ensuring and demonstrating project quality is therefore important for reassuring both investors and households, mitigating the issues associated with the securitisations of sub-prime mortgages during the 2008 financial crisis.

3.6.3. Project performance

Long-term performance contracts as part of ESA financing structures provide a clear revenue stream that can appeal to investors in a similar way to power purchase agreements for renewable generation. Whilst it was recognised that energy performance guarantees could also be a key driver for households, Joule Assets Europe (I#29) emphasised, this alone would not be sufficient to reassure private investors. Therefore, standardised procurement and quality assurance frameworks, such as the Investor Confidence Project (2015) for commercial buildings, were seen as important for attracting finance into residential retrofit.

However, requirements for energy bill neutrality such as the Green Deal's 'Golden Rule' was criticised by several interviewees. Such requirements prevent non-energy measures from being funded and obstruct deeper retrofits, particularly at high interest rates (Figure 17). For example, measures such as solid wall insulation could not be funded under the Green Deal. Restricting the focus to carbon and energy savings was also seen as a major constraint on household demand. Since customers value funding for general renovation work and aesthetic improvements, restricting funding to efficiency measures alone limits the appeal of the finance package. Mechanisms, such as the CBRP and the HEEPS equity loan and PACE to a lesser extent, allow for wider renovation measures to be funded. These schemes also do not impose strict

requirements for energy bill neutrality. However, it was noted that this needs to be balanced against affordability concerns for repayments significantly above current energy bills.

3.6.4. Point of sale

The point of sale for finance, and the ease and availability of procuring financing alongside the retrofit was viewed as critical by all interviewees. The analogy of the purchase of a car or mobile phone was used by several interviewees. In these mature sectors, suppliers provide a financing package as part of their offer to customers, whereas many retrofit programmes, require a separate interface, involving a long and complex application process. This is also usually separated from the process of actually procuring the retrofit measures.

The complexity of schemes such as the Green Deal, with a separate point of sale, is considered to be a major barrier. The success of PACE is partly attributed to the fact that approved contractors can offer financing through the scheme at the point of sale of the retrofit. This means that customers are able to procure the retrofit measures and financing on the same day and from the same person. This simplicity can dramatically increase uptake, although it requires a streamlined underwriting and approval process from the PACE loan provider, usually initially over the telephone. However, challenges remain with contractors' lack of literacy in financing, and financiers' lack of literacy in energy efficiency. Equally, Energy Programmes Consortium (USA) (I#5) emphasised that whilst USA contractors are able to promote certain financing packages, UK contractors must be accredited with the Financial Conduct Authority before they can provide such advice. Similar arrangements exist in other EU countries. These findings highlight the importance of the presentation of the finance offering to prospective households, the levels of trust in the finance provider and quality of information provided.

3.6.5. Security and underwriting

Different mechanisms require different forms of security and underwriting processes, whilst most public mechanisms are unsecured. Although there are some examples of private unsecured lending, this typically involves a high cost of capital for what is perceived as a high-risk loan without collateral. Both PACE and On-bill approaches involve novel forms of security, tied to the property tax regime and energy bills respectively. Theoretically this leads to

streamlined underwriting and draws in people with lower credit ratings - as the debt is secured to the underlying asset, rather than the individual. However, this is not always the case, with one interviewee (I#31) describing how it could take up to 60 days to get a Green Deal loan. Rapid underwriting and unconventional security can also raise concerns about the appropriateness of offering finance to vulnerable households who would otherwise not qualify for credit. EE mortgage models also require the inclusion of EPCs as part of the underwriting, although is unlikely to add a significant burden on already extensive mortgage eligibility assessments.

Thus, private sector funded mechanisms are likely to require a robust form of security or collateral in order to provide lending at lower interest rates (<10%). Publicly funded approaches offer greater flexibility on both underwriting and repayment terms so could therefore provide a good option for those in rented accommodation, on low incomes, with a poor credit history, or some combination thereof.

3.6.6. Repayment channel

The use of an existing repayment channel was viewed as a key benefit of the PACE, On-bill and mortgage-based approaches. Thus, adopting an existing bill that customers are unable to partially pay or refuse to pay the retrofit component of.

Both PACE and On-bill approaches are theoretically transferable to the new occupier of a property, addressing the split incentive issue - although currently PACE finance is only available to homeowners. Equally, mortgage or equity-release approaches such as HEEPS in Scotland, see the remaining debt resolved once the property is sold, through the equity share. Therefore, finance for measures that add value to the property strengthens the case for using mortgage-based financing. However, case studies from the USA have shown that the debt from PACE and On-bill schemes is transferred to the new occupant only about 50% of the time, thus requiring the outstanding payment on sale (Leventis et al., 2017). Further, both Energy Pro (I#23) and PACE Nation (I#31) highlighted how the PACE approach would be particularly challenging for the UK given its different system of property taxation and municipal finance.

3.7. Discussion

This paper introduced a typology of six financing mechanisms currently adopted for residential retrofit across the EU and USA. Developing a novel framework, the paper has further identified six key features of these mechanisms and shown how these contribute to the success or failure of the mechanism. The following section discusses the findings in the context of the literature on residential retrofit and EE finance. It is shown how the six features influence three outcomes that are critical for the successful uptake of residential retrofit: *cost of capital*, *source of value* and *customer journey*. The paper then discusses how the institutional and policy context of different states is likely to shape the viability of these approaches and the policy solutions required.

3.7.1. Cost of capital

The stakeholder interviews explored the significance of the cost of capital for the financing of residential retrofit projects, particular for more expensive, ‘whole-house’ approaches. The impact of the interest rate on household appeal has previously been highlighted by several studies on retrofit finance (Marchand et al., 2015; Rosenow and Eyre, 2016). Typically, deeper retrofits require capital expenditure of at least £15-20,000 (BEIS, 2017) and have payback periods of 20 years or more. Thus, in combination with requirements for energy bill neutrality, higher interest rates may prevent deeper (but ultimately necessary) measures like solid wall insulation from being financed. Although those with sufficient access to capital, or other forms of household borrowing may continue to self-finance retrofits (Webber et al., 2015), a lack of access to low cost finance remains a key barrier the uptake of residential retrofit. These higher costs may be offset by private benefits such as higher house prices (Brounen and Kok, 2011). However, the findings presented here suggest the customer journey and source of value have a greater impact on household appeal.

The results support the view that the state’s ability to borrow cheaply, absorb risks and deliver social and environmental benefits, provides a strong justification for public funding of investments such as residential retrofit (Stiglitz, 1993). However, given the scale of investment required, the extent to which day-to-day government spending alone can deliver this may be limited (Blyth et al., 2015). Therefore, countries such as Germany have funded large scale

investment through public banks, offering very low interest rates and favourable loan terms. This builds on previous research on the market-creating and shaping role that state investment banks can play (Mazzucato and Penna, 2016), particularly where such investments are seen as high risk by private finance (Mazzucato and Semieniuk, 2018).

However, in countries without state investment banks, more ‘market led’ solutions are often favoured (Hall et al., 2016). This paper has described several examples of using public money to leverage significant private finance and reduce the cost of capital through tools such as credit enhancements (see Zimring, (2014a)). These approaches can also bring in customers who would otherwise not qualify for credit (Zimring et al., 2014c). Whilst this may leverage limited public funds and reduce the cost of capital, some argue that this represents a public subsidy to private capital (Bergman and Foxon, 2017) or a socialisation of risk and a privatisation of rewards (Mazzucato, 2011). However, some form of public support is likely to be required for those with difficulty in accessing low-cost capital or in rented accommodation and fuel poverty (Sovacool, 2015).

Privately funded mechanisms are likely to require robust forms of security or collateral such as mortgage eligibility and repossession (EE Mortgages), property tax default (PACE) and energy disconnection (On-bill). These findings support work such as Blyth et al., (2015) and Hall et al., (2015) on the potential role of institutional investors, such as pension funds in the energy system. Securitisation enables small loans to be pooled and sold through financial instruments such as PACE bonds in capital markets. However, this requires sufficient scale and standardised project performance protocols currently only widespread in the PACE market and ESA’s in the non-residential sector. Therefore, widespread institutional financing of EE retrofit remains largely aspirational at present (Hall et al., 2015).

3.7.2. Customer journey

In interpreting the findings, this paper draws on the concept of the *customer journey* (Norton et al., 2013). Whilst the previous section largely concerned with how the features of finance mechanisms affect their appeal to investors, this research suggests the nature of customer journey has a greater impact on household appeal.

A key finding is that the success of schemes such as PACE and KfW's CBRP owe a lot to the ease of the customer journey in procuring retrofit financing. PACE loans are often sold by the contractor, at the point of sale of the retrofit. The streamlined underwriting of PACE programmes has enabled loans to be approved over the telephone, during the contractor's sales visit. Equally EE mortgages utilise a well-established process, which is usually essential when purchasing a property, whilst the KfW approach uses the customers' existing bank and support from accredited project managers. This simplicity is often valued ahead of a low cost of capital by households – helping to explain why expensive credit card retrofit financing remains prevalent (Zimring et al., 2014a).

These findings support previous critiques of the UK's Green Deal which involved a complex vetting and application process, requiring a separate interface with a third-party provider (O'Keeffe et al., 2016; Rosenow and Eyre, 2016). This complexity may be further compounded when additional policy measures interact with retrofit programs, such as the smart meter rollout (McCoy and Lyons, 2017) reducing household uptake. This supports arguments for *integrated business models* for residential retrofit (Brown, 2018), including a financing offer to households alongside retrofit measures (Mahapatra et al., 2013). In an ESA, financing is fully integrated into the energy performance contract, effectively upstream of the client (Brown, 2018).

An important dimension of the customer journey relates to how the information is presented to households and by whom. This research identifies the point of sale as the critical juncture in the customer journey in which to promote both the retrofit measures and the financing package in a clear and compelling way to households. This supports previous research which identifies the significance of how costs and benefits of retrofit are presented to households (Hoicka et al., 2014) and the importance of a trusted and competent advisor in disseminating this information (O'Keeffe et al., 2016; Risholt and Berker, 2013). Our findings therefore suggest that schemes are most successful, when the technical and financial elements of the customer offering are integrated by a single competent advisor - as is the case in the German KfW scheme (Rosenow et al., 2013a).

Adopting a repayment channel, and form of security that is tied to the underlying asset, theoretically enables PACE, On-bill and Green mortgage/equity release approaches to address split incentive barriers (Bird and Hernández, 2012). However, only On-bill mechanisms address the landlord-tenant dilemma. Yet, in many examples from the USA this has not been the case. Outstanding debt on properties with PACE or On-bill loans may need to be settled when homes change hands (Zimring et al., 2014a), although can be partially offset by increased property values (Sayce and Haggett, 2016). The latter, in turn, requires credible labelling schemes to allow the energy efficiency properties to be identified by potential buyers, together with more widespread appreciation of the benefits of energy efficiency for mortgage repayments.

3.7.3. Source of value

The study demonstrates how successful retrofit finance mechanisms typically involve funding for wider renovation and enabling works as part of the finance package. This builds on contemporary research on residential retrofit, where broader motivations such as environmental concerns, improved comfort and living standards, property longevity and aesthetics are often valued more highly than cost savings (Fawcett and Killip, 2014), or at least act as important drivers for retrofit projects (Kivimaa and Martiskainen, 2018b). Thus, in many cases, financing provides a means of ‘addressing a problem’, such as a broken boiler or low levels of thermal comfort. Whilst the desire to save money is often a driver (Marchand et al., 2015), households may be willing to spend more to finance these broader sources of value.

Consequently, mechanisms that have requirements for energy bill neutrality, or only fund energy measures are likely to undermine these motivations. Many of those interviewed regarded the ‘Golden Rule’ element of the Green Deal as a mistake and pointed out that no such requirements are in place for other forms of consumer finance. Equally the narrow focus on energy measures alone, may leave a finance gap for important enabling works. However, there is a need to balance these issues with concerns over affordability (Leventis et al., 2017). Other forms of project performance guarantees such as energy performance contracts, or warranties are however, likely to be valued by both households and finance providers. This supports recent work on the potential for energy performance contracts to be a demand driver

for residential retrofit (Brown, 2018; Winther and Gurigard, 2017).

Critically, all those interviewed agreed that barriers for retrofit financing were of secondary importance for driving demand for residential retrofit. Indeed Borgeson et al. (2014) describe: *'lack of financing is seldom the primary reason that efficiency projects do not happen.'* Thus, financing should be seen as an *enabler* rather than a driver of demand, with the analogy that in the Green Deal *'people were sold the loan instead of the car'* (Rosenow and Eyre, 2016).

3.8. Conclusions and policy implications

This paper presented a typology of finance mechanisms for residential retrofit, including examples that are delivering at scale. The paper develops a novel framework to understand the features of these mechanisms, including; the *source of capital*; *financial instrument(s)*, *project performance*; *point of sale*; *security and underwriting* and the *repayment channel*.

These features are shown to implicate three outcomes that affect the success of these finance mechanisms. Firstly, it is shown that a low *cost of capital* is key to the current economic viability of whole-house retrofits, such as those involving solid wall insulation. This can be achieved through public finance through state investment banks, municipal authorities or the blending of public and private sources through a range of credit enhancements. Alternatively, low cost private financing is likely to require robust forms of security, standardised project performance protocols and access to secondary markets through the aggregation of multiple projects into trade-able financial instruments. Secondly, and perhaps more significantly, mechanisms that reduce complexity by simplifying the *customer journey* are likely to achieve much higher levels of uptake. Thirdly, by enabling non-energy measures such as general improvement works, schemes can appeal to broader *sources of value* that are more highly valued by households, often 'addressing a problem', such as broken boiler or low levels of comfort.

Most importantly, the paper outlines how the finance mechanism alone is unlikely to be a driver of demand for whole-house retrofit, and so instead should be viewed as a necessary *enabler* of a much broader strategy. Thus, integrated business models that enable the wider

benefits of whole-house retrofits, alongside a range of up-front incentives and minimum standards are likely to be pre-requisites of a successful, ambitious retrofit programme. Consequently, a review of different retrofit incentives and investigation of how policy can support business model innovation, seem important avenues for further research.

This paper has emphasised the scale and importance of financing the low carbon retrofit of residential buildings. Different countries and regions may adopt different approaches based on their specific institutional context, with different approaches serving certain market segments. However, this goal is unlikely to be achieved without a broad strategy to promote demand and build supply chain capacity - only then requiring appropriate financing solutions. This paper presents a template of how this can be done effectively and provides lessons from where it has not.

4. Article 3: How intermediaries promote business model innovation: the case of 'Energiesprong' whole-house retrofits in UK and the Netherlands

(Published in SPRU working paper series (SWPS))

Abstract

Business model innovation is increasingly important for the diffusion of sustainable innovations, particularly those that are *systemic* in nature. In this paper we outline how systemic innovations - such as whole-house energy 'retrofit', may require new business models before they gain widespread adoption. Through a series of semi-structured interviews and document analysis, we undertake a case study of the 'Energiesprong' retrofit business model - contrasting this with the incumbent 'atomised' market model. We highlight the central role of an *innovation intermediary* - the Energiesprong 'market development team', in this business model innovation, and how Dutch policymakers sought to promote business model innovation through creation of this intermediary. In doing so we develop a novel framework - combining the components of business models with the functions of intermediaries to illustrate this case. Finally, the paper suggests this case and framework could provide lessons for how intermediaries and in turn policymakers might foster business model innovation in other sectors.

4.1. Introduction

The concept of the 'business model' has gained widespread use: as a means of classifying different businesses; a lens for academic research; and as an entrepreneurial tool for management practitioners (Baden-Fuller and Morgan, 2010). Increasingly the role of the business model is seen as critical for the diffusion of technological innovations (Baden-Fuller and Haefliger, 2013; Teece, 2010) and in sustainability transitions (Bidmon and Knab, 2018; Bolton and Hannon, 2016). This has led to a focus on 'business model innovation' as an important area for both incumbent and entrepreneurial firms (Chesbrough, 2010), in promoting sustainability, and in addressing climate change (Boons and Lüdeke-Freund, 2013; Sarasini and Linder, 2018). Thus, the governance of 'sustainability transitions' may require new policies that foster business model innovation (Bolton and Hannon, 2016). However, very little has been written on how policymakers might actually promote business model innovation. In

this paper we argue that one approach is the support of innovation intermediaries (Kivimaa, 2014; Mignon and Kanda, 2018).

To advance this argument, we make three propositions. First, we argue that business model innovation may be particularly important for ‘systemic innovations’ – those which require integration and configuration with other complementary processes, practices and technologies, within a system that spans the boundaries of individual organisations (Midgley and Lindhult, 2015). Second, we build on the literature on innovation intermediaries (Kivimaa and Martiskainen, 2018a; Stewart and Hyysalo, 2008), and highlight the important role that these actors can play in business model innovation. Third, by developing a novel framework we suggest that policymakers can promote business model innovation through intermediaries to facilitate systemic change (Lente and Hekkert, 2003). We illustrate these ideas through the case of the Dutch Energiesprong initiative for whole-house retrofit - addressing the following research questions:

1. How can business model innovation enable the diffusion of systemic innovations such as whole-house retrofit?
2. How did an innovation intermediary promote the Energiesprong business model?
3. How might policymakers promote business model innovation for sustainability through innovation intermediaries?

Buildings, especially homes, are the largest single consumer of energy and producer of carbon emissions in most advanced economies (IPCC, 2014). These emissions can be reduced⁴⁶ by the ‘retrofit’ of three types of measure: energy efficiency improvements to the building fabric; the adoption of low carbon heating technologies; and electricity microgeneration such as solar photovoltaics (PV). Thus far, significant savings in the European Union have been achieved through incremental measures such as fluorescent lightbulbs, loft insulation and efficient boilers (Rosenow et al., 2016). These measures have been implemented through existing supply chains, requiring limited changes in consumer and industry practices.

⁴⁶ Aside from more efficient appliances and behavioural changes

However, it is increasingly recognised that this approach will be insufficient to achieve the savings required to meet climate change targets (CCC, 2018; IPCC, 2014). Instead, emphasis is placed on the need for ‘*whole-house retrofits*’ involving multiple measures (Lewis and Smith, 2013). This involves the effective integration of multiple measures and systems and consideration of how they interact within a specific building - whether installed at once or over time (Fawcett, 2014). Thus, having the features of ‘integrative’ as opposed to ‘modular’ technologies (Sanchez and Mahoney, 1996). Recent research indicates that the diffusion of whole-house retrofit may therefore require business model innovation (Mlecnik et al., 2018) as well as significant policy support (Rosenow et al., 2017b).

In this paper, we contrast the incumbent ‘atomised’ market model with the innovative ‘Energiesprong’ business model – considered to have greater potential for the delivery of whole-house retrofits. Drawing on in-depth interviews conducted in the UK and the Netherlands to formulate a case study; we outline how the Energiesprong business model was developed by an *innovation intermediary* or ‘market development team’. Initially created by the Dutch government, although now operating independently internationally. We suggest this approach could provide a template for policymakers looking to promote business model innovation in other sectors – requiring further research to other contexts.

This paper is structured as follows. Section 4.2 reviews the literature on systemic innovation, business models and innovation intermediaries; emphasising the lack of research on policy support for business model innovation, before outlining the conceptual framework in Section 4.3. Section 4.4 summarises our case study methodology. Section 4.5 describes the operation and potential of the atomised market and Energiesprong business models and Section 4.6 assesses the role of the innovation intermediary in the emergence of Energiesprong. Section 4.7 discusses these findings in light of the existing literature on business model innovation, systemic intermediaries and innovation policy, while Section 4.8 concludes and provides recommendations for further research.

4.2. Systemic innovation, business models and innovation intermediaries

4.2.1. Systemic innovation and whole-house retrofit

The literature on systemic innovation is increasingly the point of departure for scholars grappling with the innovation policy challenges of the 21st century. Systemic innovations require complementary changes in supporting technologies, technical skills, cultural norms, user competences, organisational practices and regulations (Midgley and Lindhult, 2015). Systemic innovation may therefore result in entirely new ‘socio-technical systems’ - where technological, social and institutional elements co-evolve; resulting in whole system change (Foxon, 2011; Midgley and Lindhult, 2015). The importance of systemic innovation and its role in economic and sustainable development is recognised by the Organisation for Economic Co-operation and Development (OECD), who provide the following definition:

“System innovations...alter existing system dynamics...entailing changes in both the components and the architecture of systems. They are characterised by three main features:

- 1) disrupting or complementary types of knowledge and technical capabilities;*
- 2) fundamental changes in consumer practices and markets; and*
- 3) novel types of infrastructures, institutional rules and skill sets.” (OECD, 2015a).*

Many of the sustainability challenges facing policy makers require systemic innovation (OECD, 2015a) in a range of systems, from: food and agriculture (Klerkx and Leeuwis, 2009); healthcare (McMahon and Thorsteinsdóttir, 2013); transport (Nykvist and Whitmarsh, 2008); buildings (Mlecnik, 2013); and energy provision (Foxon et al., 2005). Systemic innovations contrast with incremental innovations; where gradual improvements in current technologies, processes or infrastructures can be easily adopted by incumbent actors, with little change required in underlying processes and practices (Mlecnik, 2013).

Whole-house retrofit is perhaps an archetypal example of a systemic innovation (Mlecnik, 2013) - needing complementary developments in regulations, financing, supply chain competences and household practices (Wilson et al., 2015), all requiring policy and institutional changes to be fully and effectively realised (Brown et al., 2018).

4.2.2. Business model innovation and sustainability

Business models⁴⁷ describe of the nature of value delivered to customers, how organisations and networks create value and the means of capturing revenues from that value (Hellström et al., 2015; Teece, 2018). Whilst the innovation studies literature focusses primarily on technological artefacts, there is growing recognition of the integral role of accompanying business models -particularly for radical, path breaking or systemic innovations (Chesbrough, 2010). Although the majority of studies on business model innovation originate from the business and management literature (Massa and Tucci, 2013), the concept is increasingly prevalent in sustainability research (Boons et al., 2013). The importance of sustainable business model innovation is emphasised by Budde Christensen et al., (2012, p. 499):

“it might be that innovative technologies that have the potential to meet key sustainability targets are not easily introduced by existing business models within a sector, and that only by changes to the business model would such technologies become commercially viable.”

Hence, the economic, environmental and social value of innovation often remains latent, until commercialised through a complementary business model (Bohnsack et al., 2014). Radical innovations, which present challenges in capturing revenues, often pose the greatest need for new business models (Teece, 2010). Thus, business model innovation may be a particularly important component of systemic innovation (Boons et al., 2013). Incumbent business models may also be incompatible with long term sustainability and the direction of technological change (Roome and Louche, 2016). Business model innovation therefore presents two key opportunities; first to enable the diffusion of sustainable innovations, and second to reconfigure existing industries towards more sustainable practices (Massa and Tucci, 2013; Schaltegger et al., 2016). Recent studies therefore highlight the potential for integrated business retrofit business models (Brown, 2018; Mahapatra et al., 2013; Mlecnik et al., 2018) and energy performance contracts⁴⁸ in the residential sector (Brown, 2018; Mcelroy and Rosenow, 2018; Winther and Gurigard, 2017).

⁴⁷ A more detailed definition used in this paper is provided in Section 3.

⁴⁸ Energy performance contracts include guaranteed reductions in energy consumption or costs for the client

However, organisations may face a range of barriers to business model innovation (Stubbs and Cocklin, 2008), including the ‘dominant logic’ of a firm or industry (Chesbrough, 2010) and wider cultural and structural barriers which have ‘co-evolved’ with incumbent business models (Bohnsack et al., 2014; Hannon et al., 2013). Organisations may thus lack the necessary knowledge, capabilities or complementary assets to innovate their existing business models, or enter new markets with new business models (Teece, 2018, 2010, 1986). These barriers and benefits may provide a rationale for policy intervention (Jaffe et al., 2005).

However, existing literature provides limited insight as to how business model innovation might be governed (Bolton and Hannon, 2016). Innovation intermediaries have been shown to overcome barriers to systemic innovation (Lente and Hekkert, 2003) with others emphasising policies to promote these intermediaries (Kivimaa, 2014). Although some have studied intermediation in the retrofit context (Kivimaa and Martiskainen, 2018b) few have linked these ideas to business models.

4.3. Intermediation for business model innovation

In this section we integrate the literature on business models, with that on innovation intermediaries to develop a new conceptual framework. We first outline the detailed components of business models before introducing the literature on innovation intermediaries. Due to the challenges of business model innovation, we argue that innovation intermediaries may be important in the creation and adoption of new business models.

4.3.1. Components of a business model

Following Boons and Lüdeke-Freund (2013), we identify the key components of a business model as the *value proposition*, *supply chain*, *customer interface*, and *financial model*. To this we add the *governance* dimension described by Zott and Amit (2010). This approach captures the both the *content* of the business model (Osterwalder and Pigneur, 2010) and its mode of *governance* within organisations and wider networks (Hellström et al., 2015; Zott and Amit, 2010). These components are integrated by Brown (Brown, 2018) and summarised in Table 7.

Table 7 Key components of a business model (Brown, 2018)

Component	Definition
Value proposition	The <i>value proposition</i> refers to the value or utility from goods and services that an organisation or network provides to the customer (Boons and Lüdeke-Freund, 2013; Engelken et al., 2016) .
Supply chain	The <i>supply chain</i> describes the upstream relationships between an organisation and its suppliers (Boons and Lüdeke-Freund, 2013). This comprises the logistical and technical elements that enable delivery of the value proposition (Osterwalder, 2004).
Customer interface	The <i>customer interface</i> covers all downstream, customer-related interactions (Boons and Lüdeke-Freund, 2013). This includes the relationship the customer has with the supplier organisations in terms of marketing, sales and distribution channels and the ongoing relationship with the product or service (Osterwalder and Pigneur, 2010).
Financial model	The <i>financial model</i> constitutes the combination of an organisation's capital and operational expenditures with its means of revenue generation (Osterwalder et al., 2005). This is linked to the value proposition, in terms of what products and services customers pay for and how revenues are collected and distributed.
Governance	Business model <i>governance</i> involves both the co-ordination and management of the other components and the organisational form of the business model (Amit and Zott, 2001; Zott and Amit, 2010). As such, business models may involve a single organisation or a network of interdependent firms that interact to provide a service or product (Hellström et al., 2015). The range of governance approaches lie along a continuum, with integrated, hierarchical firms at one end, and arm's-length, market-based contractual relationships at the other (Treib et al., 2007).

4.3.2. Innovation intermediaries and business models

A range of policy instruments to promote innovation are identified by Edler and Fagerberg (2017). These are grouped into six types; various stages of *research, development and deployment (R&D&D) funding*; policies to develop *capabilities and skills*; policies to promote *interaction and learning across networks*; *procurement policies* to generate demand; *regulations and standards*; and *missions and foresight policies* which envisage future needs and set the direction of change. Recently scholars have emphasised the need for systemic innovation policies, which move beyond a focus on individual instruments and technologies - instead seeking to promote whole system change (Wieczorek and Hekkert, 2012). Kivimaa

(2014) therefore emphasises how government affiliated intermediaries may constitute a form of systemic innovation policy (Smits and Kuhlmann, 2004).

Innovation intermediaries have been studied in different contexts since the 1990s (Bessant and Rush, 1995), covering a huge array of activities from technology transfer to innovation management and systems of innovation (Howells, 2006). Intermediaries can be characterised by their intermediation functions: for innovation in general (Howells, 2006); or in the context of sustainability transitions (Kivimaa et al., 2018; Mignon and Kanda, 2018). They can be grouped into specific types of actors based on the level and scale in which they operate, their mandate and normative orientation (Kivimaa et al., 2018). These actors may be key bridges or brokers in innovation systems, providing linkages, advocacy or technical services between multiple stakeholders, including suppliers and end-users (Howells, 2006; Hyysalo et al., 2018). Kivimaa et al., (2018) define innovation intermediaries for sustainability as:

“actors and platforms that positively influence sustainability transition processes by linking actors and activities, and their related skills and resources”

Van Lente et al (2003) contrast ‘systemic’ intermediaries, with those that have a more bi-lateral, or single technology focus (Klerkx and Leeuwis, 2009). The actions of these intermediaries may therefore play a crucial role in facilitating the emergence, development and diffusion of systemic innovations (Lente and Hekkert, 2003) - such as whole-house retrofit (Martiskainen and Kivimaa, 2018). In the retrofit context, intermediaries may include local authority agents, charities or NGOs, third sector or individual actors who facilitate projects (Kivimaa and Martiskainen, 2018).

We argue that systemic intermediaries may also play a role in promoting business model innovation. In their seminal work, Stewart and Hyysalo (2008) describe innovation intermediaries having three core roles: *facilitating, configuring and brokering* - which have been extensively applied in subsequent studies (Barnes, 2016; Kivimaa, 2014; Kivimaa et al., 2018). In Table 8 we develop these ideas and apply them to the context of business model innovation.

Table 8 Key functions of an innovation intermediary in business model innovation

Function	Definition
Facilitating	Facilitating enables networking and collaboration as well as knowledge dissemination and learning (Howells, 2006). In the context of business model innovation this involves the support and co-ordination of the networks involved in the delivery of the value proposition (Hellström et al., 2015). Thus, potentially facilitating new approaches to business model governance, towards integrated or more networked arrangements (Treib et al., 2007).
Configuring	Configuration involves the design and modification of technological, social and organisational innovations, to promote their appropriation and adoption among key stakeholders (Howells, 2006). Therefore, this involves the design, modification and testing of new business models with relevant users, suppliers and the wider regulatory environment. This is likely to include developing novel value propositions and financial models (Chesbrough, 2010), such as energy performance contracts (Nolden et al., 2016) but also capabilities in supply chains and the customer interface (Boons and Lüdeke-Freund, 2013).
Brokering	Innovation intermediaries may provide support through negotiation and representation with external sponsors or regulators (Stewart and Hyysalo, 2008). Thus, intermediaries may seek to raise financial or human resources to sustain and develop innovative activity or undertake advocacy or lobbying activities - to alter the legal or policy environment (Howells, 2006). Intermediaries may also seek to create demand for the combination of products and services embedded within the business model they are seeking to promote (Klerkx and Leeuwis, 2009), what could be termed 'market formation' (Kivimaa et al., 2018).

Table 8 presents our conceptual framework used for examining the Energiesprong case in Section 4.5. It connects Stewart and Hyysalo's (2008) innovation intermediary roles with business model components (Brown, 2018) highlighting the role they play in business model innovation.

Table 9 Conceptual framework linking innovation intermediation to business model components

	Facilitating – network formation and collaboration	Configuring – business model design	Brokering - advocacy and resource raising
Value proposition	Creating opportunities for new value propositions, by bringing new actors together-supporting and coordinating the networks involved (Hellström et al., 2015).	Configuring the mix of products and services which form the new value proposition (Chesbrough, 2010). Includes testing of alternative value propositions with users, suppliers and regulators.	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new value propositions.
Supply chain	Creating opportunities for new supply chain interactions - developing the relationship between the core business and its suppliers, which can be more complex in the case of systemic innovation (Mlecnik, 2013).	Setting rules and contract terms for suppliers, as well as training and capacity building (Mlecnik, 2013).	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new supply chain configurations.
Customer interface	Creating new connections to potential customers, interfacing between customer expectations and new business model formation.	Developing marketing and sales channels as well as new forms of customer engagement – including the use of new media (Brown, 2018).	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new customer interfaces. Creating new markets by influencing regulations or local rules (Martiskainen and Kivimaa, 2018).
Financial model	Creating links to new financing actors to develop new financial models through new sources of capital or revenue streams.	Developing new financial models – often linked to new value propositions, requiring interaction with finance providers and customers.	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new financial models. Seeking new financial resources such as research and development (R&D) funding or other fundraising activity.

Governance	By facilitating new networks and links between the other business model components this may lead to new modes of governance, towards more integrated or networked arrangements (Treib et al., 2007).	Developing the linkages between different actors involved in business model governance. This may include an active role in organisational management and 'system building' activities during the early phases of business model development (Bolton and Hannon, 2016).	Advocacy and lobbying with regulators to overcome potential barriers to business model integration or outsourcing (Howells, 2006; Klerkx & Leeuwis, 2009; Kivimaa, 2014).
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The combined business model and intermediation framework is shown in Figure 18 and illustrates how these elements work together to produce business model innovation.

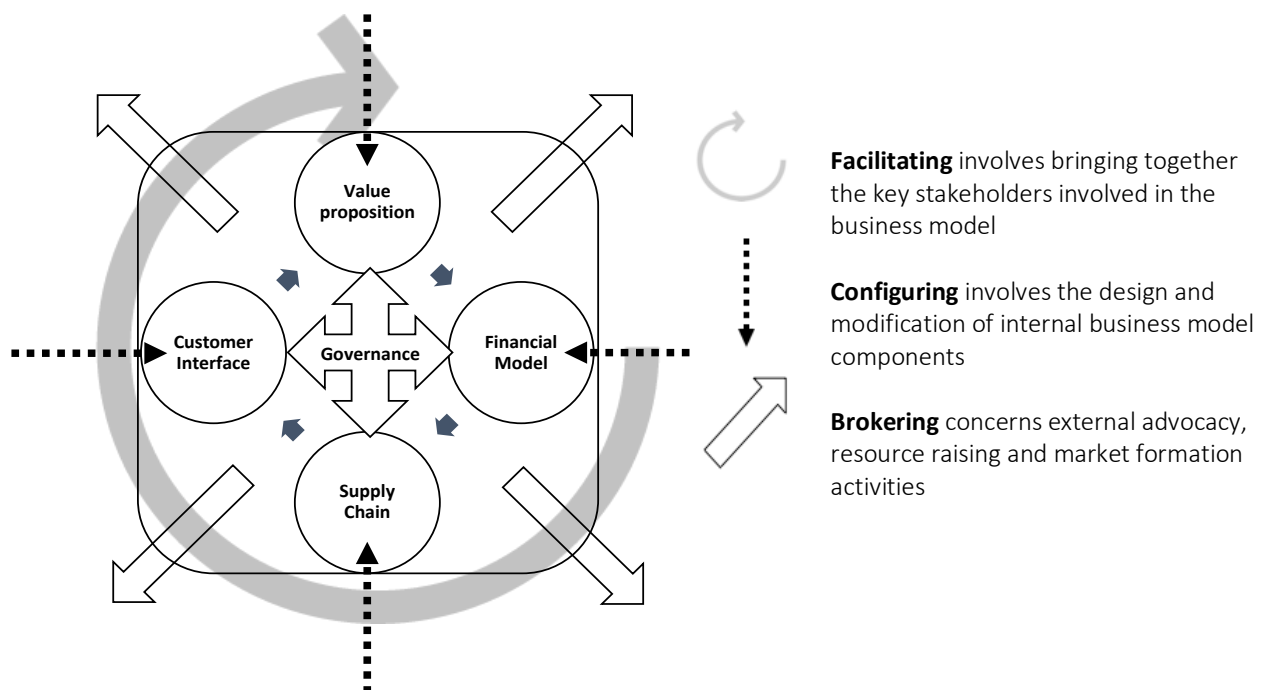


Figure 18 Business model innovation and intermediation framework

4.4. Methodology

This research involved a qualitative case study of a policy initiative to promote business model innovation for whole-house retrofit; the Energiesprong initiative. We draw on insights and empirical context from two wider research projects focussed on both (1) business models and finance mechanisms for residential retrofit and (2) the role of intermediaries in low energy housing innovation. Each project involved a total of thirty-eight and twenty-nine semi-

structured interviews⁴⁹ respectively, conducted between November 2016 and June 2018. This included seven interviews with actors directly involved in the Energiesprong initiative. Other interviews provided background both on the range of business model archetypes and financing mechanisms adopted as well as the nature of intermediation in the sector. A qualitative case study approach was considered appropriate given the need to develop an in-depth understanding of these relatively understudied processes in the retrofit context, to answer ‘how’ or ‘why’ questions (Yin, 1994) that contribute to theory development (Flyvbjerg, 2006). In building this picture, the research was undertaken in three parts.

Part one focussed on the diversity of business models and finance mechanisms adopted for residential retrofit. This initially involved nine scoping interviews with key ‘experts’ in the retrofit space in the UK, EU and USA (see Appendix A, Table A1). These experts were selected on the basis of their technical, academic and policy eminence within the retrofit sector, with further interviewees sourced through snowballing techniques (Yin, 1994). This was supplemented by extensive document analysis and attendance of industry events and seminars. The objective was to develop a typology of business models and finance mechanisms and understand how their design features contributed to their success in different contexts. The scoping interviews were followed by twenty-four interviews with key practitioners across the key business model and finance mechanism archetypes, to develop a rich understanding of their operation and the advantages and disadvantages of each approach. This identified two contrasting business model archetypes, which are explored in detail in this study. The ‘atomised’ market model that has typified the delivery of single residential retrofit measures, and highly innovative net-zero energy performance contracts; with the ‘Energiesprong’ initiative the only known residential example.

Part two provided context on intermediation in UK low energy housing sector (see (Kivimaa and Martiskainen, 2018b, 2018a; Martiskainen and Kivimaa, 2018)) and provided a background setting for analysis of intermediation in this case study. This included twenty-nine in-depth interviews and a workshop organised with stakeholders in February 2017, in which Energiesprong were a speaker (see Appendix A, Table A2).

⁴⁹ The interviews were a mix of face to face and video conference calls

Part three involved an in-depth case study⁵⁰ of the Energiesprong initiative. This phase involved six⁵¹ interviews during spring and summer 2018 with various actors in both the UK and the Netherlands. This included the *client* or housing provider; the construction *industry* partner; supporting *policymakers*, as well as the Energiesprong market development team *intermediary* themselves (see Appendix A, Table A1). The interviews focussed on understanding whole-house retrofit as a systemic innovation; the nature of the Energiesprong business model; the role of the market development team in enabling business model innovation; the policy approach that brought it into being and the ongoing interaction between the intermediary, policymakers and other stakeholders. Again, these interviews were supplemented by document analysis and attendance of relevant industry events and seminars.

Each interview was digitally recorded and transcribed and analysed using the NVivo™ qualitative analysis software. Interviewees were offered options as to the level of disclosure and anonymity (reflected in the appendices). Interview data was coded and analysed based on the framework outlined in Section 4.3.2. This also involved triangulating these findings with public available reports such as Energiesprong (2018, 2017, 2014), to add validity to the claims made in the following sections.

4.5. Business model incumbency and innovation in residential retrofit

The majority of EU low carbon retrofit has involved single measures delivered by separate contractors, without guarantees on energy saving performance. This has typically required multiple points of contact and has tended to be funded by a number of changing subsidy regimes such as energy supplier obligations, tax breaks or feed in tariff type schemes. This section first develops this ‘atomised’ market, business model - considered common retrofit practice. We then introduce the Energiesprong initiative, as a case study of an innovative Managed Energy Service Agreement (MESA) business model, delivered through a government funded intermediary. We therefore draw on the business model archetypes developed in

⁵⁰ Phase one provided sufficient detail on the atomised market model

⁵¹ One Energiesprong interview already took place in phase one

Article 1, including the: *atomised market model*; *market intermediation model*; *one-stop-shop*; *energy services agreement (ESA)*; and *managed energy services agreement (MESA)*.

4.5.1. The 'atomised' market model

Although the atomised market model has been fairly successful for incremental single measures (Rosenow and Eyre, 2014); this approach is considered problematic for undertaking whole-house retrofits. As outlined in Article 1 it creates issues for project co-ordination, energy performance gaps and unintended consequences such as air quality and damp issues - limiting consumer appeal. The following section explore this business model based on the components outlined in Table 7.

Value proposition

The traditional offer to households has been framed in terms of energy cost savings, rather than home improvement or increasing comfort. This was considered to be a mistake by many of those interviewed:

"For most people ... it's not the economics that's driving them, it really isn't. First and foremost, its comfort, its often aesthetics, what you perceive as aspirational... It's all these subtle things that are more cultural I think." (Academic - Energy Efficiency Policy-I#1)

The focus on energy cost savings is especially problematic, given that energy savings are typically based on estimated rather than guaranteed performance:

"to guarantee you performance...that's a different mind-set...and...selling performance is good because it puts a line of blame and accountability, which is what we don't have at the moment" (Director – BRE-I#4)

Therefore, the narrow offer of estimated energy cost savings without any guarantees or warranties on the work, severely limits the appeal of a whole-house retrofit. It was also commented that this approach results in poor-quality installations, with limited liability or recourse potential due to the lack of aftercare or performance guarantees.

Supply chain

The typical retrofit supply chain consists of multiple, fragmented installers, suppliers and consultants. It was discussed by several interviewees, that this is largely a reflection of the wider construction industry; typified by specialised subcontractors, each with their own division of labour and industry culture:

“Solid wall insulation it’s like an...artisanal, industry...Rather than something which is at industrial scale, and those economies of scale are never going to happen, until you got the whole supply chain working” (Energy Saving Trust-I#3)

This supply chain fragmentation, the lack of assured performance, measurement and verification alongside a skills gap were all seen to contribute to low quality retrofits, particularly for deeper measures such as solid wall insulation:

“we’ve got issues around external wall insulation ... we’ve got ... green algae growing on the outside...we’ve got so many complaints coming in from private residents” (Social Housing Provider-I#35)

Customer interface

In the atomised market model, consumer engagement⁵² has typically involved single measures, leaving the customer to seek out and project manage more comprehensive work “largely the onus is on them at the moment” (Energy Saving Trust-I#3). In procuring multiple retrofit measures, customers therefore need to engage multiple consultants and contractors, each with their own marketing channels and points of sale:

“[referring to the UK’s Green Deal⁵³] what actually happened was the customer journey was a lot longer than expected.” (Energy Efficiency Consultant-I#12).

This lack of co-ordination between different suppliers is therefore seen as complex, and likely to deter all but the most committed households. Without a trusted intermediary or a single point of contact, some interviewees also felt this made customers vulnerable to unscrupulous

⁵² Largely through the energy supplier obligations

⁵³ The Green Deal was a voluntary UK policy program based on a private sector finance mechanism, repaid on energy bills

contractors *“if Mrs Jones goes direct to the company, the company can tell her anything can’t they”* (Energy Efficiency Consultant-I#12).

Financial model

Specific financial models are not intrinsic to the atomised market model. However, this approach is synonymous with government grant and supplier obligation schemes; typified by stop start funding for single measures. Thus, many interviewees felt that this approach had resulted in a marketplace that was very grant dependent. It was further discussed that this policy approach had contributed to the piecemeal nature of installations and the very limited diffusion of whole-house retrofits. Whilst the UK’s recent Green Deal financing mechanism was intended to fund multiple measures, it still applied an incremental logic to financing:

“Green Deal was set up to fund things on a measure by measure basis. So, you have this, then you have this, then you have this. ... With the supplier obligations we worked on things ...in the order of cost-effectiveness; in an ‘incrementalist’ approach” (Energy Saving Trust-I#3)

Governance

The atomised market model is associated with a market-based mode of governance, characterised by limited integration between the different elements of the business model:

“at the moment there is no integration in the retrofit market ...somebody goes out and gets a lead ...they may get £50...they then come up with ‘yes it’s got a solid wall yes it needs windows’ it becomes a sum of parts without...a plan” (Director - BRE-I#4)

This mode of governance may be effective for large organisations, able to manage complex supply chains, multiple interfaces with suppliers and compare different financing options. However, it is considered a poor means of delivering whole-house retrofits for time poor households, who may have limited knowledge of the options available or the ability to undertake due diligence.

4.5.2. The Energiesprong MESA business model

In a MESA, customers are offered an energy performance guarantee with the financing of measures included within the value proposition. Here, an ESCO also includes the energy supply contract (natural gas, electricity) as part of the offering, typically as a single energy service payment. In the case of Energiesprong, this equates to net-zero over the calendar year, although still requiring a supply contract for periods of low generation and grid export. The following section explores this business model based on the components outlined in Table 7.

Value proposition

In the Energiesprong model, customers are offered a comprehensive whole-house retrofit, based on guaranteed net-zero energy consumption. This typically involves offsite manufactured, insulated facades, integrated with renewable heat sources and PV panels. The contractor offers a 30-year energy performance guarantee for net-zero annual energy consumption amortised over the calendar year. This is based on a guaranteed internal temperature of 21°C in living spaces, and a set allowance of hot water and electricity consumption; analogous to a mobile phone contract with usage limits. The aim is also to reduce the duration of the retrofit to under one week using offsite manufacture and modularisation. However, the model does not proscribe any specific measures but rather the performance outcome:

“This is a balanced scorecard...of outcomes, so that's energy, that's cost, that's overheating, that's noise, that's indoor air quality that do get genuinely measured, has sanctions if you do not meet them and it is over the long term” (Energiesprong Contractor-1#36)

Another key aspect of the Energiesprong offering is the emphasis on the home improvement value of the whole-house retrofit. Homes are given a visual uplift and the retrofit typically includes a number of non-energy-based maintenance measures. Unlike the atomised market model, less emphasis is placed on energy costs savings, and instead on health and comfort benefits alongside property improvement value:

“I think...in terms of desirability...the push for such a scalable solution also needs to come from an angle where people actually want to have it”. (Energiesprong International Market Development-I#33)

Supply chain

The Energiesprong business model specifies performance rather than technical solutions. However, delivery of a net-zero energy retrofit requires an integrated supply chain, typically with a single ‘solution provider’. The Energiesprong model is also driving a move to industrialisation and offsite manufacture; with integrated energy modules that can be miniaturised, and mass-produced. It is thought that this process innovation will drive down costs and installation times through economies of scale; with one-day retrofits now being achieved in the Netherlands – despite each retrofit being bespoke. The Energiesprong model therefore adopts a performance-based approach to procurement:

“In the past they would come up with a technical specification, price it up and invite competition on price. We are completely turning that round and saying you ask for a product performance to a fixed price point” (Energiesprong Project Manager-I#18)

Moreover, this procurement route is seen to improve quality and collaboration between the client and contractor:

“Energiesprong however, has real teeth, so therefore the quality is driven up because we are concerned to get it right.” (Energiesprong Contractor-I#36)

Customer interface

In the Energiesprong initiative, the initial target market has been the social housing sector. Achieving scale is considered to be easier in this market where multiple homes can be retrofitted under a single deal, also tending to have a more uniform housing stock. Interviewees felt that breaking into the owner occupier market would be much more challenging:

“They are managing larger volumes; it is much easier to converse with a provider who is managing 50, 60, 70,000 homes, than to talk to individual private landlords of one or two flats.” (Energiesprong Project Manager-I#18)

The customer interface involves a single product offering, rather than separate, sales, audit, measures and financing from different providers. Whilst for social housing this interface is initially with the housing provider, significant emphasis is placed on household engagement:

“there was quite an intensive consumer engagement process, which involved workshops with the tenants...in the local pub...so that the tenants could directly import what they wanted out of the scheme... It did genuinely make a difference” (Local Authority Partner-I#38)

Moreover, a key marketing tool of the Energiesprong approach is the visual impact of the newly renovated house, creating what is termed ‘kerbside appeal’.

Financial model

As with other forms of energy performance contract, the financial model relies on realised energy savings to fund the cost of the measures. Given the retrofit results in net-zero energy, the entire energy bill is used to recover these costs. The model has thus far been adopted in the social housing sector, and benefits from the rolling up of future maintenance⁵⁴ from the housing providers’ asset management budget:

“The financing model therefore is...the aggregation of maintenance, major repair works and the additional revenue stream for thirty years from the energy plan that comes with the property.” (Energiesprong Project Manager-I#18)

The strategy hinges on achieving economies of scale and learning rates, so that the financial model is viable based on energy costs savings and maintenance budgets alone - rather than reliant on subsidy as at present:

“the way I see it...is...this massive prize of a self-financing business model, if we achieve that then there are millions and millions of homes that could be retrofitted” (Social Housing Provider-I#35)

However, for the model to become viable in the private housing sector, third party sources of finance are likely to be necessary. The Dutch government is therefore exploring the use of

⁵⁴ Such as those for wall and roofing repairs

mortgage financing and performance-based energy service agreements tied to the property. Critical to this is the cost of capital; *“what we see now is cost of financing, structural cost of borrowing money is high in the UK, because it's fully commercial”* (Energiesprong International Market Development-I#33). Therefore, several interviewees saw an ongoing role for government in bridging the funding gap and ensuring low interest rates.

Governance

The Energiesprong business model adopts an integrated mode of governance. Central to this has been the market development team, who have brought together the key stakeholders and facilitated collaboration and innovation towards a common goal:

“We've made an innovation of the Energiesprong, and I guess this is one of the biggest things...it's the way, more the governance...the way it was organised” (Dutch Energy Policymaker-I#37)

“So, there was quite a lot of collaboration...when we were developing our tender, we could do some market testing through Energiesprong, through the market development team” (Social Housing Provider-I#35)

This ‘partnership approach’ has been central to developing a business model where customer interface, supply chain, financing and net-zero energy retrofit are integrated into an offering from a single solution provider - which can be easily understood by the customer. Thus, simplifying the customer journey, improving quality and is potentially scalable to create a mass market for whole-house retrofit.

Table 10 compares the atomised market model and Energiesprong business model, illustrating the difference across the components of the respective business models.

Table 10 Comparison of the atomised market model and Energiesprong business models.
Adapted from: (Brown, 2018)

	'Atomised' market model	'Energiesprong' energy performance contract
Value proposition	<ul style="list-style-type: none"> • Single measures • Emphasis on energy cost savings • Savings are estimated rather than guaranteed 	<ul style="list-style-type: none"> • Multiple measures or whole-house approach • Emphasis on home improvement and comfort • Energy performance contract • Energy service guarantee of temperature (21°C), hot water volume (150L/day) and electricity (fixed kWh/year) • Energy supply contract subsumed in energy service agreement
Customer interface	<ul style="list-style-type: none"> • Largely left to the market to promote and engage customers, with responsibility for the marketing and engagement for the different components (i.e. measures, audit, finance) of the retrofit typically separated 	<ul style="list-style-type: none"> • One point of contact for the promotion, marketing and sales of the full package necessary to achieve the retrofit, provided by the host company as a one-stop-shop • Emphasis on customer engagement through housing provider and face to face workshops
Supply chain	<ul style="list-style-type: none"> • Fragmented relationship with traditional separated trades (plumbers, carpenters etc.) installing the retrofit measures in sequence with limited co-ordination 	<ul style="list-style-type: none"> • Highly integrated package of measures, using offsite manufacture techniques - provided in house or through trusted subcontractors • Supply chain may require legal and finance skillsets • Additional supply chain for electricity supply required, can be through fully licensed supplier model or through a white label scheme
Financial Model	<ul style="list-style-type: none"> • Finance is arranged via third party with little involvement in the retrofit process 	<ul style="list-style-type: none"> • Lender developer / investor seeking to use energy performance contract structure to fund retrofits • Lender captures energy savings and charges back to property owner based on historic consumption • Retrofit supplier assumes responsibility for payment of energy bill

	'Atomised' market model	'Energiesprong' energy performance contract
Governance	<ul style="list-style-type: none"> Highly fragmented arrangement of suppliers with little co-ordination between the various elements – project management is left to the customer 	<ul style="list-style-type: none"> Integrated mode of governance where components of the business model are delivered and co-ordinated by a single organisation, who take responsibility for project delivery.

4.6. Innovation intermediaries and residential retrofit

In this section we first introduce the Energiesprong market development team as a case of an innovation intermediary. Subsequently we explore the key intermediation functions of facilitating, configuring and brokering (Stewart and Hyysalo, 2008) and how these contributed to the business model innovation outlined in the previous section. The case further illustrates how this radical business model necessitates systemic innovation across supply chains, legal, financing and regulatory spheres (Mlecnik, 2013). Drawing on the interviews from Article 1 we subsequently introduce two other intermediaries in the UK retrofit sector: The Energy Saving Trust and the RE:NEW program. We discuss how the narrower remit of these intermediaries is unlikely to facilitate the systemic changes that the Energiesprong market development team is looking to promote.

4.6.1. Energiesprong market development team

In 2013, the Dutch government funded a large-scale (€45 million) market led initiative to achieve net-zero energy homes known as the 'Energiesprong' or 'energy leap' initiative (Energiesprong, 2014). The aim was to overcome many of the issues identified in the previous section, thus, facilitating a self-sustaining market for net-zero energy homes⁵⁵, through a new type of policy - delivered by an innovation intermediary.

"There was a strong belief here in this ministry that we should not do this... ourselves. This is not [what] we are good at. [We] had to bring out new people with knowledge of the market to make a connection with the market... We are making policy... we're not judging business plans" (Dutch Energy Policymaker-I#37)

⁵⁵ The program is focused both on net-zero-energy whole-house retrofit and new build

The Energiesprong initiative, since emerging from its pilot phase, has now begun a period of growth and expansion to other national contexts - having signed a deal with 175 housing industry partners in the Netherlands to deliver 110,000 net-zero energy homes by 2020 (Energiesprong, 2014). This included the creation of market development teams in the UK, France, Germany and in North America, building on the Dutch experience (Energiesprong, 2017). Thus far (2018), 4,500 net-zero energy homes (a mix of new-build and retrofit) have been delivered in the Netherlands, with 10 and 24 retrofits completed in the UK and France respectively - with many more planned (Energiesprong, 2018). Initially entirely state funded, the initiative is now supported by national and European Union innovation funds and a range of local authority, industry and public sector partners in these respective countries.

To achieve its goals, the market development team performs three key forms of intermediation; *facilitating*, *configuring* and *brokering* that are crucial to business model innovation, and market formation.

Facilitating

The overarching role of the market development team is to co-coordinate the key stakeholders of the housing provider, the construction industry, financiers and policymakers, facilitating collaboration and learning.

“So, what we saw is that it's much easier if you put an interlocutor or a catalyst in the middle that understands where the market needs to go ...what the financing conditions need to be, what the regulatory conditions need to be, that you organise some demand, and then the market is right there.” (Energiesprong International Market Development-I#33)

This has involved multiple project partners including large construction companies, social housing providers, local authorities and municipalities. The aim has been to create a shared vision for net-zero energy buildings and develop a diverse skillset and knowledge base through events, publications and pilot projects. Interestingly, the market development team sees this role as temporary. It is hoped that over time and with sufficient experience, its role would become obsolete as the business model becomes mainstream.

Configuring

The Energiesprong market development team were tasked to develop a novel solution that would overcome many of the issues surrounding the traditional atomised market model. Whilst funded by a large government grant in the Netherlands, it was effectively independent of the ministry that created it. This provided significant autonomy to fundamentally redesign the business model through which retrofit was delivered:

"In the beginning... were able to do pretty radical things, right? Because there was nothing out there yet. Performance guarantees for 30 years, energy service plans, retrofit solution in a week? Nobody had...there was no example to look at the time... So, we really had to do a lot of activation. That budget allowed us to do that." (Energiesprong International Market Development-I#33)

This involved intensive innovation in partnership with contractors to determine what was technically possible, and extensive legal and policy work to develop the procurement approach and energy performance contracts. The Energiesprong team thus draws on extensive technical expertise, crucial in moving from concept to reality. However, the model has required re-configuration to the UK context due to the different regulatory environment, industry culture and consumer expectations:

"It was about promoting what had been done in the Netherlands, and saying, "This is how it works." I think what we've ended up with understanding... "It doesn't really work like that here." (Social Housing Provider-I#35)

Brokering

The market development team has also played a critical advocacy role - brokering policy changes, procurement volumes and raising financial and human resources. This included lobbying the Dutch government to allow placement of energy service charges on rents, performance-based efficiency subsidies, and mortgage eligibility assessments to account for net-zero-energy performance. This was made possible, because despite its independence Energiesprong was essentially an arm's length government programme:

"Interesting, why could we play this role? We were funded by the government. So, the fact that we brought together these organisations and we always said.... we're going to

work on the supply side. We're going to work on the demonstrable goal. Also, we're going to work with the legislator.” (Energiesprong founding partner-l#34)

The UK team have also secured innovation funding through various European Union grants and are now seeking a large UK government grant of over £150 million - for thousands of homes. It is hoped this scale will enable the financial model to be fully commercial. Critical to this is also securing demand volume; where in the Netherlands housing providers have agreed to retrofit 110,000 homes to net-zero standards (Energiesprong, 2014). However, significant work remains for the model to become self-sustaining:

“after you know, 45 million.... the idea was always that after that, the market would it do itself. That is still not the case here [Netherlands] and it's also not in the UK.” (Dutch Energy Policymaker-l#37)

A summary of these intermediation activities and how they relate to the components of the Energiesprong business model is provided in Table 11.

Table 11 Intermediation activities for the Energiesprong business model

	Facilitating – network formation and collaboration	Configuring – business model design	Brokering - advocacy and resource raising
Value proposition	Bringing together the necessary skillsets for energy performance contracts including expertise in offsite manufacture, asset and energy management, law and finance.	Designing performance contracts and developing the customer offer through collaborative design with the stakeholders in the network. Testing the customer offer through small scale trials and feedback with the end user.	In the Netherlands the intermediary secured regulatory changes surrounding energy service charges on social rents.
Supply chain	Co-ordinating actors within the supply chain to deliver net-zero energy retrofits through greater integration – facilitating learning and adoption of offsite manufacture techniques and modular solutions through collaborative procurement.	Managing procurement, tender process and contract terms with suppliers, as well as training and capacity building with the retrofit supply chain.	Securing agreement from housing providers for large order volumes for net-zero energy homes – providing security for the supply chain to scale up operations.
Customer interface	Network formation and involvement of local community actors as well as public and private sector partners, holding regular events and outreach activities.	Developing marketing materials and customer outreach in collaboration with the housing provider or other representatives of residents. This included social media channels as well as more conventional forms of engagement, including focus groups.	Recruitment of housing association executives into the market development team to lobby for procurement of large numbers of net-zero energy retrofits within their host firms.
Financial model	Incorporating key financial stakeholders from both the private sector and government into the consortium from the earliest stages.	Mobilising financial resources and designing contracts, building on dedicated financial and legal expertise to develop the financial model.	In the Netherlands securing policy changes: for both efficiency subsidies and mortgage eligibility to be based on energy performance. UK and EU level: lobbying for innovation funding under EPRD; Interreg; and UK Industrial Strategy Challenge Fund.
Governance	A system building role – improving the links and between the elements of the business model towards an integrated mode of governance, through a single solution provider.	Formalising the links within the supply chain and wider network. In the UK, case this involved the creation of a new business venture ‘Melius Homes’ which will act as an integrated solution provider.	Widespread PR and advocacy campaign across UK and EU to promote the Energiesprong business model with business leaders, local authorities and the Industry. With the aim of creating a network of ‘advocates’.

4.6.2. Retrofit intermediaries and systemic innovation

The UK has a history of different and overlapping intermediaries in the retrofit and energy efficiency space (see Kivimaa and Martiskainen, 2018b for an overview). Two notable examples are the Energy Saving Trust (EST) and the RE:NEW program for London. The EST was set up by the UK government in 1993 to provide consumer advice and support in the implementation of energy efficiency policies. However, unlike Energiesprong its remit has limited scope for supply chain engagement:

“one of the ideas which we’ve not thought about, or not focused on a lot is trying get the industry supply chain up and running for solid wall insulation ... as a consumer facing organisation we’ve tended to focus on what is [the] cost benefit for consumers installing solid wall insulation, which...[is currently] not going to pay back without additional assistance.” (Energy Saving Trust-I#3)

In 2011 in England and Wales, the EST’s central government funding was cut by half, further limiting its reach and advisory role. In Scotland the EST has continued to receive funding from the Scottish government, acting as its main interlocutor for the HES and HEEPS funding and loan programs:

“it is a pilot scheme that we're running on behalf of the Scottish government in just three of the local authority areas in Scotland ... available to home owners ... it's an equity loan. So, based on the equity that house holders have in their own property” (EST - HEEPS-I#24)

The RE:NEW programme established in 2009 provides a framework for housing associations and local authorities to procure retrofit measures in Greater London. The scheme is designed to simplify, standardise and improve quality assurance in the procurement of retrofit projects. Therefore, the scheme is largely aimed at improving the relationship between the supply chain and the housing provider, rather than the interface with individual households.

“some [housing providers] may have the skillset, some may not because they are just pulled in too many directions as big organisations, sometimes you need a bit of handholding, a bit of help” (Manager- RE:NEW - GLA-I#10)

Both of these intermediaries have had success in facilitating, configuring and brokering the uptake of single measure residential retrofits in the UK. However, they have played a much more limited role in promoting whole-house retrofit and have done little to challenge the

underlying business model of the industry (Article 1). By contrast, the Energiesprong market development team has a broader remit to engage with multiple actors including the construction industry, housing providers, financiers and policymakers. The aim has been to promote the systemic changes necessary for such a radical business model to become viable as shown in Table 12.

Table 12 A comparison of three retrofit intermediaries in the UK

	Energy Saving Trust	RE:NEW London	Energiesprong Market Development Team
Facilitating	Core role in engaging end customer/households on energy efficiency and retrofit. Limited focus on other stakeholders	Facilitate interaction between key supply chain actors and housing provider. Limited focus on other stakeholders	Facilitate interaction between multiple stakeholders: client, supply chain, financiers, government
Configuring	Some development of financial model through low interest loans in Scotland No role in configuring retrofit value proposition - traditional business model largely unchallenged	Configure contractual arrangement with supply chain through procurement framework. No role in configuring retrofit value proposition - traditional business model largely unchallenged	As outcome of facilitation developed entirely novel business model for sector based on net-zero energy performance guarantee and supply chain industrialisation
Brokering	Brokering and advocacy with government on consumer energy issues and energy efficiency policy. Less influence since curtailment of government funding.	Brokered deals at city level but limited input to wider policy, finance or industry landscape	Brokered policy changes in the Netherlands, and secured funding through EU and UK innovation grants. Less influence since curtailment of government funding.

Consequently, without such systemic intermediaries, radical business models such as the Energiesprong MESA will struggle to gain a foothold and deliver the widespread adoption of whole-house retrofits. However, given the scale of its ambitions, it remains to be seen if this Energiesprong will continue to be effective without the support of central government, as was the case in the Netherlands.

4.7. Discussion

The goal of this paper was to understand how and why intermediaries and in turn policymakers might support business model innovation. We illustrate this through the case of an innovative business model for whole-house residential retrofit: the Energiesprong approach.

In understanding the role of new business models in systemic innovation, the case of whole-house retrofit is particularly instructive. Whole-house retrofit involves the assemblage and co-ordination of a complex mix of technologies, processes, human and financial resources which interface both user *and* industry practices. Among these groups the imperative of saving energy remains a low priority. Equally, the wider regulatory and institutional environment remains poorly aligned to achieving this, particularly as it also constitutes a shift toward a more distributed energy supply system (Richter, 2013a). Whole-house retrofit thus represents an archetypal example of a systemic innovation (Mlecnik, 2013).

This paper builds on an earlier phase of research involving a systematic comparison of alternative retrofit business models (Brown, 2018). We show that the traditional atomised market business model, whilst suitable for the delivery of single retrofit measures is poorly suited to whole-house retrofit and is a weak driver of demand.

The Energiesprong initiative radically overhauls this approach, through an integrated business model. Thus, our findings support recent research on the potential for supply chain integration (Mahapatra et al., 2013; Mlecnik et al., 2018, 2012, n.d.) and energy performance contracts for promoting whole-house retrofit (Brown, 2018; Winther and Gurigard, 2017). Therefore, these findings emphasise how the ‘integrative technologies’ - which characterise whole-house retrofit are best suited to hierarchical or integrated modes of governance (Hoetker, 2006; Sanchez and Mahoney, 1996).

Consequently, business model innovation is able to exploit the added value of systemic innovations like whole-house retrofit - such as improved energy services and household comfort (Roelich et al., 2015). New business models achieve this by reconfiguring relationships within supply chains, mobilising financial resources and engaging customers in new or

improved ways (Boons et al., 2013). Our case further emphasises how the *governance* of the business model is critical for the integration and management of these components, and the impact this has on the customer (Hellström et al., 2015). Business model innovation thus reconfigures organisational practices and their management to enable systemic innovations to become viable:

“of significance is the business model’s ability to create a fit between technology characteristics and (new) commercialisation approaches that both can succeed on given and new markets.” (Boons and Lüdeke-Freund, 2013)

However, the adoption of innovative business models, such as the Energiesprong approach remains challenging - due to a range of cultural and structural barriers (Stubbs and Cocklin, 2008). Our findings show how the incumbent business model is a product of the wider construction industry - characterised by fragmentation, lowest cost procurement, and few guarantees on performance. This reflects established ways of undertaking construction work and contract design, based on the ‘dominant logic’ of the industry (Chesbrough, 2010). Many SMEs lack the necessary knowledge for whole-house retrofits, capabilities such as energy monitoring and finance or complementary assets such as energy management ventures - preventing them from offering long term energy performance contracts (Teece, 2018, 2010, 1986). As identified by Budde Christensen et al., (2012) incumbent firms may thus be locked into a path dependent business model, with a limited demand for whole-house retrofit, providing few incentives to change.

Crucial to overcoming these barriers has been an open approach to innovation, where learning is widely disseminated rather than held within individual firms (Chesbrough, 2006). Thus, the market development team created standardised contracts and procurement processes, critical in reducing transaction costs for energy service contracts (Nolden et al., 2016). The intermediary also played an instrumental role in lobbying for policy changes and financial resources. Moreover, the negotiation of delivery volumes and the targeting of the social housing market is ostensibly an organisational ‘strategy’ rather than a business model (Teece, 2010). Thus, the intermediary roles of configuring, facilitating and brokering (Stewart and Hyysalo, 2008) were critical for business model innovation, market formation *and* strategy for the diffusion of whole-house retrofit. Interestingly, the temporary nature of the market

development team was also observed in Kivimaa's (2014) study of two Finnish innovation agencies. Both studies emphasise the risks of too short an intervention and the importance of maintaining neutrality whilst retaining policy influence - a challenging balancing act (Kivimaa and Martiskainen, 2018b; Klerkx and Leeuwis, 2009).

Where this study breaks new ground is by highlighting the role of an innovation intermediary in overcoming these barriers to business model innovation. We develop a novel framework (Table 9 and Figure 18) which integrates the components of the business model with intermediation functions for the first time. The Energiesprong market development team is therefore shown to be instrumental in developing the concept of a net-zero energy retrofit, engaging the supply chain to develop innovative approaches, as well as developing the legal and policy framework necessary for it to work. By highlighting the specific processes by which intermediaries can support business model innovation; these findings are an important contribution to the literature on innovation intermediaries (Klerkx and Leeuwis, 2009), and business model innovation (Bolton and Hannon, 2016) – emphasising how one can promote the other.

Our case study also contributes to understanding the role of intermediaries and business model innovation in innovation policy. Drawing on Edler and Fagerberg's (2017) typology; the formation of the market development team was primarily a policy to promote *interaction and learning across networks*. What is interesting is that the intermediary was able to engage with the market and influence policy in a range of other areas. This included: securing *R&D&D funding* in the form of European Union grants as well as changes to the energy efficiency subsidy regime; *procurement policies* to generate demand through volume agreements with public housing providers; changes in *regulations and standards* to allow energy service charges to be bundled with rent; and *missions and foresight policies* including the goal for net zero energy homes by 2050 and the gradual disconnection of neighbourhoods from the natural gas grid in the Netherlands.

The catalytic role of the intermediary can thus be seen both in terms of market *and* policy formation. Recognising the limited generalisability of our case study approach, we suggest that by bringing together the literature on systemic innovation, business models and innovation

intermediaries - our findings and framework (Table 9 and Figure 18) provide some transferable theoretical insights. We demonstrate how government affiliated intermediaries like the Energiesprong market development team can be viewed as a decentralised and potentially effective form of innovation policy (Kivimaa, 2014). Policymakers created an intermediary who facilitated business model innovation, which in turn has enabled systemic innovation in the form of whole-house retrofit. Accordingly, policymakers wishing to promote business model innovation in other sectors, may achieve these aims through the creation of innovation intermediaries such as the market development team.

However, the transferability and wider significance of these findings, both for the empirical context of retrofitting and intermediation for business model innovation, requires qualification. For now, the Energiesprong business model requires significant scale before it is viable without subsidy; thus, contingent on promising but as yet unrealised learning rates (Energiesprong, 2017). The findings also emphasise the greater challenges in entering the owner occupier market, where diversity of building forms and consumer preferences make mass produced solutions more challenging (Haines and Mitchell, 2014). Equally, these findings highlight issues of compatibility for the transfer of radical business models to new contexts. The absence of 'net metering' for renewable microgeneration, the lack of public financing support through low cost loans, or a general unwillingness for policymakers to promote specific technological solutions are all significant challenges for the UK. Therefore, these findings highlight the difficulty in transferring systemic innovations and new business models to different institutional contexts (Hall et al., 2016) and political economies (Baker et al., 2014).

4.8. Conclusion

In this paper we advance three related propositions. First, we outline how business model innovation may play a key role in unlocking the potential of systemic innovations. We illustrate how the radical 'Energiesprong' business model, based on zero-energy performance contracts, an industrialised supply chain, integrated governance and a simple customer offer, could greatly improve the appeal, delivery and scalability of whole-house energy retrofit.

Second, we show how a range of barriers to business model innovation may be overcome through an innovation intermediary; in our case the Energiesprong market development team. This intermediary has played an instrumental and catalytic role, facilitating stakeholder collaboration, configuring the design of the business model, and brokering the policy changes, financial resources and procurement volumes needed for the business model to be viable.

Third, we describe how such entities can be created by policy, and in turn shape the policy and institutional landscape towards new business models. Our case demonstrates how the creation of a market facing intermediary enabled the Dutch government to achieve its policy aims through a decentralised body - the Energiesprong market development team. This intermediary's role in market formation and business model innovation could thus present a template for both policymakers and academics looking to facilitate and study systemic innovation in a range of other sectors. Therefore, these findings show how policymakers can promote business model innovation through the creation and support of innovation intermediaries. These organisations may further shape the policy and institutional landscape, in a process of feedback between policy and market design in ways that market or government actors alone cannot.

Given the limited generalisability of this single case study, future research could incorporate this framework into a more representative cross-sectional research design of the sector at large. Future research could also explore these processes in other sectors such as food, transport, healthcare or manufacturing; using the theoretical links we make in this paper. Future research on business models for whole-house retrofit could also incorporate quantitative methods, such as on project performance or customer satisfaction to add validity to the claims made here.

5. Article 4: Overcoming the systemic challenges of retrofitting residential buildings in the United Kingdom, A herculean task?

(Pre-print, published in CIED book chapter)

5.1. Introduction

In Greek mythology, the Hydra was a giant serpent with many heads. The second of the 12 labours of Hercules was to kill the Hydra. However, when one of the Hydra's heads was cut off, two more grew in its place. In many ways, overcoming the 'multi-headed-challenges' of achieving widespread energy efficiency (EE) retrofit is an equally herculean task. Policy initiatives in the UK, such as the Energy Companies Obligation (ECO) and the Green Deal, have sought and failed to achieve the mass uptake of residential retrofit. This chapter will argue that such policies have failed to address four systemic challenges that constrain uptake for whole-house retrofits, and that a more comprehensive and wide-reaching policy approach will be needed to overcome each of these challenges. The chapter is therefore focused on some of the solutions to these challenges from the perspective of three key elements of a retrofit: the business model, financing and intermediaries. It also discusses the ways in which policy could support these outcomes.

Retrofit of buildings involves the *"construction approach involving the action of introducing [retrofitting] new materials, products and equipment into an existing building with the aim of reducing the use of energy of the building"* (Baeli, 2013, p. 17). This is different from renovating or refurbishing - which refers to work undertaken to repair homes or make them more aesthetically pleasing (Baeli, 2013). Retrofits of residential buildings have significant potential to reduce carbon dioxide emissions (CCC, 2016), fuel poverty (Sovacool, 2015), and improve occupant health and wellbeing (Willand et al., 2015). However, in the UK, much of this potential is yet to be realised. Residential buildings account for almost a quarter of the UK's carbon emissions (CCC, 2016), and for every £1 spent on retrofitting fuel poor homes an estimated £0.42 is saved in National Health Service spending (UKGBC, 2017). The Committee on Climate Change (CCC, 2015b) estimates that there is cost effective⁵⁶ potential to reduce

⁵⁶ The CCC define the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes together with measures that may cost more than the projected carbon price but are necessary in order to manage costs and risks of meeting the 2050 target (CCC 2013).

direct emissions⁵⁷ from all buildings by a third by 2030, with the need to achieve near-zero emissions from the sector by 2050 (CCC, 2016). It is estimated that this level of retrofit activity would create a Gross Domestic Product (GDP) effect of approximately £25.3bn in gross value added (Guertler and Rosenow, 2016). The UK government has therefore announced a target for all UK homes to achieve an Energy Performance Certificate (EPC) rating of C or above by 2035 (HM Government, 2017).

To achieve these targets, an increasingly comprehensive whole-house approach to residential retrofit will be needed (Hansford, 2015). Such an approach involves multiple measures with strategies for insulation, draught proofing, ventilation, heating systems and low carbon microgeneration (Hansford, 2015). However, the traditional policy approach to residential retrofit has tended to incentivise single measures and piecemeal interventions, which may cause damaging unintended consequences⁵⁸; such as mould growth, poor air quality and in some cases structural damage (Davies and Oreszczyn, 2012). Thus, a comprehensive whole-house retrofit; where the entire building is treated as a system rather than as individual elements or measures, can mitigate such issues and achieve greater reductions in emissions (Hansford, 2015). Much literature in this area has focussed on the key ‘barriers’ to uptake (Fylan et al., 2016; Kangas et al., 2018; Sorrell et al., 2004). However, this focus on barriers has tended to characterise retrofit decision making in terms of rational choices whilst ignoring broader social and contextual factors (Walker et al., 2014). This framing also carries the assumption that there is a latent *demand* for retrofit (Wilson et al., 2015).

The UK is an interesting case study – although achieving major progress in power sector decarbonisation, it still has one of the least efficient housing stocks in Europe. This is despite recent policy initiatives for residential EE. This chapter starts with a brief overview of recent UK policy on residential retrofit. It then moves onto characterising four challenges that constrain demand for retrofits, then proposes solutions centred around three key elements of successful whole-house retrofits: business models (Brown, 2018); financing (Borgeson et al.,

⁵⁷ Those that result from heating, ventilation and cooling systems as well as and hot water. This term excludes emissions from electricity consumption

⁵⁸ Such as mould growth, poor air quality and interstitial condensation; due to poor detailing, and in-sufficient consideration of building physics, airtightness and ventilation

2013) and intermediaries (Kivimaa and Martiskainen, 2018a). Drawing on recent empirical work at the CIED, we then argue that achieving these ambitions will require a comprehensive mix of policies (Kern et al., 2017; Kivimaa et al., 2018).

5.2. UK policy on residential retrofit

Improved EE has played a pivotal role in reducing the UK's energy use and carbon emissions. On a temperature corrected basis, total UK household energy use decreased by 19% between 2002 and 2016, despite a 1% increase in the number of households and a 10% increase in population (BEIS, 2017). Per-household energy consumption fell by 37% between 1970 and 2015, with most of this decrease (29%) occurring since 2004 (BEIS, 2017). EE improvements in individual households have offset the 46% increase in the number of households, the 5.6°C increase in average internal temperatures and the rapid growth in appliance ownership over this period, with the result that total household energy consumption has increased by only 7% in 45 years.

Although rising energy prices and the 2008 recession contributed to recent trends, the bulk of the reduction in per-household energy consumption can be attributed to public policies to improve EE (CCC, 2018; DECC, 2015a; Odyssee, 2017; Thurlwell et al., 2011). Of particular importance have been the major home insulation programmes funded by successive 'supplier obligations' (SOs) such as the Carbon Emissions Reduction Target (CERT - 2008 to 2012) (Rosenow, 2012) and ECO – 2013 onwards. Since 1994, energy and carbon saving targets imposed on electricity and gas suppliers have allowed them to recover the costs through a levy on household energy bills. Also important were the requirement for condensing boilers within the UK Building Regulations and the progressive tightening of EU standards on the EE of electrical appliances (Thurlwell et al., 2011). Evaluations of these policies have shown them to be highly cost-effective, both in terms of the cost savings to participating households and in terms of broader societal welfare (Lees, 2006, 2008; Rosenow and Galvin, 2013). This experience supports the argument that market forces alone cannot deliver all cost-effective investments in residential buildings, owing to multiple and overlapping market failures. Instead, policy intervention can be used to increase the uptake of residential retrofit through a mix of regulation, public engagement and incentives.

Despite dozens of instruments in the broader EE policy mix, targeting residential buildings (Kern et al., 2017) and the apparent success in reducing energy demand through policy, in more recent years there has been a marked shift in the policy landscape. Previously, SOs supported relatively low-cost EE measures, and dedicated grant programmes funded through general taxation provided support for low-income households to invest in EE measures. The last version of such grant programmes - Warm Front, was terminated in 2011 and the government decided to radically change the way EE was delivered in the UK. Through the introduction of the Green Deal in 2013, an On-bill-repayment loan scheme, the government intended to trigger substantial investment in EE retrofits whilst the SO would fund only the costlier EE measures. It is now widely recognised that this approach failed - the Green Deal was effectively terminated in 2015 and funding provided through SOs has been significantly reduced (Rosenow and Eyre, 2016). As a result, the uptake rate of EE improvements has stalled since 2012.

There are, however, signs of a change to the approach taken. The Clean Growth Strategy, launched by the UK government on October 12, 2017, sets out ambitious long-term targets for EE - especially for buildings and would require a significant increase of the current EE improvement delivery rate. The targets specify that all homes as far as possible should reach Energy Performance Certificate (EPC) band C by 2035 and all fuel poor homes by 2030. This requires both adjusting the ambition levels of existing policies and the implementation of new instruments. At the time of writing, government is consulting on several new policy measures, and has recently introduced minimum energy efficiency standards (MEES) for the private rented sector.

5.3. Key challenges for residential retrofit

The limited uptake of cost-effective EE measures; characterised as the 'energy efficiency gap' (Jaffe and Stavins, 1994), remains the focus of much academic and policy research. This is especially the case with residential buildings, where the benefits of retrofitting go beyond emissions reductions, including improvements to health and wellbeing, social welfare and economic development (UKGBC, 2017).

Previous literature on retrofit has adopted key ‘barriers’ to uptake as the theoretical basis for understanding this gap (Fylan et al., 2016; Rosenow et al., 2017a). Yet the original focus of much of this barriers literature, such as Sorrell et al., (2004), was on firm level decision making, rather than on households. As such, the focus on barriers has tended to characterise retrofit decision making in terms of rational economic choices, whilst downplaying social and contextual factors (Walker et al., 2014). This framing also carries the inherent assumption of latent *demand* for retrofit once these barriers are removed (Wilson et al., 2015). This framing has come to dominate the design of recent policy initiatives such as the Green Deal and ECO, which were predicated on households saving money on their energy bills (Rosenow and Eyre, 2016).

We argue that this framing is problematic, primarily because it misrepresents how, why and by whom home renovation decisions are made. This chapter instead frames the problem in terms of four interrelated challenges that continue to contribute to low household uptake of residential retrofits. This framing is an outcome of the empirical work conducted across the previous three articles. We therefore provide illustrative quotations as footnotes with reference to interview codes, which can be found in Appendix A.

5.3.1. Information, engagement and trust

A lack of knowledge of the specific options and benefits of retrofit remains widespread amongst households in the UK (Marchand et al., 2015). While many of the technologies and tools exist to retrofit existing buildings, their uptake is not widespread, largely due to a lack of household knowledge and interest⁵⁹ (Bonfield, 2016). Public engagement and marketing schemes have tried to generate demand but tended to be top-down (Rosenow and Eyre, 2016), short term, and focus on specific subsidy schemes (UKGBC, 2017). This has also created a supply chain largely reliant on short term policy incentives⁶⁰ (CCC, 2015b). Complicated

⁵⁹ “Not everybody knows what’s already possible. If more people would know it, it would scale up more rapidly. So, knowledge dissemination is always ... important.” (I#34)

⁶⁰ “The industry is delivering against the signals and demands and policy levers. What’s wrong is, there isn’t joined up thinking. We are simply looking to the next step ahead and the danger is we will go up cul-de-sacs and ... and come back down them again.” (I#36)

government programmes such as the Green Deal have often been difficult for households to grasp⁶¹ (Marchand et al., 2015). Households who do decide to retrofit often have to interact with multiple tradesmen and installers, who influence decisions on technology choices and subsequent use⁶² (Maby and Owen, 2015). These challenges of gaining appropriate advice, concerns over post-retrofit performance, combined with poor quality workmanship has undermined trust with the wider public⁶³ (Pettifor et al., 2015).

5.3.2. Uncertain benefits and quality

Predicted energy and cost savings from retrofits are based on modelled energy performance. There is consistently a 'performance gap' between these models and actual energy performance outcomes⁶⁴ (Fylan et al., 2016). This is characteristic of an industry with a reputation for low quality, with few contractual penalties for under-performance⁶⁵ (Bonfield, 2016). Equally, retrofit interventions may alter a buildings' existing features, affecting a household's routines and practices in ways that may make them reticent to change⁶⁶ (Wilson et al., 2015). By only focusing on financial savings, policies have also failed to recognise that retrofits could be framed and promoted in terms of aesthetics, comfort and wellbeing (Rosenow and Eyre, 2016). Much evidence now suggests that those who undertake energy retrofits do so because of these non-economic *sources of value*⁶⁷, such as environmental concerns, desire for improved comfort and living standards, property longevity and aesthetics (Fawcett and Killip, 2014; Kivimaa and Martiskainen, 2018b).

⁶¹ "it is even more complex with a split occupancy and ownership; it is difficult enough to get started with those who own their house already" (I#14)

⁶² "It's not the kind of thing that you know that there are many examples of anyone doing on their own." (I#5)

⁶³ "I think there is still a challenge around trust...that's something that I've found so difficult." (I#35)

⁶⁴ "You need guarantees for energy savings. The problem has been the performance gap in retrofit; no one has bothered to look at it." (I#2)

⁶⁵ "You need to be rigorous, contractors need to be high quality, have guarantees that if it is not done properly you can go back" (I#1)

⁶⁶ "to overcome you know scepticism and risk aversion...if no one takes that risk you have no one to ask...or none of your friends have done it ... you kind of can't get to that trust level." (I#5)

⁶⁷ "They want to fix a problem in their home, whether that's a leaking roof, it's a thermostat issue, whatever that might be" (I#31)

5.3.3. Complexity, disruption and timing

Whole-house retrofits involve multiple activities carried out by multiple contractors and consultants. Management of this process is complex and time consuming for the household⁶⁸ (Pettifor et al., 2015). Alongside the significant disruption of extensive works, this can be a major deterrent to uptake⁶⁹ (Snape et al., 2015). Thus, households may prefer to retrofit gradually, when it is less disruptive to do so, despite the higher costs and longer duration (Fawcett, 2014). Consequently, energy retrofit may only be considered during wider renovations⁷⁰ (Wilson et al., 2015). Identifying such ‘trigger points’ could therefore promote retrofit in certain circumstances, such as moving into a new home (Maby and Owen, 2015).

5.3.4. Capital cost and split incentives

Whilst retrofits result in long term energy savings, whole-house retrofits typically require long periods before the capital cost can be recovered in energy savings (Gouldson et al., 2015). Thus, many households lack access to up-front capital⁷¹, with the benefits of the investment not being realised when moving house or in a landlord-tenant situation – termed ‘split incentives’⁷² (Sorrell et al., 2004). Whilst the up-front cost barrier has largely been the focus of recent policy initiatives in the UK, the economics of long term financing is extremely sensitive to interest rates⁷³ (Gouldson et al., 2015), particularly if energy bill neutrality⁷⁴ is required (Rosenow and Eyre, 2016). Further, whilst households may value funding for wider non-energy measures, such as general repairs, the majority of policies fund EE measures alone⁷⁵ (Borgeson et al., 2013). These four related challenges are shown in Figure 19.

⁶⁸ “So, the way to do it it's to make it simpler and clear and really consumer centric.” (I#31)

⁶⁹ “Do you want it in your house if it's not final? I mean, I'm an energy specialist and I still replace my boiler much later than I was supposed to because it's a hassle, isn't it?” (I#38)

⁷⁰ “So, ... use the existing stuff that's going on. I think that's a really important point. The ... trigger points” (I#23)

⁷¹ “Capital is addressed in very isolated pockets, and access to capital is certainly a barrier” (I#26)

⁷² “There's a split incentive for renters to have more efficient housing or appliances.” (I#26)

⁷³ “your cost of capital, every % that you pay more or less on your interest rate tells you what you can do technically in your building, most heat engineers I know have not a clue about finance” (I#17)

⁷⁴ Energy bill neutrality may include requirements that modelled savings are ‘cash-flow positive’ meaning that finance repayments are equal to, or result in, net energy cost savings (Borgeson et al., 2013).

⁷⁵ “because you can't strip ... out the pure energy component of an investment even if you use the best energy performance contract even if you're the best ESCO in the world even if you're doing this simplest thing such as changing the LED light bulbs of a street light.” (I#19)

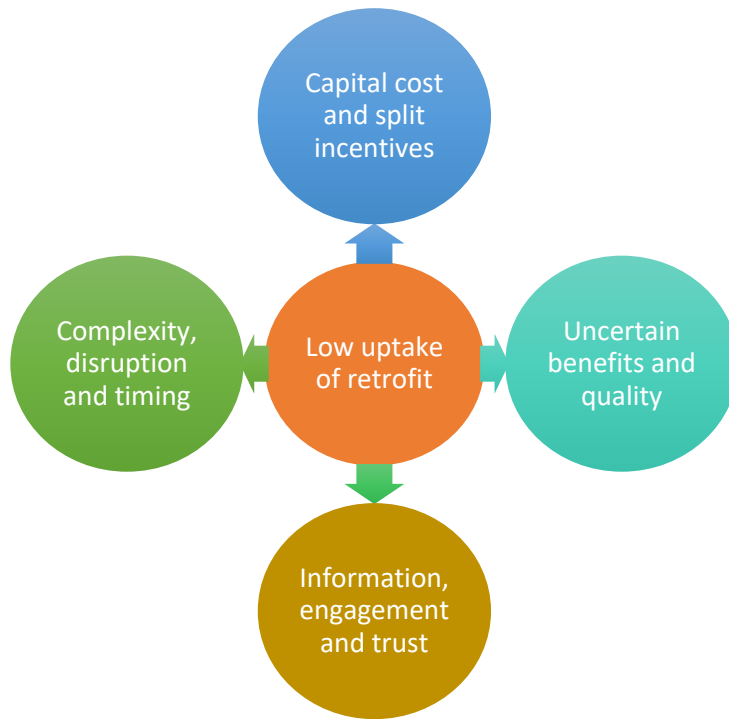


Figure 19 Key systemic challenges for driving retrofit uptake

Typically, policy interventions in this area have targeted one, or at most two, of these issues. However, to overcome these ‘multi-headed-challenges’ and deliver on the promise of residential retrofit, a systemic approach across multiple sectors and involving multiple government departments will be necessary (see Section 5.5). This article draws on three emerging research themes: business models; financing and intermediaries. Building on these insights we then propose policy solutions to overcome the challenges for the widespread diffusion of whole-house residential retrofit.

5.4. Overcoming the challenges for residential retrofit

In the following section we explore how best practice approaches to retrofit: business models; financing and intermediaries, can overcome many of the challenges that constrain uptake identified in the previous section.

5.4.1. Retrofit business models

A business model is defined as the nature of the products or services delivered to customers; the activities involved in delivering these; and the means of capturing revenue from these activities (Boons et al., 2013). Many radical innovations only became widespread once a complimentary business model enabled their diffusion (Teece, 2010). Examples such as the MP3 player, low cost air travel and smartphones owe their success to the effective pairing of the technology with an appropriate business model and in many cases financing package. Emerging 'service-based' business models provide the useful end service rather than the technology or commodities themselves, shifting incentives for resource efficiency onto suppliers (Bocken et al., 2014). Consequently, energy service business models are promoted as a means of reducing energy demand (Labanca et al., 2014). Innovations such as distributed energy⁷⁶ and whole-house retrofit may therefore require novel, complementary business models before they are viable on a large scale (Hall and Roelich, 2016). Drawing on recent research at the CIED (Brown, 2018), we argue that despite significant policy action in this area, a major reason for the lack of uptake of whole-house retrofit is the limitations of the traditional business model.

The dominant business model for residential retrofit (Figure 20) is characterised by a piecemeal offering; with a fragmented supply chain, a focus on single (rather than multiple, complementary) measures, and no guarantees on performance. This is typically marketed on estimated energy cost and carbon savings and involves measures and technologies installed by separate contractors. Customers procure the individual measures, energy audits and finance separately, with the result that multiple interfaces are required for a whole-house residential retrofit. The offer of energy savings is based on modelled impacts of measures, and no performance guarantees are provided. Therefore, any finance package is based on estimated rather than guaranteed savings. Such an approach has typified the delivery of the EE through UK policies such as ECO and the Green Deal.

⁷⁶ Defined as electricity generation feeding into the local distribution network (operating from 132kV down to 230V), as opposed to the regional or national transmission grid (which operates from 400kV and 275kV).

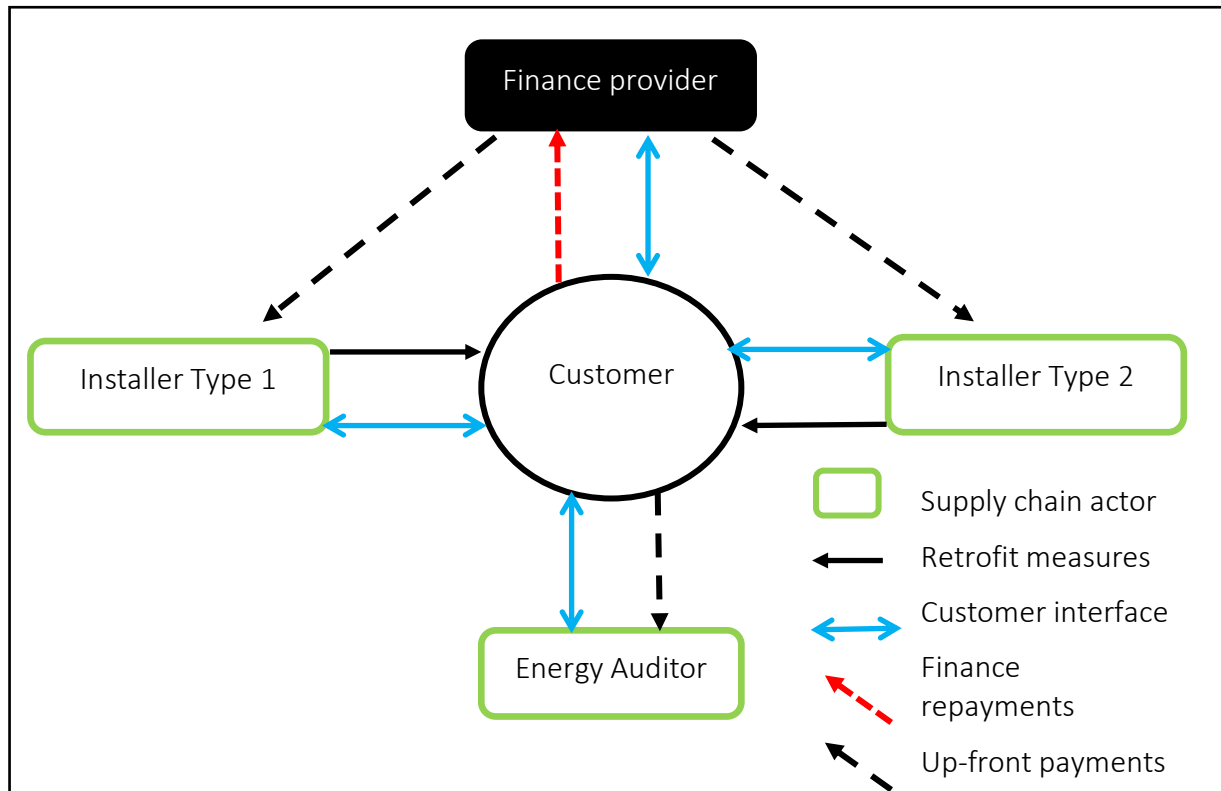


Figure 20 The incumbent 'atomised market model' (Brown 2018)

This approach introduces significant *complexity* for customers in managing multiple interfaces with sub-contractors, energy auditors and finance providers, also tending to result in major *disruption* for a whole-house retrofit. Equally, the narrow emphasis on estimated cost savings, without performance or ongoing maintenance guarantees, means *uncertain benefits* for the customer and provides limited trust on installation *quality*. Unsurprisingly, this approach has resulted in low demand for whole-house residential retrofits.

Recently, novel, integrated business models for residential retrofit have begun to emerge. These approaches emphasise a broader source of value for a whole-house retrofit; focussed upon aesthetics, increased property value, comfort, health and wellbeing alongside energy and carbon savings. Such approaches involve integrated and increasingly industrialised supply chains providing comprehensive whole-house retrofits, through a single contractor or well integrated network of sub-contractors. These approaches are characterised by a simplified customer interface with a single expert point of contact to co-ordinate entire project. Some

examples also offer integrated financing packages, and in some cases energy performance guarantees.

The Energiesprong initiative originated in the Netherlands and has expanded into the UK (Energiesprong, 2017). Customers are offered a whole-house residential retrofit, based upon net-zero energy consumption. Typically, an Energiesprong retrofit involves the rapid delivery and installation of off-site manufactured, insulated wall facades, integrated with renewable heat systems and photovoltaic panels as well as ventilation and controls. The provider offers a 30-year energy performance guarantee (based on set internal temperature) for annual net-zero energy consumption, with specified energy usage limits, alongside an upstream financing package. An energy service contractor (ESCO) also takes on responsibility for the payment of the energy bill of the customer to provide ‘total energy management’. This represents a holistic energy services offering to the household, commonly termed a Managed Energy Services Agreement (MESA) (Kim et al., 2012) shown in Figure 21. This approach is currently being trialled in multi-family buildings and across large social housing estates.

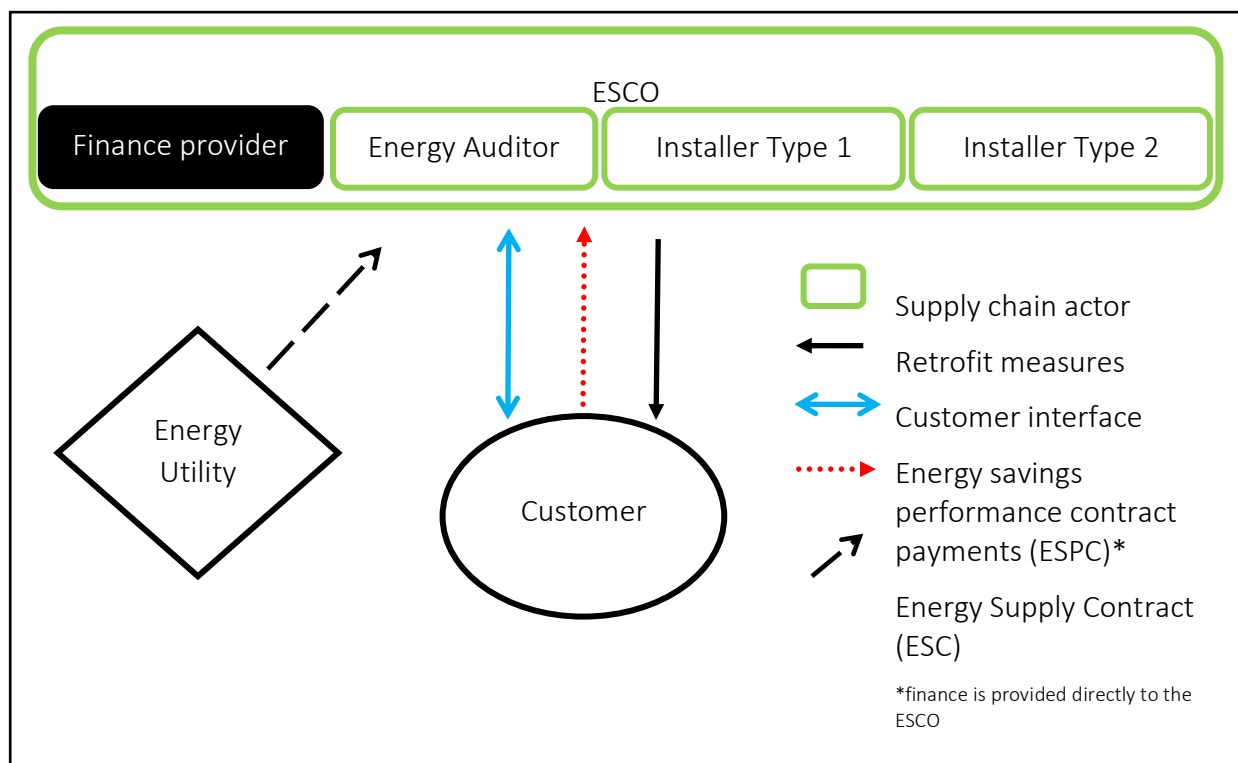


Figure 21 Energiesprong Managed Energy Services Agreement (MESA)

Integrated business models such as the MESA have significant potential to drive demand for residential retrofit. By emphasising broader sources of value and including additional

renovation measures as part of the offering, suppliers can attract customers by appealing to the *wider benefits* of improved aesthetics, increased property value, comfort, health and wellbeing alongside energy and carbon savings. Creating a simplified customer journey through an integrated supply chain, project co-ordination and a financing offer reduces *complexity* and minimises *disruption* for households. Further, the offer of energy performance guarantees provides *certainty* surrounding the ongoing performance benefits of the retrofit and the *quality* of the installation. While this may be the optimal solution, it is worth noting that integrated business models also face barriers and their uptake has been slow in the residential sector (Kangas et al., 2018).

Business model innovation involves novel approaches and relationships for the delivery of products and services (Chesbrough, 2010). However, incumbent business models may be heavily embedded with existing industry practices, technological artefacts and regulatory regimes (Hannon, 2012). Therefore, adopting integrated energy service business models remains a challenge for an industry dominated by small scale SMEs.

5.4.2. Retrofit finance

The up-front *capital cost* of retrofit measures and the *split incentives* faced by tenants and landlords, remain a key challenge for the scaling up of whole-house residential retrofits. Many UK households are also still in fuel poverty - defined as the necessity to spend more than 10% of household income on energy bills (Sovacool, 2015).

As noted above, the UK's market-based SOs have funded significant loft and cavity wall insulation, low energy lightbulbs and other low-cost measures (Rosenow and Eyre, 2014). ECO. The latest evolution of the SO policies was initially designed to fund more expensive retrofit measures, such as solid wall insulation. It has since been criticised for its focus on single measures (Brown, 2018), dis-incentivising comprehensive installations, with no funding for complementary work such as ventilation and damp prevention (Hansford, 2015). SO policies require a levy on all households' energy bills, and thus increase the energy bills of households that do not benefit from programmes such as ECO (Rosenow et al., 2013b). The ECO has now been redesigned focus on the 'fuel poor'. Although, having added approximately £50 a year to

average household bills - a total of £1.3Bbn annually (DECC, 2013a), policies like ECO are arguably a poor tool for addressing fuel poverty (Rosenow et al., 2013b).

Meeting the UK's retrofit targets will require an estimated £85.2bn of net investment to 2035 (Rosenow et al., 2017a). Achieving this level of investment through an SO like ECO could introduce politically unacceptable bill rises (Kern et al., 2017) and be particularly regressive for the fuel poor who do not adopt retrofit measures (Rosenow et al., 2013b). Previous fuel poverty policies such as Warm Front did not raise wider energy bills as they were funded by general taxation (Sovacool, 2015). A fuel poverty policy funded by general taxation is also more consistent with targeting the co-benefits of social welfare (Rosenow et al., 2013b) and improved health and well-being (UKGBC, 2017).

Alongside fuel poverty grants, there is a likely need for repayable retrofit financing for the 'able-to-pay' segment (Freehling and Stickles, 2016). The UK's Green deal policy involved a novel *finance mechanism*, intended to deliver approximately 2 million retrofit installations per year and leverage billions of pounds of private sector investment. The scheme was based on private sector lending to households, paid back through energy bills—known as On-bill-repayment. However, the scheme achieved a fraction of its targets, and resulted in a significant loss to the UK taxpayer before its premature scrappage in 2015 (Rosenow and Eyre, 2016).

A range of other retrofit finance mechanisms have been developed, in the UK, wider EU and USA, including several that have been markedly more successful than the Green Deal (EEFIG, 2015). Examples include property assessed clean energy finance (PACE) in the USA, repaid through property taxes (Kim et al., 2012); low cost public loans (such as the German KfW scheme) (Schröder et al., 2011); utility funded On-bill-financing (Zimring et al., 2014a); retrofit mortgages (EEFIG, 2015); state backed guarantee funds (Borgeson et al., 2013); and energy service agreements (ESA) - where finance for measures is procured upstream by an ESCO as part of an energy performance contract (Kim et al., 2012).

Examples of successful retrofit financing programmes, including Germany's KfW programme and California's PACE scheme, share some common features. These schemes typically include; a *cost of capital* that is low enough not to deter households and enable deeper retrofit

measures to remain cost effective (Rosenow and Eyre, 2016); a simplified *customer journey* - with finance often arranged by the contractor or project manager (Brown, 2018), use of an existing repayment channel (such as property taxes), attaching the debt to the property not the householder (resolving the spilt incentive issue); and funding for *broadier sources of value*, such as wider renovation work or essential home improvements, that are often more highly valued by households (Fawcett and Killip, 2014).

By contrast the Green Deal involved a complex vetting and application process that required a separate interface with a third-party provider, with no funding available for wider improvements. Introducing significant complexity that was likely to be off-putting for most households. The Green Deal also had relatively high interest rates of 7-11% (Marchand et al., 2015). Indeed, the total cost of capital amounted to at least 49% of total Green Deal Plan costs over 15 years (UKGBC, 2014). Programmes such as the KfW scheme offer finance at extremely low or zero interest rates (>2%) (Schröder et al., 2011). Such offers are likely to be more appealing to households (Marchand et al., 2015) and drastically improve the economics of whole-house retrofits with longer payback periods (UKGBC, 2014).

Several approaches exist to reduce the cost of capital for retrofit finance. Privately funded schemes such as PACE and retrofit mortgages are *secured* against the property and can be securitised and sold to secondary markets – reducing risk and transaction costs for investors (Borgeson et al., 2013). State actors may also assist in reducing the cost of capital, particularly where customers face difficulties or high costs in accessing finance. Policy options include interest subsidies (Gouldson et al., 2015), state provision of subordinated (high risk) capital (Zimring et al., 2014a), investor guarantee funds (Borgeson et al., 2013) or the direct provision of low cost loans, as has been the case in Germany's KfW programme (Schröder et al., 2011).

However, there are limits to what financing alone can achieve. In most cases financing is likely to be an *enabler* of retrofit projects rather than a *driver* of demand (Borgeson et al., 2014). Consequently, policymakers can introduce a range of incentives to promote demand for retrofit. These include fiscal or energy supplier incentives, such as variable property taxes (i.e. stamp duty or council tax), income tax rebates, VAT reductions or EE feed in tariffs (Rosenow and Cowart, 2017; UKGBC, 2013). Some can be made fiscally neutral through penalizing

properties that do not meet a certain performance level (UKGBC, 2013). Incentives are likely to be particularly effective when they are available at key junctures when broader renovation decisions are being made. Thus, approaches that target key *trigger points* such as when properties change hands, during extensive renovations or heating replacements, are likely to be most successful (Maby and Owen, 2015).

5.4.3. Retrofit intermediaries

Intermediaries – that can be individuals, organisations or platforms – facilitate innovation processes (and broader transition processes) by educating, collecting and allocating financial and human resources, assessing new technologies and practices, creating partnerships, and influencing changes in regulations and rules (Stewart and Hyysalo, 2008). They may also shape how innovation occurs when it faces the user and negotiate on behalf of other actors (Stewart and Hyysalo, 2008). Intermediaries may act as a single point of contact between households and retrofit contractors. In this section, we focus on how intermediaries can (1) stimulate, guide and manage different whole-house retrofit projects, and (2) aid the creation of a market for new retrofit business models and financing solutions, supporting a transition towards a low energy housing stock.

To address the challenges of *information, engagement and trust* as well as the complexity of whole-house retrofits, intermediary actors are needed both at project level (e.g. specific retrofits) and the broader market level. In the former, intermediaries interconnect different technological, human and financial solutions. In the latter, they can have a crucial role in building trust and aggregating and disseminating clear and reliable information on retrofit techniques, suppliers and contractors.

A review of European case studies (Kivimaa and Martiskainen, 2018b) shows that two types of intermediaries are specifically important in driving the market for retrofit. First, *innovation funders* such as Innovate UK are important in supporting successful piloting of complex architectural or systemic innovation (i.e. interconnecting innovative and standard solutions to deliver whole-house retrofits). Second, *social housing providers and local community actors* are crucial in market creation and advancing retrofits in practice. Yet, the role of social housing

providers has lately diminished through policies introducing rent caps and ‘right to buy’ schemes, as well as local authority budget cuts – leaving less resources for housing providers to carry out retrofits in their building stock. In addition, *business networks*, such as the Passive House Platform in Belgium (Mlecnik, 2013) are important in pooling together different types of companies and solutions to create new business models and promote retrofitting. In the UK, the Green Deal Pioneering Places also stimulated cooperatives to deliver retrofits. What still seems to be largely lacking in the UK are intermediaries that can effectively stimulate the market for whole-house retrofitting by owner occupiers and private landlords, at the community level.

At the project level, intermediaries are needed to stimulate interest in whole-house retrofits, share experiences among home owners, and provide necessary expertise during planning and implementation. Platforms, such as Eco Open Houses in the City of Brighton and Hove, organised in 2008 and between 2010-2015, enabled people to see and visit sustainable homes. These cases demonstrate that such events have been extremely useful in providing information, stimulating engagement and sharing knowledge on whole-house retrofits, as well as providing details of trusted local tradespeople and installers. When planning and executing whole-house retrofits, individual actors taking up intermediary roles – for example, *architects*, *building cooperatives* or *local authority officers* taking actions beyond their usual roles - are valuable in helping households make choices over technologies and materials. Previous research has shown the importance of local authority energy managers, planners (Lovell, 2008) and sustainability officers (Martiskainen and Kivimaa, 2018) as important intermediaries in project planning and implementation.

Recent CIED research involved a case study of a 3-bedroom terraced home built in 1860 in Southampton Street, Brighton. The house was part of a local project obtaining funding from the ‘Green Deal Pioneer Places’ Programme (a national government-funded programme that sought to demonstrate the benefits of EE). The house has undergone an extensive retrofit, motivated by the owners’ interest in climate change and sustainable living, though the owners had no specific knowledge or interest to carry out a retrofit themselves. This was coordinated by the Green Building Partnership, which was formed initially to take part in the programme. The owners therefore did not have to acquire knowledge on the technical or policy aspects of

the retrofit. The retrofit measures included external solid wall insulation, loft insulation, improved windows, new boiler and heating controls - involving multiple partners. While the Green Building Partnership led the process, from the perspective of the owner, there was no one key intermediary communicating between the broader scheme and the owners, leading to some confusion. Southampton Street later became part of local Eco Open Houses event, acting as an example to others.

Without these intermediary roles, projects may become much more complicated. Intermediaries provide information on the retrofit options available for the building projects and help to create a plan that meets regulations. More support is, however, needed from dedicated intermediaries, to facilitate 'one-stop-shops' for retrofitting (Brown, 2018), through which households can access trustworthy advice on technological and financing options, as well as tradesmen, contractors and installers. In this way intermediaries are often the key actors in providing *information* for households on the options and benefits of undertaking whole-house retrofits; *engaging* communities and supply chains to promote retrofit at a local level; and are also likely to be more *trusted* than actors with a financial stake in promoting certain services or products.

Overall, some factors for successful intermediaries can be depicted. On a broader scale, most impact occurs over a longer timeframe. For example, the Centre on Alternative Technology established in the 1970s still influences the expectation and visions behind home retrofits. Whilst the Eco Open Houses events have been popular in Brighton, they were not organised in 2016-2017, creating uncertainty about future knowledge exchange and example setting locally. Another important determinant in market formation is the positioning between ambitious sustainability aims and connections to business and supply chains.

Innovative business models, such as the Energiesprong approach, owe much of their success to dedicated intermediaries, often initiated by government policy. Energiesprong was brought into being through a €45m grant from the Dutch government, and the setting up of a *market development team* (Energiesprong, 2017). These market development teams brought together stakeholders including; the construction industry, housing providers, policy makers and financiers to radically re-think the business model through which EE retrofit is delivered. Whilst

these approaches still face challenges, they could represent a template for how the UK could deliver on its ambitious retrofit targets.

5.5. Conclusions and policy recommendations

In the ancient Greek myth, the Hydra was invulnerable only if it retained at least one head. Heracles, realising that he could not defeat the Hydra alone, worked with Iolaus, and through a combination of decapitating the beasts' multiple heads and burning the stumps with a firebrand, stopped them growing back. The Hydra's remaining immortal head was cut off with a golden sword given to Heracles by Athena. Heracles placed the head—still alive and writhing—under a great rock and shot it with an arrow dipped in the Hydra's poisonous blood. Thus, his second task was complete.

The previous sections outline how tackling the 'multi-headed-challenges' of whole-house residential retrofit, will require a similarly sophisticated and multifaceted approach. Promoting business model innovation, delivering a range of financing options and incentives along with the establishment of strategic intermediaries, at both local community and national levels will require a wide reaching and systemic policy strategy. This strategy should incorporate a mix of regulations, financing and incentives along with the establishment of new institutions and the recognition of EE as a strategic infrastructure priority. Equally, different solutions will be required for socially rented, privately rented and owner occupier sectors. This will require joined up action across multiple government departments including but not limited to: Business Energy and Industrial Strategy (BEIS), Ministry of Housing, Communities and Local Government's (MHCLG), the Treasury (HMT), Education (DfE) and Health (DH), the Department for Work and Pensions (DWP), Her Majesty's Revenue and Customs (HMRC) and the National Infrastructure Commission (NIC). The following section provides an outline of the range of policies (Table 13) that could contribute to achieving the enormous potential for the whole-house retrofit of residential buildings.

Table 13 Policy mix for achieving widespread whole-house residential retrofit in the UK

Policy type	Policy	Challenge addressed	Government department
Regulation (sticks)	EE as an Infrastructure Priority and given the level of strategic support and status as other forms of infrastructure (Frontier Economics Ltd, 2015)	<i>All</i>	HMT, NIC
	Minimum EE Standards (MEES) moving to EPC C in 2035 (Sustainable Energy Association, 2017)	<i>All</i>	MHCLG
	New retrofit quality assurance standard such as home Quality Mark (Bonfield, 2016)	<i>Uncertain energy savings and quality</i>	BEIS, MHCLG
Financial (carrots)	Financial Incentives at trigger points, options could include: (UKGBC, 2013) -Variable Stamp duty -Variable Council tax -0% VAT on renovation work that includes retrofit -Income tax rebates -EE Feed in Tariff	<i>Capital cost and split incentives Complexity, disruption and timing</i>	BEIS, HMT, HMRC
	Government backed low interest financing mechanism secured to property and available at point of sale of retrofit (Borgeson et al., 2013)	<i>Capital cost and split incentives Complexity, disruption and timing</i>	BEIS, HMT, NIC
	Fuel poverty obligation funded by general taxation (Rosenow et al., 2013b)	<i>Capital cost and split incentives</i>	BEIS, HMT, DH, DWP
New institutions and intermediaries (tambourines)	National Retrofit Taskforce/Agency (Rosenow et al., 2017a) with central Information Hub and a Data Warehouse	<i>All</i>	BEIS, MHCLG, HMT, DfE, DH, NIC
	Area based intermediaries based on Community Social Enterprise or Local Authority Arm's Length Management Organization (ALMO) delivery models (UKGBC, 2017). Market facing intermediaries and standardised procurement frameworks (Nolden et al., 2016)	<i>Information, engagement and trust Complexity, disruption and timing</i>	BEIS, MHCLG, HMT, DfE, DH, NIC

5.5.1. Standards and regulations

EE retrofits create economic benefits that are often several multiples of the initial investment (Guertler and Rosenow, 2016). Cost effective investments in residential EE to 2035 have a current net present value of £7.5bn. With wider benefits such as GDP effects and health improvements that could be up to £47bn (Rosenow et al., 2017a). Thus, EE investments share the characteristics of other forms of infrastructure as identified in HM Treasury's valuation guidance (Frontier Economics Ltd, 2015). Therefore, we argue that EE should be re-framed as an infrastructure priority by the UK government and given the level of strategic support and status as other forms of infrastructure; such as road, rail and supply side energy infrastructure and be included within the remit of the NIC (Rosenow and Cowart, 2017).

The UK Clean Growth Plan set an aspirational goal for all residential buildings to achieve and EPC level C or higher by 2035. We support these aims, but argue the government could go further, mandating minimum EE standards (MEES) for the owner occupier sector in the 2020s. This could take the form of a gradual step change through to a minimum EPC level of C by 2035 at the point of sale, with potential for ever tightening standards moving into the 2040s and beyond (Sustainable Energy Association, 2017).

There remain concerns surrounding the standard and quality of many installations currently funded under ECO, particularly solid wall insulation, which is to be a key part of the UK's targets (Hansford, 2015). Therefore, we support the findings of the recent Each Home Counts – 'The Bonfield Review', that the government should establish a new quality assurance standard such as a home Quality Mark (Bonfield, 2016). Such a policy should be designed not to introduce a further regulatory and cost burden on SMEs and could build on existing standards of good practice along the lines of the Investor Confidence Project in the commercial sector (Investor Confidence Project, 2015).

Taken together these three high-level regulatory policies would set the strategic direction for UK residential retrofit policy and would send market signals for the development of integrated business models, novel financing solutions and market intermediaries. However, on their own, top down regulations are unlikely to build a sufficient market for whole-house retrofit.

5.5.2. Financial measures

Overcoming the up-front capital cost of EE retrofit remains a challenge for many households. Current fuel poverty schemes such as ECO are limited in size and have inherent design flaws (Rosenow et al., 2013b). For those in fuel poverty we instead propose that these costs should largely be met through government grants in the form of a fuel poverty obligation paid for by general taxation. This would allow the government to better spread the costs of such a scheme, and if properly designed could reduce spending in areas such as health, social care and welfare (Rosenow et al., 2017a).

For the ‘able to pay’ segment a range of market led financing mechanisms may eventually emerge, including mortgage-based approaches and other private sector offerings. Yet, we argue that the government should learn the lessons of the failed Green Deal and promote a new low-cost financing mechanism tied to the property, perhaps retaining the On-bill repayment channel. Successful financing schemes such as Germany’s KfW program have used government funds to provide a *low cost of capital*, involved a simplified *customer journey* and funded *broader sources of value* such as wider renovation works, which are likely to be perceived as higher value by households (Schröder et al., 2011).

Although providing sources of lending for EE measures is key to *enabling* retrofit projects, it is unlikely that low cost financing alone will be *drive* demand for retrofit (Borgeson et al., 2014). Therefore, government can introduce a range of fiscal incentives at key trigger points to promote uptake. These might include; variable VAT, stamp duty land tax, council tax, income tax rebates or an EE feed in tariff for households who have undertaken measures – with increasing benefits for deeper retrofits (UKGBC, 2013). Such approaches will be most effective when they are targeted at key trigger points such as moving home or when undertaking major renovations (Maby and Owen, 2015).

5.5.3. New institutions and intermediaries

A key challenge for residential retrofit remains the paucity of information, engagement and trust within communities. Recent work at the UK Green Building Council (2017) has highlighted a new role for intermediaries to catalyse retrofit and regeneration activity in local areas. These

actors would engage local communities on the benefits of retrofit and re-generation and be the key point of contact for: information, marketing, financing and project delivery, through dedicated project managers/coordinators – drawing on the pre-existing networks of diffuse intermediaries already operating in many communities (Martiskainen and Kivimaa, 2018). These intermediaries could be based on Community Social Enterprise or Local Authority Arm's Length Management Organization (ALMO) delivery models, and funded through a combination of local authority budgets, central government grants and community shares (UKGBC, 2017).

Intermediaries also play a role in promoting business model innovation for the delivery of whole-house residential retrofit. Examples such as the Dutch Energiesprong scheme (Brown, 2018) and the RE:FIT program in London (Nolden et al., 2016) demonstrate how public bodies can promote business model innovation, through the creation of new market facing intermediaries and standardised procurement frameworks. These initiatives help reduce transaction costs and bring together stakeholders to foster learning, new funding approaches and supply chain integration.

Achieving the promise of residential retrofit and tackling the 'multi-headed-challenges' that stand in the way, will require a joined up and co-ordinated strategy - as outlined in this chapter. To deliver this vision, we argue that the UK government should set up a National Retrofit Taskforce. This body would be responsible for the planning and delivery of the MEES targets through an overarching strategy, monitoring and verification process that brings together key stakeholders, including, Government, Third sector, Industry and Consumer groups (Rosenow and Cowart, 2017). This new high-level intermediary would also be responsible for the management of a central Information Hub (to act as a collection point for best practice advice and guidance) and a Data Warehouse (to act as a store for property-level data and information) (Bonfield, 2016). Advising multiple government departments, this body could monitor progress towards the UK's targets for the sector and propose policies to keep this progress on track.

Climate change is perhaps the biggest challenge facing humanity in the 21st century. Buildings are perhaps the biggest single contributor to carbon emissions, with the existing residential buildings by far the largest component (CCC, 2016). Such a herculean challenge will require an equally herculean effort. We argue that the considerable rewards are more than worth rising

to this challenge, and that the proposals presented here could go a long way towards achieving this.

6. Discussion

This chapter discusses the findings of this thesis in the context of the wider literature on business models, finance, residential retrofit and retrofit policy. It synthesises the findings of the four articles and discusses their combined contribution to the research aims. Section 6.1 indicates the contribution of the thesis to the broader theoretical literature; Section 6.2 discusses the strengths and weaknesses of the methodology; Section 6.3 discusses the empirical findings of the thesis to the understanding of residential retrofit; Section 6.4 explores the wider policy relevance of the findings; and Section 6.5 summarises the overall contribution to knowledge of the thesis.

6.1. Conceptual contributions

This thesis makes three main conceptual contributions to the academic literature on business models, finance and innovation studies. First, the merits of a business model framing and the contribution of governance as a component of business models is illustrated, followed by a novel typology of retrofit business models. Second, the value of the novel framework describing the features of a finance mechanism, is demonstrated, followed by a novel typology retrofit finance mechanisms. Third, it is argued that business model innovation may be a necessary component of systemic innovation, further highlighting the role of innovation intermediaries.

6.1.1. Business model components

This thesis contributes to the business model literature by demonstrating how business model *governance* is an essential component common to all business models (Ritter and Lettl, 2018); thus adopting a modified version of Boons and Lüdeke-Freund, (2013) components framework - synthesising several elements from the literature (Hellström et al., 2015; Zott and Amit, 2010). This highlights some important limitations of Osterwalder and Pigneur's (2010) well known 'business model canvas'. While suitable for case studies, (Foxon et al., 2015; Hannon et al., 2013; Joyce and Paquin, 2016), the nine-point framework is too cumbersome for a cross-sectional research design. Boons and Lüdeke-Freund (2013), therefore, aggregate these to four components: *value proposition*, *supply chain*, *customer interface* and *financial model*. These components enable commensurability of the components of different business models

within an industry (Osterwalder, 2004) – although provide no description of how they are linked.

The business model framework used in this thesis addresses this gap through the addition of the *governance* component. This concept, most associated with Zott and Amit, (2001; 2010) emphasises how networks typify the delivery of most products and services. Thus, governance describes how business model components are integrated and whether a hierarchical or market logic dominates (Hellström et al., 2015; Wells, 2013). This has significant implications for the nature and success of business models.

The significance of business model governance is illustrated by how different archetypes involve different modes of governance (Articles 1 and 3). Whilst the *atomised market model* operates a market-based logic, where no single focal firm dominates (Zott and Amit, 2010); the *one-stop-shop* business model involves an integrated mode of governance – typically through a single organisation. Thus, the mode of governance is the critical means of differentiating these business models, even where the fundamental value proposition is the same. Moreover, both Articles 1 and 3 show that this integrated mode of governance is a more effective means of delivering whole-house retrofit, whereas in other industries more disaggregated business models may be more effective (Amit and Zott, 2001).

This strengthens Boons and Lüdeke-Freund's (2013) four components, by showing who governs these activities and how well they fit together (Wells, 2013; Zott and Amit, 2010). Consequently, Figure 22, shows how the five components used in this thesis relate to the nine from Osterwalder and Pigneur's (2010) business model canvas - highlighting the role of governance. Therefore, this provides a useful contribution to the business model literature, particularly for comparing alternative business models.

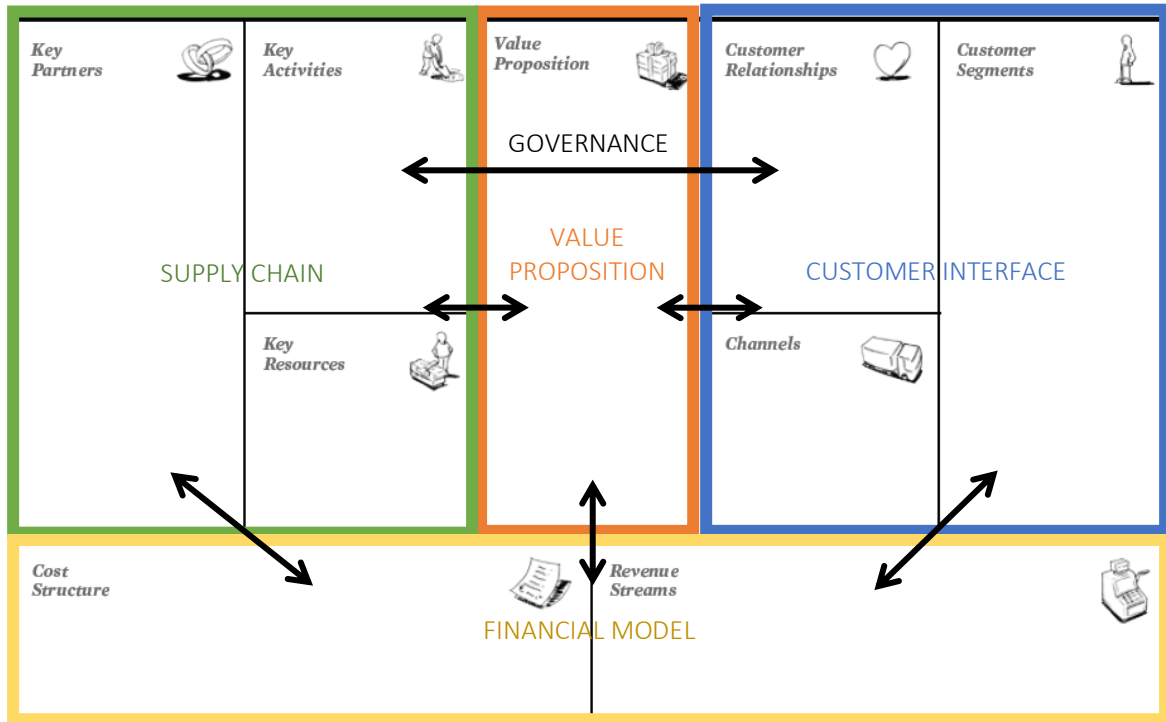
The Business Model Canvas

Figure 22 Business model framework. Adapted from: Osterwalder and Pigneur (2010), Boons and Lüdeke-Freund, (2013) and Zott and Amit, (2010)

However, this framework also has several limitations. Firstly, as shown in Figure 22, the aggregation of Osterwalder and Pigneur's (2010) nine components to five obscures some detail. For example, a common theme across the interviews was the importance of *customer segmentation* (a sub component of the customer interface in Figure 22) between housing tenure, demographics and building type.

Furthermore, the business model concept itself lacks the detail of individual studies of: supply chain dynamics; customer relationships; marketing; and revenue models (Baden-Fuller and Morgan, 2010; DaSilva and Trkman, 2014) or studies of the social and cultural relationships between firms, individuals and society (Doganova and Eyquem-Renault, 2009). Equally, there are issues of wider relevance beyond the business model, such as the political and economic context and social and cultural practices which influence the viability and relevance of particular business models (Wells, 2013).

These weaknesses can, however, also be viewed as strengths. The business model provides a comprehensive overview of an organisation and its networks; drawing together several dimensions and situating them within a single framework (Ritter and Lettl, 2018). Therefore, as Section 6.2 will show, the strength of the business model concept is its synthesis of several fields including: management, economics, innovation studies and sociology (Foss and Saebi, 2018). By combining elements of these perspectives, the business model can more fully explain how organisations create, deliver and capture value - clarifying their role in technological change. Thus, providing an appropriate conceptual framework for addressing the research aims of this thesis.

6.1.2. Finance mechanisms and financial models

This thesis makes an important conceptual contribution to the literature on finance for energy efficiency and sustainable innovation. The framework developed in Article 2 identified the generic features common to different finance mechanisms as the *source of capital*; the *financial instrument(s)*; the *project performance requirements*; the *point of sale*; the *nature of the security and underwriting*; *repayment channel* and the *customer journey*. As shown in Article 2, this allowed a comparison of these features, helping to explain why certain mechanisms are more or less successful. This framework could be applied to different forms of financing for energy systems or to other sectors.

The review of the academic literature in Article 2 demonstrated that few existing studies provide a conceptual basis for understanding the features of alternative mechanisms (Diaz-Rainey et al., 2017). This thesis addresses this gap, contributing to broader debates on the role of finance in the energy transition. While several studies have discussed the structural and cultural barriers to investment in sustainable innovations and new asset classes (Auerswald and Branscomb, 2003; Hall et al., 2015; Masini and Menichetti, 2013, 2012), this study, along with several others (Blyth et al., 2015; Gouldson et al., 2015; Hall et al., 2016; Mazzucato and Penna, 2016), identifies some of the ways these barriers can actually be overcome. Thus, Article 2 describes how the features of alternative forms of finance can affect their success in different contexts.

Article 2 also introduces a novel typology of six retrofit finance mechanism archetypes which are differentiated by their features, moving from the most to the least common these include: *public loan/credit enhancement(s); On-bill finance and repayment; property assessed clean energy financing, green mortgages; energy service agreement financing; and community financing*. Whilst different mechanisms with different features (such as different ratios of debt and equity (Tapia, 2012)) will be more or less suitable in different sectors; this thesis identifies three important outcomes for the success of finance mechanisms - the *cost of capital*, the *customer journey* and the *sources of value* funded.

Firstly, and most obviously, the cost of capital is critical for the viability of capital-intensive investments, such as those which characterise sustainable energy systems (Donovan and Corbishley, 2016; Donovan and Nuñez, 2012). Secondly, reducing the complexity of the customer journey in procuring finance (Norton et al., 2013) and the transaction costs for finance providers (Sorrell, 2007; Yildiz, 2014), can greatly increase the efficacy of financing solutions - particularly for smaller scale investments such as residential retrofit. Thirdly, funding for broader sources of value, in this case wider renovation measures - may be critical in the success of retrofit finance mechanisms (Borgeson et al., 2014). Different forms of financing affect these issues in complex ways. However, mechanisms, which foreground them in their design are likely to be more successful.

The thesis also identifies the relationship between finance and business models - another area that is neglected in the literature. Residential retrofit often necessitates third-party financing as an integral part of the financial model (Blyth et al., 2015). Whereas in many sectors customers pay for the full cost of products and services, others necessitate a range of financing solutions to enable the value proposition to be realised (OECD, 2015b). Articles 1, 2 and 3 outline how retrofit finance mechanisms are an essential component of effective business models. Thus, while distinct from the financial model (DaSilva and Trkman, 2014), integrated finance mechanisms an essential element of a successful retrofit business model.

6.1.3. Business models and systemic innovation

This thesis demonstrates the importance of new business models in the diffusion of systemic innovations. Systemic innovations require complementary changes in supporting technologies, technical skills, cultural norms, user competences, organisational practices and regulations (Midgley and Lindhult, 2015). Previous authors have emphasised the importance of business model innovation in technological change (Baden-Fuller and Haefliger, 2013; Chesbrough, 2010; Teece, 2010; Zott and Amit, 2009) and how radical technologies are most likely to require new business models (Teece, 2010). Whilst previous studies implicitly link business model and systemic innovation (Boons et al., 2013; Boons and Lüdeke-Freund, 2013; Mlecnik, 2013; Rohrbeck et al., 2013), Article 3 argues that in many cases one may be a pre-condition of the other.

Therefore, systemic innovations, such as whole-house retrofit, are often incompatible with incumbent business models (Mlecnik, 2013). As shown in Articles 1 and 3, complementary innovation in the value proposition, supply chain, customer interface, financial model and mode of governance can promote the adoption of systemic innovations - particularly when deployed in combination (Boons and Lüdeke-Freund, 2013). Therefore, new business models enable systemic changes in ways technological innovation alone cannot. By formalising these links and demonstrating them empirically; this thesis provides a useful contribution to the literature on systemic and business model innovation.

Article 1 also identifies a novel typology of business model archetypes, moving from the incumbent to the most innovative these are the: *atomised market model*; *market intermediation model*; *one-stop-shop energy services agreement (ESA)*; and *managed energy services agreement (MESA)*. Articles 1 and 3 argue that the more innovative archetypes based on energy performance contracts facilitate the adoption of whole-house retrofit - often requiring complementary innovations in process and technology (Massa and Tucci, 2013). These archetypes therefore involve varying degrees of both technological and business model innovation. These findings emphasise the value of identifying exemplary business model archetypes as shown in other studies (Bohnsack et al., 2014; Hall and Roelich, 2016).

Article 3 outlines the role of innovation intermediaries as catalysts for business model innovation, drawing on the Energiesprong case study. Few previous studies have identified how policymakers can support business model innovation. Article 3 argues that setting up or supporting innovation intermediaries could be one such way. Drawing on Stewart and Hyysalo (2008), intermediaries are shown to overcome barriers to business model innovation (Stubbs and Cocklin, 2008) through the activities of *facilitating* stakeholder engagement, *configuring* new business model designs and *brokering* external support and regulatory changes. Article 3, therefore, contributes to the innovation policy literature (Smits and Kuhlmann, 2004; Wieczorek and Hekkert, 2012) suggesting how policymakers can promote business model innovation through the support of innovation intermediaries developing a novel framework (Table 9) – exemplified by the Energiesprong case.

These findings and the Energiesprong case are an example of an intermediary operating at the system or sector level. Such ‘systemic intermediaries’ have been observed to broker between multiple actors within innovation systems: between firms, research institutes, government, infrastructure providers and financiers (Kivimaa et al., 2018; Lente and Hekkert, 2003). As outlined in Article 3, the Energiesprong case is notable for the intermediaries’ engagement with multiple actors including Dutch financial, energy and housing regulators, social housing providers, construction industry actors as well as banks and other financial institutions. These findings suggest that creating the selection environment necessary to facilitate radical business models, such as that for whole-house retrofit, necessitates such a wide strategy of engagement (Klerkx and Leeuwis, 2009; Mlecnik, 2013). The case also suggests that the initial success of this strategy in the Netherlands was largely contingent on the close support and relationships with government (Kivimaa, 2014). This is consistent with other studies who have argued that systemic intermediaries are likely to require strong policy support to remain effective (Hannon and Skea, 2014).

Several other studies argue that intermediaries may be supported by policymakers to facilitate sustainable innovation by acting as catalysts in collaborations between universities, government and industry (Barrie et al., 2017; Etzkowitz and Leydesdorff, 2000; Kivimaa, 2014; Lente and Hekkert, 2003). Although Barrie et al., (2017) show how an intermediary facilitated

circular economy business models, few previous studies have explicitly emphasised their role in business model innovation.

The relationships between the business model, finance mechanism and business model innovation frameworks developed in this thesis are shown in **Error! Reference source not found..** The figure highlights the centrality of governance within business models. The figure also shows the relationship between the features of finance mechanisms and their relationship to the business model. Finally, illustrating the role of innovation intermediaries in promoting business model innovation.

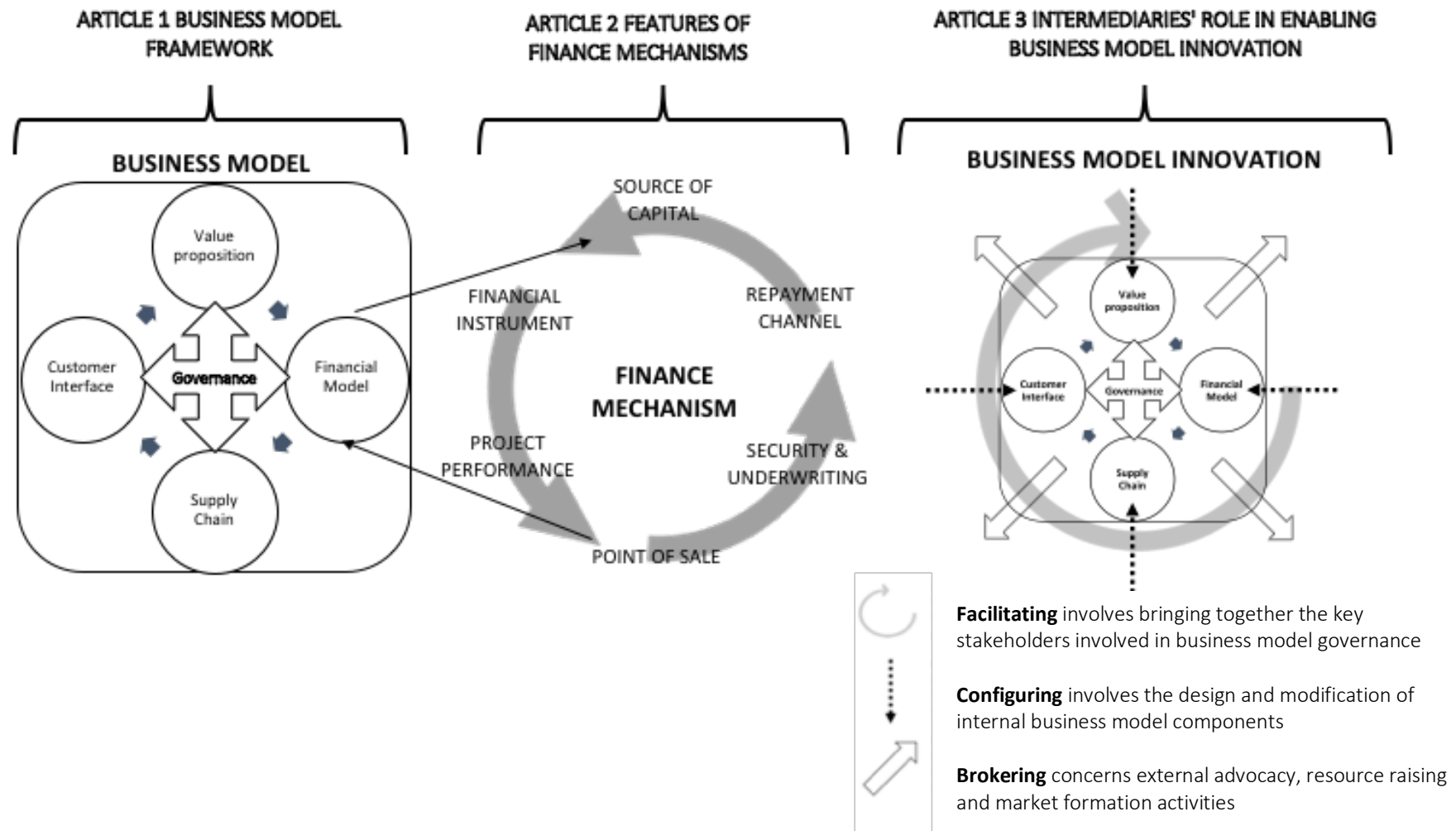


Figure 23 Relationship between conceptual frameworks

6.2. Methodological considerations

This section evaluates the methodological approach and its suitability for addressing the research aims. This thesis involved an iterative research design – with focus of the articles and plan for gathering data developed reflexively throughout the project (Maxwell, 2012). This approach had particular value for a thesis by papers, with each article becoming a building block in the development of the conceptual and empirical understanding of the thesis.

The inductive approach adopted in Articles 1 and 2 was essential for developing the conceptual frameworks. This approach is consistent with the principles of inductive 'theory building' as described by De Vaus, (2002) and Yin, (1994). In particular, the development of the conceptual framework for Article 2 involved a 'grounded theory' approach (Glaser and Strauss, 2017). This framework was an essential pre-requisite to the subsequent cross-sectional study - given the limited literature differentiating alternative forms of financing. A grounded approach has been successfully used in a previous study of ESCO business models (Hannon, 2012) - helping to develop the conceptual foundations for subsequent phases of analysis.

The cross-sectional research design in Articles 1 and 2 provided a means of comparing key retrofit business model archetypes and finance mechanisms; drawing on the concepts from the previous phase. This approach was more akin to deductive theory testing (De Vaus, 2002); although the respective frameworks provided a structure to discuss competing explanations, rather than a predictive hypothesis. This qualitative cross-sectional design, comparing different business models in a sector, is consistent with other studies into electricity supply (Hall and Roelich, 2016) and electric vehicle business models (Bohnsack et al., 2014). Comparative studies such as these, help develop explanations of why specific features of business models affect their success – such as in facilitating the uptake of whole-house retrofit.

Case studies provide greater depth of understanding than cross-sectional studies. Article 3 involved an in-depth case study of an innovative business model, identified in Article 1 as an important avenue for further investigation. This depth of understanding would not have been possible through a cross-sectional study - validating the iterative strategy advocated by Maxwell (2012). The results are consistent with Flyvbjerg's (2006) assertion of the value of

‘exemplars’ such as the Energiesprong case - as observed in other case studies of innovative business models, such as Chesbrough and Rosenbloom’s (2002) study of Xerox printers, Budde Christensen et al’s., (2012) exploration of an electric auto-mobility business model and Olofsson et al’s., (2018) study of an electricity retail social enterprise.

The synthesis of the findings in Article 4 provides an overview of their contribution and begins to draw together some wider insights for policy. Building on this synthesis and viewing the overall research strategy (Figure 9); the four articles in combination provide an answer to the primary research question.

There are however limitations to the research methodology.

First, the reliance upon particular ‘experts’ for the scoping interviews creates a risk of selection bias, in that the individuals chosen may not be representative of the wider field. This was mitigated through a sampling strategy based on interviewing authors from several publications in the respective fields - from academic, industry and government sources. Subsequently, snowballing techniques provided a means of sourcing further interviewees (Yin, 1994), although all these sampling approaches are still subject to a degree of selection bias.

Secondly, the frameworks and typologies developed inevitably over simplify complex phenomena (Baden-Fuller and Morgan, 2010). These concepts were corroborated with published documents and established industry terminology, as well as with the interviewees themselves. However, the business model and financing archetypes in this thesis may miss variants or features which have greater importance in some circumstances.

Thirdly, the qualitative research methods employed have inherent limitations as well as strengths. Qualitative data such as that derived from interviews is inseparable from the context and interpretation of both the interviewee and interviewer⁷⁷. Whilst this in itself is not problematic (Kvale, 2008), these epistemological issues are not discussed in any depth in this thesis. Further, while a qualitative approach provides greater depth and nuanced

⁷⁷ Although quantitative research is also subject to such biases (Kvale, 2008)

understanding - this is at the expense of breadth and generalisability (Grix, 2010). The potential of a quantitative research approach for future studies is therefore discussed in Section 7.2.

In summary, the methodological approach adopted in this thesis is considered appropriate, acknowledging these limitations and the resources available. The option for broadening the research methodology to other data sources and quantitative approaches is discussed in 7.2.

6.3. Empirical contribution and limitations

This section outlines the empirical contributions of the thesis and discusses these in the context of the literature on residential retrofit, energy service business models and energy efficiency finance. Firstly, the need for a whole-house approach to retrofit is introduced, followed by an evaluation of the role of new business models and finance mechanisms. Subsequently, the critical challenges for the uptake of whole-house retrofit are explored, including a discussion of the extent to which new business models and finance mechanisms may overcome these challenges. This includes discussion of how the findings provide a broader contribution to the literature.

6.3.1. The need for whole-house retrofit

A core thread running throughout this thesis is the need for a whole-house approach to residential retrofit. Historically, the UK has made significant progress through single retrofit measures (Rosenow, 2012). The UK's climate change targets are however, necessitating the uptake of more invasive and complex interventions into homes (CCC, 2018). It is increasingly recognised that these retrofit measures have the potential to cause damaging unintended consequences, especially for these more complex interventions (Davies and Oreszczyn, 2012). These issues as highlighted in the interviews (Articles 1 & 3) are corroborated by several sector wide studies, which highlight problems, especially with SWI and heat pumps delivered under UK government subsidy schemes (Hansford, 2015; Milsom, 2016).

As outlined in Section 1.4.6 a whole-house approach is likely to mitigate unintended consequences and deliver a greater and more rapid reduction in emissions. Whole-house

retrofits involve a strategy for the whole building, involving multiple measures and an understanding of how they interact - whether installed at once or over time (Fawcett, 2014; Fawcett et al., 2014). Equally, a whole-house multi-measure approach that covers building fabric, low carbon heat and electricity microgeneration, is needed to deliver the scale and pace of change required to meet climate change targets (Gupta et al., 2015). An integrated whole-house strategy is therefore likely to overcome the issues of the piecemeal approach (Shrubsole et al., 2014), and realise the multiple benefits outlined Section 1.4.4. Although previous studies have touched on these arguments (Davies and Oreszczyn, 2012; Dowson et al., 2012; Fawcett, 2014; Shrubsole et al., 2014), this thesis explicitly calls for the whole-house approach to be the cornerstone of any home retrofit strategy.

6.3.2. The role of new business models

A second key argument of this thesis is that new business models are needed to deliver whole-house retrofits. As outlined in Article 1, the incumbent 'atomised market' business model, is considered unsuitable, due to inherent complexities in project management, the lack of assured performance and the 'silos' of the current supply chain. Articles 1, 3 and 4 instead argue that new business models involving a range of core principles can overcome the issues inherent in the incumbent business model.

These principles include a value proposition that guarantees energy performance (Mcelroy and Rosenow, 2018), even if it does not deliver cost savings. This value proposition should also deliver improvements to comfort, aesthetics, health and wellbeing (Fawcett and Killip, 2014) as part of a broader renovation offering (UKGBC, 2017). This will require increasingly integrated supply chains, with single solution providers offering holistic packages of measures (Mahapatra et al., 2013). The Energiesprong case study from Article 3, also demonstrates the value of industrialisation and process innovation, both as a means of delivering economies of scale and also in reducing the time and hassle of the interventions. A linked issue is the need for a single customer interface, reducing complexity and improving trust (Brown et al., 2014).

Thus, the emphasis on the customer journey – both in the delivery of the measures (Articles 1 and 3) and the procurement of finance – is a key determining factor in the success of retrofit

business models. Relatedly, the long payback periods and split incentives, inherent in retrofit projects (Bird and Hernández, 2012) necessitates a financial model based on a long term financing mechanism. Business models that integrate a financing offer into the value proposition or provide assistance in accessing capital will therefore be more readily adopted (Articles 1, 2, 3 and 4). In aggregate, these findings suggest that integrated modes of governance -where the components of the supply chain, customer interface and financing are brought together to form co-ordinated offering (Mahapatra et al., 2013; Mlecnik et al., 2018, 2012) - are more likely to be successful for the delivery of residential retrofit. This is in stark contrast to the market-based logic that has dominated the sector to date.

By identifying the full range of retrofit business models and the key factors for their success, (Articles 1 and 3) this thesis makes a substantial contribution to the currently limited literature on retrofit business models (Gauthier and Gilomen, 2016; Mahapatra et al., 2013; Mlecnik et al., 2018, 2012; Moschetti and Brattebø, 2016). These findings should be of substantive value to researchers, practitioners and policymakers in this field.

6.3.3. Financing whole-house retrofits

This thesis also makes an important and timely contribution to the literature on retrofit and energy efficiency finance. As outlined in Article 2, the extant literature is both conceptually and empirically limited. Previous studies explore the economics of energy efficiency and barriers to investment (Sorrell et al., 2004), the issues of split incentives for tenants (Bird and Hernández, 2012) supplier obligation policies (Rosenow, 2012; Rosenow and Galvin, 2013) and specific financing mechanisms (Rosenow and Eyre, 2016; Schröder et al., 2011). However, there remain few studies evaluating the range of different financing mechanisms (as defined in Section 1.5.5) or the features of successful ones.

This thesis addresses this gap in the literature, by introducing a typology of retrofit finance mechanisms (Article 2 and Section 6.1.2) as well as three key principles for successful mechanisms. The first key principle is that the up-front cost and long payback periods of whole-house retrofit necessitate a low cost of capital (Figure 17). This is consistent with previous studies emphasising the role of interest rates in the failure of the UK's Green Deal (Rosenow

and Eyre, 2016, 2014) and the success of Germany's KfW scheme (Rosenow, 2013; Schröder et al., 2011). However, Article 2 argues that two other principles are likely to have a greater impact on household appeal. The second principle concerns the customer journey in procuring retrofit financing. Long or complex customer journeys are likely to deter households from procuring financing. This is consistent with several studies and Article 1 which emphasise complexity and the 'hassle factor' in the low uptake of whole-house retrofits (O'Keeffe et al., 2016; Risholt and Berker, 2013; Snape et al., 2015). A third principle concerns the sources of value and range of measures that are funded. Articles 1, 2 and 3 all emphasise the importance of a broad value proposition that includes general home improvement and renovation. Thus, successful finance mechanisms should fund these value propositions of wider home improvement - as was observed in several of the examples in Article 2 (Fawcett and Killip, 2014; Wilson et al., 2015) - rather than energy efficiency measures alone. However, a further message from Article 2 is that financing alone is likely to be of limited importance in driving demand for retrofit. The following sections therefore sets out how new business models, finance mechanisms intermediaries and policy initiatives will be required in combination to generate demand.

6.3.4. Overcoming the challenges of whole-house retrofit

Several challenges continue to constrain the uptake and delivery of whole-house retrofit. As argued in Article 4, the traditional 'barriers' framing (Sorrell et al., 2011, 2004) ignores wider issues that influence the adoption of retrofit measures. From a literature review and interviews this thesis identified four broader challenges which undermine demand and hamper delivery of whole-house retrofit, namely: *1) uncertain benefits and quality; 2) complexity, disruption and timing; 3) up-front capital cost and split incentives and 4) information, engagement and trust.*

In this section, these concepts structure the discussion of how new business models, finance mechanisms and policy approaches can promote the uptake of whole-house retrofit. This builds on recent work such as Fylan et al., (2016) and Kangas et al., (2018) in identifying a broader range of barriers, but argues that this 'barriers' framing itself is problematic. Instead, the overarching challenge for whole-house retrofit is one of generating demand, rather than

overcoming barriers (Wilson et al., 2015). This shift in rhetoric has important implications for how the retrofit issue is framed and the solutions proposed. The following sections discuss each of these challenges in turn and the extent to which new business models and finance mechanisms can overcome them.

Uncertain benefits and quality

A critical factor in the limited uptake of whole-house retrofit is the uncertain benefits and quality of retrofit work. Much of this is due to a 'performance gap' that remains commonplace (Gupta and Gregg, 2016). Alongside concerns over the energy performance and the quality of retrofits, many households remain dubious about its benefits (Wilson et al., 2015).

New business models address these challenges primarily through new value propositions. As shown in Articles 1, 3 and 4, value propositions based upon energy performance guarantees can overcome performance gaps through long-term contracts with guaranteed energy or cost savings. These findings support other studies on the potential of residential energy performance contracts for overcoming the performance gap (Mcelroy and Rosenow, 2018; Winther and Gurigard, 2017). Additionally, the Energiesprong case demonstrates how 'unintended consequences' can be mitigated, such as through additional guarantees for interior air quality supported by enhanced monitoring (Davies and Oreszczyn, 2012). These findings also provide the first comprehensive academic examples of residential energy performance contracts (Steinberger et al., 2009).

Energy service business models based on energy performance contracts often have high transaction costs (Sorrell, 2007). The examples in this thesis reduced these costs through standardisation and economies of scale. The *energy service agreement* examples of ICF Habitat and RENESCO focussed on large multi-family apartments. Although Energiesprong has targeted single-family dwellings; it focusses on the social housing sector - brokering deals for multiple homes using standardised documents and retrofitting entire terraces at a time. These findings emphasise the importance of customer segmentation; with performance contracts being much more challenging in the single-family, owner-occupier segment - due to high transaction costs (Sorrell, 2007). A further finding was the importance of value propositions

which offer broader home improvement measures and foreground the non-financial aspects of retrofits (Gram-Hanssen, 2014); together with finance mechanisms that fund those broader sources of value (Article 2). Again, these findings are consistent with other studies on the importance of the non-energy benefits of retrofits (Fawcett and Killip, 2014; Walker et al., 2014; Wilson et al., 2015).

Complexity, disruption and timing

The complex and disruptive nature of whole-house retrofit combined with a lack of integration with wider renovations is critical in explaining its limited uptake. Unlike single measures, whole-house retrofits typically involve the coordination and management of multiple tradespeople, suppliers and consultants (Dowson et al., 2012). As shown in Article 1 the complexities in project management, which characterise the incumbent business model are likely to be off-putting for many households (Mahapatra et al., 2013; Mlecnik et al., n.d.).

Business models based on integrated supply chains and process innovation can reduce this complexity, minimise disruption and reduce the duration of works. These business models integrate the governance of multiple activities under the remit of a single organisation, or through a well-co-ordinated network of sub-contractors. As shown in Articles 1 and 3, this enables a more effective delivery and coordination of multiple measures and energy performance outcomes, even without energy performance guarantees. These findings complement the growing literature on the value of integrated business models or ‘one-stop-shops’ for the delivery of whole-house retrofit (Mahapatra et al., 2013; Mlecnik, 2013; Mlecnik et al., 2018, 2012). Article 2 also shows the importance of finance mechanisms that integrate with the business model, in reducing this complexity. The Energiesprong case from Article 3 further shows how through process innovation, offsite manufacture and modular design – zero-energy retrofits can be achieved in a single day, with the occupants remaining in the home. This supports the argument for one-off retrofits as opposed to staged approaches (Fawcett, 2014).

Capital cost and split incentives

The financial barriers surrounding the up-front capital cost and split incentives are perhaps the most well-known yet understudied challenge for the uptake of retrofit. Overcoming these challenges requires a range of financing solutions, tailored to specific tenure types and demographics. Article 2 outlines the diversity of retrofit financing mechanisms and emphasises how their design features affect their success in different contexts. Examples such as green mortgages may play a significant role for homeowners, and low-interest loans from public banks may be necessary for certain income groups. The thesis therefore contributes to the currently limited literature on energy efficiency finance (Copiello, 2016; Parker and Guthrie, 2016; Rezessy and Bertoldi, 2010).

In many cases, finance mechanisms can address split incentives by securing and linking repayments to the underlying asset (Article 2). Further, as outlined in the previous section the success of these mechanisms is also contingent on the cost of capital, the ease of the customer journey and the sources of value that are funded. Hence, as shown in Articles 1 and 3 these mechanisms have important implications for the wider business model, as a necessary element of its financial model.

However, there are limits to what finance mechanisms can achieve. As discussed in Article 4 a large proportion of UK households are in fuel poverty. Arguably the social welfare and health benefits of retrofit justify an approach based on grants for these segments, funded through general taxation (Rosenow et al., 2013b). Further, the findings from Articles 2 and 4 emphasise that financing alone is a weak demand driver and that, alongside new business models and financing mechanisms, a range of fiscal incentives may be more effective (Rosenow et al., 2014). These issues are discussed further in Section 6.4.2.

Information, engagement and trust

Above all, the majority of households remain unaware and disengaged with whole-house retrofit and have a mistrust of the construction industry at large. Thus, a lack of knowledge of the options for and benefits of retrofit pervades the majority of the general public (Marchand et al., 2015).

The extent to which new business models and finance mechanisms can overcome these challenges is contingent on their ability to reach customers and offer them a compelling value proposition. Here the role of the customer interface is critical. Both Articles 1 and 3 emphasise how a single point of contact, can improve trust and communication on a project, itself a product of integrated supply chains. Web platforms such as Retrofitworks (Article 1), represent a new means of engaging consumers, enabled by developments in information technology (Teece, 2018). These findings complement research on the potential of such platforms to drive collaboration between supply chains and promote consumer engagement (Mlecnik et al., 2011).

Further, the Energiesprong case study emphasises how a value proposition of improved aesthetic appeal of the newly renovated house can be a key driver of demand (Fawcett and Killip, 2014). However, the extent to which these factors alone can drive consumer engagement remains to be seen and appears reliant on significant marketing activities from small firms operating in a nascent sector. Therefore, Article 4 argues for the need for engagement policies, particularly at the local and community level; building on recent research on the role of customer-facing intermediaries in this capacity (Kivimaa and Martiskainen, 2018; Martiskainen and Kivimaa, 2018).

6.4. Policy implications

This section outlines the contribution of this thesis to broader retrofit, energy and innovation policy debates. Firstly, drawing on the empirical findings, it is shown how policymakers might overcome barriers to business model innovation, through innovation intermediaries. A range of wider policy recommendations to promote whole-house retrofit are then discussed.

6.4.1. Intermediation for business model innovation

Business model innovation may be crucial in meeting retrofit targets, although incumbent businesses face both cultural and structural barriers to innovating their business models (Stubbs and Cocklin, 2008). As shown in Articles 1, 2 and 3 these include: the conservatism of

the industry; a lack of skills and competencies in areas such as energy monitoring and finance; fragmentation within the supply chain; and the need to adopt innovative technologies and processes such as offsite manufacture (Chesbrough, 2010; Teece, 2018, 2010, 1986). This thesis therefore emphasises an important role for policymakers in overcoming these barriers and the challenges, outlined above.

Article 3 highlights the role of innovation intermediaries supported by public policy in promoting integrated business models, - such as the Energiesprong market development team. These intermediaries are seen to focus on both the *internal* processes of developing new business models (facilitation and configuration) as well as helping to modify the *external* selection environment (brokering) to be more favourable to these new business models (Bolton and Hannon, 2016). Thus, the market development team developed a *vision* for net-zero-energy homes; *facilitated* collaboration between key stakeholders; was involved in the design and *configuration* of a radical new business model; and *brokered* policy changes and secured financial resources. Energiesprong market development team was successful in achieving policy influence due to its status as an arm's length intermediary, funded by the Dutch government. This status facilitated changes to regulations surrounding energy performance contracts, renewable energy subsidies, Dutch planning regulations, mortgage eligibility guidelines and to seek further innovation funding (Article 3). The market development team is now attempting to catalyse the market for whole-house retrofit in the UK.

This thesis therefore highlights a role for policymakers to promote business model innovation by supporting innovation intermediaries – consistent with examples of intermediation policies for circular economy business models (Barrie et al., 2017). These findings show the need for further work to explore if these lessons are transferrable to other sectors - also emphasising the limits of business models and finance mechanisms in overcoming the challenges for retrofit. Thus, an interesting finding (Article 3) is the intermediaries' role in brokering broader policy changes (Kivimaa, 2014). Article 4 therefore outlines a range of other policies required to deliver the widespread uptake of whole-house retrofit in the UK. The following section discusses these broader policy implications of the thesis.

6.4.2. Wider implications for UK policy

Delivering the extensive uptake of whole-house retrofit in the UK will require a wide-ranging and systemic policy approach to support new business models, finance mechanisms and intermediaries. As shown in the previous section, new business models and finance mechanisms can overcome many of the challenges to the uptake of whole-house retrofit, described in Section 6.2. However, this will require complementary changes in standards and regulations (EPCs, UK SAP), financial and fiscal policies and new institutions and intermediaries (Rosenow et al., 2017b). In this way, business models and financing are not alternatives to effective public policy, but complementary developments in the wider economy that often require policy interventions to be realised.

Many of the financing mechanisms discussed in Article 2 owe their existence to public policy - such as the direct government funding of the KfW low-interest loan schemes, or the use of the tax collection channels of US local governments to fund PACE. While a range of mechanisms may eventually become prevalent, these are unlikely to emerge on their own and may necessitate regulatory changes, public subsidy of interest rates (Gouldson et al., 2015) and policies to promote household engagement. By identifying the range of different mechanisms and explaining why certain approaches are more successful, this thesis provides some lessons for policymakers for the support of future financing programs.

This thesis argues that repayable finance mechanisms should play a more significant future role than supplier obligation policies (Rosenow et al., 2013b). Whilst supplier obligations have delivered the majority of retrofit savings to date (Rosenow and Eyre, 2014), they are poorly suited to whole-house retrofit. This is due to a focus on least cost, single measures - as opposed to a broad spectrum of solutions, and a lack of funding for wider non-energy measures (Articles 1, 2 & 3). Supplier obligations - traditionally based only on carbon savings, thus tend to create unintended consequences and perverse incentives (Hansford, 2015; Milsom, 2016) and place significant levies on energy bills which can be regressive (Kern et al., 2017). However, both supplier obligations and finance mechanisms should necessarily play a more limited role in addressing fuel poverty, where grant-based schemes should dominate (Article 4). Article 4 also points to the potential role of fiscal incentive schemes such as variable stamp duty as a demand

driver (Jahn and Rosenow, 2017; Rosenow et al., 2014; UKGBC, 2013). However, the complex ways these funding sources could interact is beyond the scope of this thesis.

An important, but often overlooked, area concerns household engagement - helping to explain much of the low uptake of whole-house retrofits (Balcombe et al., 2014; Marchand et al., 2015). While improved business models can assist in this area, they are unlikely to be sufficient. Various studies highlight the potential contribution of intermediary actors such as local authorities, NGOs and community groups in providing information and encouraging household engagement (Kivimaa et al., 2018; Kivimaa and Martiskainen, 2018a). In many cases, these actors are under-resourced and lack the powers to effect meaningful change at scale. Therefore, to support these activities and coordinate local actors, Article 4 proposes a role for a national body or task-force – following similar recommendations from Hansford (2015) and Rosenow and Cowart (2017). This body would build on a tradition of arm’s-length government agencies focused on specific policy objectives; which in this case would be to facilitate the widespread and comprehensive retrofit of the UK’s homes.

Article 4 also calls for the introduction of minimum energy performance standards (EPCs) across all UK housing – consistent with several recent studies (Brown et al., 2018; Rosenow and Cowart, 2017; Sustainable Energy Association, 2017). However, even if stringent standards were imposed and enforced, these would be unlikely to overcome the challenges identified in Section 6.2. Consequently, minimum EPC regulations should be viewed as complementary to new business models and finance mechanisms rather than a substitute. Article 4 also supports studies emphasising how the current policy framework surrounding training, accreditation, energy assessment monitoring and verification requires updating (Kelly et al., 2012; Mcelroy and Rosenow, 2018). Thus in addition, new quality assurance methodologies and accreditation standards would seem an essential step – as are currently being proposed in the UK (Bonfield, 2016).

Finally, this thesis argues that residential retrofit (and wider energy efficiency) should be considered a national infrastructure priority, in a similar manner to other forms of infrastructure. This would indicate political will at the highest levels of government and would be justified by the macroeconomic benefits that retrofit generates (Rosenow et al., 2018;

Washan et al., 2014). These arguments build on some recent academic studies (Bergman and Foxon, 2017) although have been more extensively explored in non-academic policy literature (Frontier Economics Ltd, 2015; Washan et al., 2014).

6.5. Summary of contribution

This section has shown the contribution that new business models and finance mechanisms can make to increase the uptake of whole-house retrofit. New value propositions based on energy performance contracts and broader renovation value, may address performance gaps and improve household appeal. Integrated supply chains reduce the complexity and disruption of whole-house retrofits, particularly when combined with financing and process innovations such as offsite manufacture. A range of finance mechanisms can overcome issues of access to capital and split incentives and are most effective when these are ‘hand in glove’ with the wider business model. Thus, improved value propositions and integrated supply chains may present a compelling offer to households when promoted through a single and simplified customer interface. The corollary is that an integrated approach to business model governance is most effective in the retrofit context, due to the complexity faced by household in managing multiple suppliers, consultants and financing options.

While essential, new business models and finance mechanisms should be viewed as elements of a broader strategy involving training, regulations, civil society and political leadership – all necessary for widespread whole-house retrofit in the UK. These new business models and financing mechanisms are unlikely to emerge on their own and will often require policy support. This thesis has therefore highlighted how public policy can promote business model innovation through the support of innovation intermediaries. These intermediaries can help to create the market conditions for innovative business models as well as engage households, secure the necessary financial resources and regulatory changes for these models to be successful.

A summary of the conceptual and empirical contributions of this thesis is shown in Table 14.

Table 14 Summary of the conceptual and empirical contributions of this thesis

Conceptual contribution	Evidence
1. Governance is a core component of a business model alongside the value proposition, supply chain customer interface and financial model	Articles 1 & 3
2. The key features of finance mechanisms are: the source of capital; the financial instrument(s); the project performance requirements; the point of sale; the nature of the security and underwriting and the repayment channel.	Article 2
3. Business model innovation may be an essential pre-requisite to the adoption of systemic innovations such as whole-house retrofit	Article 3
4. Innovation intermediaries may play a key role in promoting business model innovation such as for whole-house retrofit.	Article 3
Empirical contribution	
5. A whole-house approach to retrofit will be necessary for meeting the UK's climate change targets and requires new kinds of business models and finance mechanisms to be more widely adopted	Chap. 1
6. New business models and financing mechanisms can overcome the challenges for whole-house retrofit in the following ways: <ul style="list-style-type: none"> • <i>Value propositions</i> based on energy performance guarantees and wider renovation value deliver broader and more certain benefits • Integrated <i>supply chains</i> and process innovation reduce costs, complexity and disruption • A single <i>customer interface</i> and simplified customer journey reduce complexity and increase consumer engagement • A financial model based on an integrated financing mechanism and linked to energy performance outcomes enable all the above • Integrated business model <i>governance</i> through a single provider or well-coordinated network of subcontractors is more effective for the delivery of whole-house retrofit 	Article 1, 2, 3 & 4
7. A low cost of capital, simplified customer journey and funding for broader sources of value such as wider renovation measures are crucial in the design of retrofit finance mechanisms	Article 2
8. The traditional barriers framing for the energy efficiency gap is excessively narrow. Instead this thesis introduces four related challenges which limit demand and hamper delivery: 1) <i>uncertain benefits and quality</i> ; 2) <i>complexity, disruption and timing</i> ; 3) <i>up-front capital cost and split incentives</i> and 4) <i>information, engagement and trust</i> .	Article 4
9. Widespread uptake of whole-house retrofit will require a systemic policy approach supporting new business models, finance mechanisms and intermediaries; requiring supporting changes in standards and regulations, financial and fiscal policies and new institutions and intermediaries	Article 4

7. Conclusion

This thesis has shown how and why new business models and finance mechanisms can promote the uptake of whole-house retrofits and has identified the key characteristics of successful models and mechanisms. It has further argued that innovation intermediaries may be a new policy approach to facilitate their uptake. The findings point to the need for a step-change in how retrofits are promoted, delivered and funded – which in turn will require an overhaul of the traditional policy approach. To conclude, Section 7.1 summarises the answers to each of the research questions, while Section 7.2 suggests some avenues for future research.

7.1. Answers to research questions

Research question 1 How and why can new business models encourage the uptake of whole-house retrofit?

The uptake of whole-house retrofit can be greatly increased through the adoption of new and integrated business models, such as energy service agreements based on energy performance contracts. These business models can: better facilitate wider sources of value that are actually desired by households, such as home improvement; deliver realised energy performance outcomes; enable supply chain integration and process innovation – driving down costs and installation times; smoothen the customer journey and reduce complexity in project management; as well as leverage of new forms of finance through a more robust and long-term business case based on realised savings.

New business models are likely to be particularly important for the diffusion of systemic innovations, such as whole-house retrofit. This is because systemic innovations require complementary technological change and reconfiguration of regulations, organisational and social practices across multiple domains. Innovative business models are, however, able to address these multiple and overlapping domains simultaneously. New business models may thus exploit the emergent features of new technologies through new value propositions, reconfigured networks and supply chains, leverage new types of financial resources and engage users and consumers in new and innovative ways.

Research question 2 How and why can new finance mechanisms encourage the uptake of whole-house retrofit?

Although finance can promote the uptake of whole-house retrofit, it should be viewed as an enabler rather than a driver of demand - an essential part of the wider business model. The key design features, of finance mechanisms, are the source of capital; the financial instrument(s); the project performance requirements; the point of sale; the nature of the security and underwriting and the repayment channel. Effective retrofit finance mechanisms are successful for three key reasons. Firstly, the capital-intensive and long-term nature of whole-house retrofits necessitates mechanisms that have a low cost of capital. Second, successful mechanisms involve a simplified customer journey, so that they fit 'hand in glove' with the business model for the delivery of the measures. Third, mechanisms that fund broader sources of value, including non-energy measures – often solving an existing problem for the household, are more likely to be adopted. These mechanisms may require various forms of policy support to play a significant role in countries such as the UK.

Research question 3. How can public policy encourage new business models for whole-house retrofit through intermediaries?

Incumbent actors and organisations in the retrofit sector may face multiple barriers to business model innovation, presenting a role for policymakers to help promote it. This role requires activities to facilitate network formation and collaboration, the configuration and testing of new business models in the marketplace, as well as independent brokering and advocacy—procuring financial resources and regulatory changes. The Energiesprong example from the Netherlands provides an exemplary case study, indicating that such a role may be successfully achieved by independent intermediaries who can act as a catalyst between the key stakeholders in industry, finance, housing and government but retain independence from them.

Research question 4 How can the uptake of whole-house retrofit in the UK be accelerated by public policy?

Delivering the goal of widespread whole-house retrofit will necessitate a systemic policy approach across multiple domains. This will include a role for new business models and finance mechanisms supported by changes in regulation, taxation, public spending and incentives as

well as softer measures including information and engagement programmes, market intermediation activities to promote business model innovation and supply chain development, as well as high-level political leadership.

Together these approaches can overcome four key challenges that undermine demand and delivery of whole-house retrofit: a widespread lack of information, engagement and trust with households on the options for and advantages of retrofit; the uncertain benefits and quality of retrofit work; the significant complexity, disruption and poor integration with the timing of other renovation decisions; and, the up-front capital cost and split incentives between landlords and tenants, or those looking to move. Without such an approach, countries such as the UK are unlikely to overcome the problems with the current piecemeal strategy and realise the enormous benefits of whole-house retrofit for the environment and society.

7.2. Avenues for further research

Contemplating the contribution of this thesis to the literature, and the gaps it leaves, this section provides some suggestions for further research.

Firstly, the conclusions drawn in this thesis come from empirical data from the supply side. Hence the study of business models, finance mechanisms and policy solutions are primarily derived from semi-structured interviews with experts and practitioners, rather than from users or households. Given the lack of previous research on these issues, the absence of studies which identify the features of these approaches or ready-made typologies of retrofit business models and financing; the approach taken here is a logical first step. However, building on these findings there is an important opportunity for research to explore the perceptions of these different approaches in practice. Perhaps drawing on wider research methods such as focus groups or surveys with households, as well as meta-analyses of multiple case studies.

Second, there is a qualitative bias to the research. Building on the conceptual foundations and the range of 'types' developed here, several avenues for quantitative investigation are apparent. As described above, some larger scale surveys of user perceptions, energy performance outcomes and project costs across various business model archetypes, could add

validity to some of the claims made here. Equally, studies of the cost of capital, utilising the financing variables developed in Article 2 to quantify which factors are most important would be valuable. Thus, developing an understanding of how these features influence the cost of capital in different contexts - although this may present some challenges in data collection.

A third important avenue for future research concerns the application of the theoretical contributions developed here to other domains. As argued in the previous section the features of finance mechanisms framework could be applied to other studies on different forms of financing for energy efficiency or other forms of sustainable infrastructure such as power, housing, transport or waste systems. Equally, the combined business model and intermediation framework developed in Article 3 may have useful application to other sectors where business model innovation is being promoted; such as the circular economy, energy other service business models or those designed to enhance natural capital such as organic farming and permaculture models.

7.3. Concluding remarks

This thesis has shown the potential contribution of new business models, finance mechanisms and supporting policy approaches - through innovation intermediaries, for increasing the uptake of whole-house retrofits. The significance of these findings is in their contribution to addressing one of the most important and intractable policy problems of the 21st century – the energy consumption, carbon emissions, social welfare and health impacts of the current housing stock.

Famous examples of the novel pairing of technology with an innovative business model show how previously unwanted technologies such as the mp3 player and electric vehicles have since become highly desirable. However, it remains to be seen if innovative business models such as Energiesprong will become household names alongside the likes of Apple and Tesla. The success of these approaches, therefore, remains contingent on developing products and services that people actually want to buy - emphasising the limits of what new business models and finance alone can achieve. In any case, there remains a critical role for policy in enabling these new business models and finance mechanisms to succeed, as well as creating a

regulatory environment to facilitate the uptake of whole-house retrofits to millions of homes in the coming decades.

8. References

- Achtnicht, M., Madlener, R., 2014. Factors influencing German house owners preferences on energy retrofits. *Energy Policy* 68, 254–263.
<https://doi.org/10.1016/j.enpol.2014.01.006>
- Amit, R., Zott, C., 2001. Value creation in E-business. *Strateg. Manag. J.* 22, 493–520.
<https://doi.org/10.1002/smj.187>
- Aravena, C., Riquelme, A., Denny, E., Denny denny, E., 2016. Money, Comfort or Environment? Priorities and Determinants of Energy Efficiency Investments in Irish Households. *J Consum Policy* 39, 159–186. <https://doi.org/10.1007/s10603-016-9311-2>
- Arnold, U., Yildiz, Ö., 2015. Economic risk analysis of decentralized renewable energy infrastructures - A Monte Carlo Simulation approach. *Renew. Energy* 77, 227–239.
<https://doi.org/10.1016/j.renene.2014.11.059>
- Auerswald, P.E., Branscomb, L.M., 2003. Valleys of death and Darwinian seas: Financing the invention to innovation transition in the United States. *J. Technol. Transf.* 227–239.
<https://doi.org/10.1023/A:1024980525678>
- Baden-Fuller, C., Haefliger, S., 2013. Business Models and Technological Innovation. *Long Range Plann.* 46, 419–426. <https://doi.org/10.1016/j.lrp.2013.08.023>
- Baden-Fuller, C., Morgan, M.S., 2010. Business models as models. *Long Range Plann.* 43, 156–171. <https://doi.org/10.1016/j.lrp.2010.02.005>
- Baeli, M., 2013. Residential retrofit: 20 case studies. RIBA Publishing, London.
- Baker, L., Newell, P., Phillips, J., 2014. The Political Economy of Energy Transitions: The Case of South Africa. *New Polit. Econ.* 19, 791–818.
<https://doi.org/10.1080/13563467.2013.849674>
- Balcombe, P., Rigby, D., Azapagic, A., 2014. Investigating the importance of motivations and barriers related to microgeneration uptake in the UK. *Appl. Energy* 130, 403–418.
<https://doi.org/10.1016/j.apenergy.2014.05.047>
- Barnes, J.P., 2016. The local embedding of technologies through community-led initiatives: the case of sustainable energy.
- Barrie, J., Zawdie, G., João, E., 2017. Leveraging triple helix and system intermediaries to enhance effectiveness of protected spaces and strategic niche management for transitioning to circular economy. *Int. J. Technol. Manag. Sustain. Dev.* 16, 25–47.
https://doi.org/10.1386/tmsd.16.1.25_1
- BBC, 2017. UK “must insulate 25 million homes” - BBC News [WWW Document]. URL <https://www.bbc.co.uk/news/business-39107973> (accessed 9.16.18).
- BEIS, 2018. Updated short-term traded carbon values, Used for UK Public Policy Appraisal.
- BEIS, 2017. Energy Consumption In The UK. Department for Business, Energy and Industrial Strategy.
- Bergman, N., Foxon, T.J., 2017. Reorienting Finance Towards Energy Efficiency in the UK. *eccee 2017 Summer Study Proc.* January, 1–11.
- Bertoldi, P., Hinnells, M., Rezessy, S., 2006. Liberating the power of Energy Services and ESCOs in a liberalised energy market, in: *Proceedings of the EEDAL 2006 Conference*. London, UK.
- Bessant, J., Rush, H., 1995. Building bridges for innovation: the role of consultants in technology transfer. *Res. Policy* 24, 97–114.
- Bidmon, C.M., Knab, S.F., 2018. The three roles of business models in societal transitions: New linkages between business model and transition research. *J. Clean. Prod.* 178, 903–

916. <https://doi.org/10.1016/J.JCLEPRO.2017.12.198>
- Bird, S., Hernández, D., 2012. Policy options for the split incentive: Increasing energy efficiency for low-income renters. *Energy Policy* 48, 506–514.
<https://doi.org/10.1016/j.enpol.2012.05.053>
- Bleyl-Androschin, J., Schinnerl, D., 2007. Comprehensive refurbishment of buildings with energy services, in: ECEEE 2007 Summer Study . Saving Energy – Just Do It! 817. pp. 817–828.
- Bleyl, J.W., Adilipour, N., Bareit, M., Bourgois, C.-H., Vanstraelen Fedesco Knowledgecenter, L., 2013. ESCo market development: A role for Facilitators to play, in: ECEEE Summer Studies. Belambra Presqu’île de Giens, France, pp. 3–472.
- Blyth, W.W., McCarthy, R., Gross, R., 2015. Financing the UK power sector: Is the money available? *Energy Policy* 87, 607–622. <https://doi.org/10.1016/j.enpol.2015.08.028>
- Bocken, N.M.P., Short, S.W., Rana, P., Evans, S., 2014. A literature and practice review to develop sustainable business model archetypes. *J. Clean. Prod.* 65, 42–56.
<https://doi.org/10.1016/j.jclepro.2013.11.039>
- Bohnsack, R., Pinkse, J., Kolk, A., 2014. Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. *Res. Policy* 43, 284–300. <https://doi.org/10.1016/j.respol.2013.10.014>
- Bolton, R., Foxon, T.J., 2015. A socio-technical perspective on low carbon investment challenges - Insights for UK energy policy. *Environ. Innov. Soc. Transitions* 14, 165–181.
<https://doi.org/10.1016/j.eist.2014.07.005>
- Bolton, R., Hannon, M., 2016. Governing sustainability transitions through business model innovation: Towards a systems understanding. *Res. Policy* 45, 1731–1742.
<https://doi.org/10.1016/J.RESPOL.2016.05.003>
- Bonfield, P., 2016. Each Home Counts - An Independent Review of Consumer Advice, Protection, Standards and Enforcement for Energy Efficiency and Renewable Energy. Department for Business, Energy and Industrial Strategy (BEIS) and Department for Communities and Local Government (DCLG).
- Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. *J. Clean. Prod.* 45, 9–19.
<https://doi.org/10.1016/j.jclepro.2012.07.007>
- Boons, F., Montalvo, C., Quist, J., Wagner, M., 2013. Sustainable innovation, business models and economic performance: An overview. *J. Clean. Prod.* 45, 1–8.
<https://doi.org/10.1016/j.jclepro.2012.08.013>
- Borgeson, M., Todd, A., Goldman, C., 2013. Getting the Biggest Bang for the Buck Exploring the Rationales and Design Options for Energy Efficiency Financing Programs.
- Borgeson, M., Zimring, M., Goldman, C., 2014. The Limits of Financing for Energy Efficiency.
- Bradach, J.L., Eccles, R.G., 1989. Markets versus hierarchies: From ideal types to plural forms. *Annu. Rev. Sociol.* 15, 97–118. <https://doi.org/10.1146/annurev.so.15.080189.000525>
- BRE, 2014a. BREEAM UK New Construction non-domestic buildings technical manual 2014.
- BRE, 2014b. SAP 2012 The Government ’ s Standard Assessment Procedure for Energy Rating of Dwellings. *Energy* 174. <https://doi.org/10.1007/s13398-014-0173-7.2>
- Brounen, D., Kok, N., 2011. On the economics of energy labels in the housing market \$.
<https://doi.org/10.1016/j.jeem.2010.11.006>
- Brown, D., 2018. Business models for residential retrofit in the UK: a critical assessment of five key archetypes. *Energy Effic.* 1–26. <https://doi.org/10.1007/s12053-018-9629-5>
- Brown, D., Kivimaa, P., Rosenow, J., Martiskainen, M., Bird, J., 2018. Warm Homes for All.

Brighton, UK.

- Brown, P., Swan, W., Chahal, S., 2014. Retrofitting social housing: Reflections by tenants on adopting and living with retrofit technology. *Energy Effic.* 7, 641–653.
<https://doi.org/10.1007/s12053-013-9245-3>
- Budde Christensen, T., Wells, P., Cipcigan, L., 2012. Can innovative business models overcome resistance to electric vehicles? Better Place and battery electric cars in Denmark. *Energy Policy* 48, 498–505. <https://doi.org/10.1016/J.ENPOL.2012.05.054>
- CCC, 2018. Reducing UK emissions – 2018 Progress Report to Parliament.
- CCC, 2017. Energy Prices and Bills - impact of meeting carbon budgets.
- CCC, 2016. Meeting Carbon Budgets - 2016 Progress Report to Parliament.
- CCC, 2015a. The Fifth Carbon Budget - The next step towards a low-carbon economy - November 2015.
- CCC, 2015b. Sectoral scenarios for the Fifth Carbon Budget, Committee on Climate Change.
- CCC, 2013. Committee on Climate Change. Fourth Carbon Budget Review – part 2.
- Chesbrough, H., 2010. Business model innovation: Opportunities and barriers. *Long Range Plann.* 43, 354–363. <https://doi.org/10.1016/j.lrp.2009.07.010>
- Chesbrough, H., Rosenbloom, R.S., 2002. The role of the business model in capturing value from innovation : evidence from Xerox Corporation ’ s technology spin-off companies 11, 529–555.
- Chesbrough, H.W., 2006. Open innovation: The new imperative for creating and profiting from technology. Harvard Business Press.
- Collins, M., Dempsey, S., Curtis, J., 2018. Householder preferences for the design of an energy efficiency retrofit subsidy in Ireland. *Econ. Soc. Rev. (Irel)*. 49, 145–172.
- Copiello, S., 2016. Leveraging energy efficiency to finance public-private social housing projects. *Energy Policy* 96, 217–230. <https://doi.org/10.1016/j.enpol.2016.06.003>
- Curl, A., Kearns, A., Mason, P., 2015. Physical and mental health outcomes following housing improvements: evidence from the GoWell study. *J Epidemiol Community Heal.* 69, 12–19. <https://doi.org/10.1136/jech-2014-204064>
- DaSilva, C.M., Trkman, P., 2014. Business model: What it is and what it is not. *Long Range Plann.* 47, 379–389. <https://doi.org/10.1016/j.lrp.2013.08.004>
- Davies, M., Oreszczyn, T., 2012. The unintended consequences of decarbonising the built environment: A UK case study. *Energy Build.* 46, 80–85.
<https://doi.org/10.1016/j.enbuild.2011.10.043>
- De Groote, M., Lefever, M., Reinaud, J., 2016. Scaling up deep energy renovation unleashing the potential through innovation & industrialisation.
- De Vaus, D., 2002. Research Design in Social Research. *Res. Des. Soc. Res.*
- DECC, 2015a. Domestic Green Deal and Energy Company Obligation in Great Britain, Headline Report.
- DECC, 2015b. Energy Efficiency Statistical Summary 2015 Energy Efficiency Deployment Office.
- DECC, 2014. Final Stage Impact Assessment for the Green Deal and Energy Company Obligation. 2014.
- DECC, 2013a. Energy Company Obligation (ECO) delivery costs.
- DECC, 2013b. Fuel Poverty: a Framework for Future Action.
- DECC, 2012. Which energy efficiency improvements qualify for Green Deal Finance? 14.
- Diaz-Rainey, I., Robertson, B., Wilson, C., 2017. Stranded research? Leading finance journals are silent on climate change. *Clim. Change* 143, 243–260.

- DOE, 2016. Best Practice Guidelines for Residential PACE Financing Programs DOE Best Practice Guidelines for Residential PACE Financing Programs.
- Doganova, L., Eyquem-Renault, M., 2009. What do business models do?: Innovation devices in technology entrepreneurship. *Res. Policy* 38, 1559–1570. <https://doi.org/10.1016/j.respol.2009.08.002>
- Donovan, C., Corbishley, C., 2016. The cost of capital and how it affects climate change mitigation investment. Grantham Inst. Brief. Pap.
- Donovan, C., Nuñez, L., 2012. Figuring what's fair: The cost of equity capital for renewable energy in emerging markets. *Energy Policy* 40, 49–58. <https://doi.org/10.1016/j.enpol.2010.06.060>
- Dowson, M., Poole, A., Harrison, D., Susman, G., 2012. Domestic UK retrofit challenge: Barriers, incentives and current performance leading into the Green Deal. *Energy Policy* 50, 294–305. <https://doi.org/10.1016/j.enpol.2012.07.019>
- Duplessis, B., Adnot, J., Dupont, M., Racapé, F., 2012. An empirical typology of energy services based on a well-developed market: France. *Energy Policy* 45, 268–276. <https://doi.org/10.1016/j.enpol.2012.02.031>
- EC, 2018. Directive (EU) 2018/ of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, Official Journal of the European Union.
- EC, 2014. A policy framework for climate and energy in the period from 2020 to 2030. Communication from the Commission to the European Parliament, the Council, the European economic and social Committee and the Committee of the Regions, Publication Office of the European Union. <https://doi.org/10.1017/CBO9781107415324.004>
- Ecology Building Society, 2017. C-Change Mortgage Discounts | Ecology Building Society [WWW Document]. URL <https://www.ecology.co.uk/mortgages/c-change-discounts/> (accessed 6.15.17).
- Edler, J., Fagerberg, J., 2017. Innovation policy: What, why, and how. *Oxford Rev. Econ. Policy* 33, 2–23. <https://doi.org/10.1093/oxrep/grx001>
- Edrich, B., Beagley, K., Webber, P., Kelling, S., 2010. Kirklees Warm Zone Final Report 2007-2010 25.
- EEFIG, 2015. Energy Efficiency – the first fuel for the EU Economy. <https://doi.org/10.1021/ja982781y>
- EeMAp, 2017. Energy Efficient Mortgages Action Plan (Eemap) Initiative Eemap Energy Efficiency (EE) Financing: Emerging Analysis. Brussels.
- Element Energy, 2013. Review of potential for carbon savings from residential energy efficiency.
- Energiesprong, 2018. The Netherlands – Energiesprong [WWW Document]. URL <http://energiesprong.eu/country/the-netherlands/> (accessed 5.8.18).
- Energiesprong, 2017. United Kingdom – Energiesprong [WWW Document]. URL <http://energiesprong.eu/country/united-kingdom/> (accessed 3.7.17).
- Energiesprong, 2014. Transition Zero 1–30.
- Engelken, M., Römer, B., Drescher, M., Welp, I.M., Picot, A., 2016. Comparing drivers, barriers, and opportunities of business models for renewable energies: A review. *Renew. Sustain. Energy Rev.* 60, 795–809. <https://doi.org/10.1016/j.rser.2015.12.163>
- Eriksson, P.E., 2008. Procurement and governance management: Development of a conceptual procurement model based on different types of control. *EconStor*.

- <https://doi.org/10.1007/s10273-011-1262-2>
- EST, 2017. HEEPS Equity Loan | Energy Saving Trust [WWW Document]. URL <http://www.energysavingtrust.org.uk/scotland/grants-loans/heeps/heeps-equity-loan-scheme> (accessed 12.21.17).
- EST, 2011. Local Authority Large Scale Retrofit: A Review of Finance Models.
- Etzkowitz, H., Leydesdorff, L., 2000. The dynamics of innovation: from National Systems and “Mode 2” to a Triple Helix of university–industry–government relations. *Res. Policy* 29, 109–123. [https://doi.org/10.1016/S0048-7333\(99\)00055-4](https://doi.org/10.1016/S0048-7333(99)00055-4)
- Fawcett, T., 2014. Exploring the time dimension of low carbon retrofit: owner-occupied housing. *Build. Res. Inf.* 42, 477–488. <https://doi.org/10.1080/09613218.2013.804769>
- Fawcett, T., Killip, G., 2014. Anatomy of low carbon retrofits: evidence from owner-occupied Superhomes. *Build. Res. Inf.* 42, 434–445. <https://doi.org/10.1080/09613218.2014.893162>
- Fawcett, T., Killip, G., Janda, K.B., 2014. Innovative Practices in Low Carbon Retrofit : Time , Scale and Business Models 3–4.
- Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. *Qual. Inq.* 12, 219–245. <https://doi.org/10.1177/1077800405284363>
- Foss, N.J., Saebi, T., 2018. Business models and business model innovation: Between wicked and paradigmatic problems. *Long Range Plann.* 51, 9–21. <https://doi.org/https://doi.org/10.1016/j.lrp.2017.07.006>
- Foxon, T.J., 2011. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecol. Econ.* 70, 2258–2267. <https://doi.org/10.1016/j.ecolecon.2011.07.014>
- Foxon, T.J., Bale, C.S.E., Busch, J., Bush, R., Hall, S., Roelich, K., 2015. Low carbon infrastructure investment: extending business models for sustainability. *Infrastruct. Complex.* 2, 4. <https://doi.org/10.1186/s40551-015-0009-4>
- Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: Drivers, barriers and systems failures. *Energy Policy* 33, 2123–2137. <https://doi.org/10.1016/j.enpol.2004.04.011>
- Freehling, J., Stickles, B., 2016. Energy Efficiency Finance: A Market Reassessment (An ACEE White Paper).
- Frontier Economics Ltd, 2015. Energy efficiency: An infrastructure priority.
- Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2015. Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Econ.* 48, 145–156. <https://doi.org/10.1016/j.eneco.2014.12.012>
- Fylan, F., Glew, D., Smith, M., Johnston, D., Brooke-Peat, M., Miles-Shenton, D., Fletcher, M., Aloise-Young, P., Gorse, C., 2016. Reflections on retrofits: Overcoming barriers to energy efficiency among the fuel poor in the United Kingdom. *Energy Res. Soc. Sci.* 21, 190–198. <https://doi.org/10.1016/j.erss.2016.08.002>
- Gauthier, C., Gilomen, B., 2016. Business Models for Sustainability: Energy Efficiency in Urban Districts. *Organ. Environ.* 29, 124–144. <https://doi.org/10.1177/1086026615592931>
- Gillingham, K., Newell, R.G., Palmer, K., 2009. Energy Efficiency Economics and Policy. <https://doi.org/10.1146/annurev.resource.102308.124234>
- GLA, 2017. RE:NEW success | London City Hall [WWW Document]. URL <https://www.london.gov.uk/what-we-do/environment/energy/renew-0/renew-success> (accessed 3.7.17).
- Glaser, B.G., Strauss, A.L., 2017. Discovery of grounded theory: Strategies for qualitative

- research. Routledge.
- Gouldson, A., Kerr, N., Millward-Hopkins, J., Freeman, M.C., Topi, C., Sullivan, R., 2015. Innovative financing models for low carbon transitions: Exploring the case for revolving funds for domestic energy efficiency programmes. *Energy Policy* 86, 739–748. <https://doi.org/10.1016/j.enpol.2015.08.012>
- GOV.UK, 2017. Standard Assessment Procedure - GOV.UK [WWW Document]. URL <https://www.gov.uk/guidance/standard-assessment-procedure> (accessed 9.28.17).
- Gram-Hanssen, K., 2014. Retrofitting owner-occupied housing: remember the people. *Build. Res. Inf.* 42, 393–397. <https://doi.org/10.1080/09613218.2014.911572>
- Green Investment Group, 2017. Energy Solutions - Making energy work harder, in: SEAF Investor Forum.
- Grix, J., 2010. *Demystifying postgraduate research*. A&C Black.
- Guertler, P., Rosenow, J., 2016. *Buildings and the 5th Carbon Budget*. London.
- Gupta, R., Chandiwalla, S., 2010. Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments. *Build. Res. Inf.* 38, 530–548. <https://doi.org/10.1080/09613218.2010.495216>
- Gupta, R., Gregg, M., 2016. Do deep low carbon domestic retrofits actually work? *Energy Build.* 129, 330–343. <https://doi.org/10.1016/j.enbuild.2016.08.010>
- Gupta, R., Gregg, M., Passmore, S., Stevens, G., 2015. Intent and outcomes from the Retrofit for the Future programme: Key lessons. *Build. Res. Inf.* 43, 435–451. <https://doi.org/10.1080/09613218.2015.1024042>
- Haines, V., Mitchell, V., 2014. A persona-based approach to domestic energy retrofit. *Build. Res. Inf.* 42. <https://doi.org/10.1080/09613218.2014.893161>
- Hall, S., Foxon, T.J., Bolton, R., 2016. Financing the civic energy sector: How financial institutions affect ownership models in Germany and the United Kingdom. *Energy Res. Soc. Sci.* 12, 5–15. <https://doi.org/10.1016/j.erss.2015.11.004>
- Hall, S., Foxon, T.J., Bolton, R., 2015. Investing in low-carbon transitions: energy finance as an adaptive market. *Clim. Policy* 3062, 1–19. <https://doi.org/10.1080/14693062.2015.1094731>
- Hall, S., Roelich, K., 2016. Business model innovation in electricity supply markets: The role of complex value in the United Kingdom. *Energy Policy* 92, 286–298. <https://doi.org/10.1016/j.enpol.2016.02.019>
- Hannon, M., 2012. Co-evolution of innovative business models and sustainability transitions : the case of the Energy Service Company (ESCo) model and the UK energy system 1–348.
- Hannon, M.J., Bolton, R., 2015. UK Local Authority engagement with the Energy Service Company (ESCo) model: Key characteristics, benefits, limitations and considerations. *Energy Policy* 78, 198–212. <https://doi.org/10.1016/j.enpol.2014.11.016>
- Hannon, M.J., Foxon, T.J., Gale, W.F., 2015. “Demand pull” government policies to support Product-Service System activity: The case of Energy Service Companies (ESCos) in the UK. *J. Clean. Prod.* 108, 1–16. <https://doi.org/10.1016/j.jclepro.2015.05.082>
- Hannon, M.J., Foxon, T.J., Gale, W.F., 2013. The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition. *Energy Policy* 61, 1031–1045. <https://doi.org/10.1016/J.ENPOL.2013.06.009>
- Hannon, M.J., Skea, J., 2014. Facilitating and coordinating UK energy innovation through systemic innovation intermediaries, in: 5th International Conference on Sustainability Transitions, 27-29 August 2014, Utrecht, the Netherlands.
- Hansford, P., 2015. Solid wall insulations: unlocking demand and driving up standards.

London.

- Hellström, M., Tsvetkova, A., Gustafsson, M., Wikström, K., 2015. Collaboration mechanisms for business models in distributed energy ecosystems. *J. Clean. Prod.* 102, 226–236. <https://doi.org/10.1016/j.jclepro.2015.04.128>
- HM Government, 2017. The Clean Growth Strategy Leading the way to a low carbon future.
- HM Government, 2008. Climate Change Act.
- Hoetker, G., 2006. Do modular products lead to modular organizations? *Strateg. Manag. J. Strat. Mgmt. J* 27, 501–518. <https://doi.org/10.1002/smj.528>
- Hoicka, C.E., Parker, P., Andrey, J., 2014. Residential energy efficiency retrofits: How program design affects participation and outcomes. *Energy Policy* 65, 594–607. <https://doi.org/10.1016/J.ENPOL.2013.10.053>
- Howells, J., 2006. Intermediation and the role of intermediaries in innovation. *Res. Policy.* <https://doi.org/10.1016/j.respol.2006.03.005>
- Hyland, M., Lyons, R.C., Lyons, S., 2013. The value of domestic building energy efficiency - evidence from Ireland. *Energy Econ.* 40. <https://doi.org/10.1016/j.eneco.2013.07.020>
- Hyysalo, S., Juntunen, J.K., Martiskainen, M., 2018. Energy Internet forums as acceleration phase transition intermediaries. *Res. Policy* 47, 872–885. <https://doi.org/10.1016/J.RESPOL.2018.02.012>
- IEA, 2017. Market-based Instruments for Energy Efficiency.
- IEA, 2013. Transition to sustainable buildings: Strategies and opportunities to 2050, OECD. <https://doi.org/10.1787/9789264202955-en>
- Investor Confidence Project, 2015. Fueling investment in energy efficiency.
- IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Summary for Policymakers and Technical Summary, Climate Change 2014: Mitigation of Climate Change. Part of the Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. <https://doi.org/10.1017/CBO9781107415416.005>
- Irrek, W., Suerkemper, F., Labanca, N., Bertoldi, P., 2013. ESCOs for residential buildings : market situation in the European Union and policy recommendations. *ECEEE Summer Study Proc.* 1339–1347.
- Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: Technology and environmental policy. *Ecol. Econ.* 54, 164–174. <https://doi.org/10.1016/j.ecolecon.2004.12.027>
- Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap What does it mean? *Energy Policy* 22, 804–810. [https://doi.org/10.1016/0301-4215\(94\)90138-4](https://doi.org/10.1016/0301-4215(94)90138-4)
- Jahn, A., Rosenow, J., 2017. Property transfer tax reform – a game changer for energy efficiency retrofits ? *ECEEE 2017 Summer Study – Consum. Effic. Limits* 1351–1358.
- Jankel, Z., 2013. Delivering and Funding Housing Retrofit: A Review of Community Models.
- Johnson, M.W., Suskewicz, J., 2009. How to Jump-Start the Clean-Tech Economy. *Harv. Bus. Rev.* 87, 1–8.
- Johnson, W.H.A., 2008. Roles, resources and benefits of intermediate organizations supporting triple helix collaborative R&D: The case of Precarn. *Technovation* 28, 495–505. <https://doi.org/10.1016/J.TECHNOVATION.2008.02.007>
- Joyce, A., Paquin, R.L., 2016. The triple layered business model canvas: A tool to design more sustainable business models. *J. Clean. Prod.* <https://doi.org/10.1016/j.jclepro.2016.06.067>
- Kangas, H.-L., Lazarevic, D., Kivimaa, P., 2018. Technical skills, disinterest and non-functional regulation: Barriers to building energy efficiency in Finland viewed by energy service

- companies. *Energy Policy* 114, 63–76. <https://doi.org/10.1016/j.enpol.2017.11.060>
- Kats, G., Menkin, A., Domm, J., Debold, M., 2011. Energy Efficiency Financing -Models and Strategies, Capital E.
- Kelly, S., Crawford-Brown, D., Pollitt, M.G., 2012. Building performance evaluation and certification in the UK: Is SAP fit for purpose? *Renew. Sustain. Energy Rev.* 16, 6861–6878. <https://doi.org/10.1016/j.rser.2012.07.018>
- Kern, F., Kivimaa, P., Martiskainen, M., 2017. Policy packaging or policy patching? The development of complex energy efficiency policy mixes. *Energy Res. Soc. Sci.* 23, 11–25. <https://doi.org/10.1016/j.ERSS.2016.11.002>
- Kerr, N., Gouldson, A., Barrett, J., 2017. The rationale for energy efficiency policy: Assessing the recognition of the multiple benefits of energy efficiency retrofit policy. *Energy Policy*. <https://doi.org/10.1016/j.enpol.2017.03.053>
- Kim, C., O'Connor, R., Bodden, K., 2012. Innovations and Opportunities in Energy Efficiency Finance, Wilson Sonsini Goodrich & Rosati.
- Kindström, D., Ottosson, M., 2016. Local and regional energy companies offering energy services: Key activities and implications for the business model. *Appl. Energy* 171, 491–500. <https://doi.org/10.1016/j.apenergy.2016.03.092>
- Kivimaa, P., 2014. Government-affiliated intermediary organisations as actors in system-level transitions. *Res. Policy* 43, 1370–1380. <https://doi.org/10.1016/j.respol.2014.02.007>
- Kivimaa, P., Boon, W., Hyysalo, S., Klerkx, L., Group, I., 2018. Towards a typology of intermediaries in sustainability transitions : a systematic review and a research agenda. *Res. Policy* 17, 1–31. <https://doi.org/10.1016/j.respol.2018.10.006>
- Kivimaa, P., Martiskainen, M., 2018a. Dynamics of policy change and intermediation: The arduous transition towards low-energy homes in the United Kingdom. *Energy Res. Soc. Sci.* 44, 83–99. <https://doi.org/10.1016/j.ERSS.2018.04.032>
- Kivimaa, P., Martiskainen, M., 2018b. Innovation, low energy buildings and intermediaries in Europe: systematic case study review. *Energy Effic.* 11, 31–51. <https://doi.org/10.1007/s12053-017-9547-y>
- Kivimaa, P., Martiskainen, M., 2016. Innovation towards low energy buildings and the role of intermediaries in the transition-Review of Scholarly Case Studies in Europe. *Creat. built Environ. new Oppor.* 1, 103.
- Klerkx, L., Leeuwis, C., 2009. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technol. Forecast. Soc. Change* 76, 849–860. <https://doi.org/10.1016/j.techfore.2008.10.001>
- Knoeri, C., Steinberger, J.K., Roelich, K., 2016. End-user centred infrastructure operation: Towards integrated end-use service delivery. *J. Clean. Prod.* 132, 229–239. <https://doi.org/10.1016/j.jclepro.2015.08.079>
- Koh, L., Jones, C.R., Genovese, A., Acquaye, A., Marchand, R., Scott, F., 2013. Promoting the Green Deal to low income communities : Initial insights from Yorkshire & The Humber. Sheffield.
- Kvale, S., 2008. *Doing interviews*. Sage.
- Labanca, N., Suerkemper, F., Bertoldi, P., Irrek, W., Duplessis, B., 2014. Energy efficiency services for residential buildings: Market situation and existing potentials in the European Union. *J. Clean. Prod.* 109, 284–295. <https://doi.org/10.1016/j.jclepro.2015.02.077>
- Lambert, S.C., Davidson, R.A., 2013. Applications of the business model in studies of enterprise success, innovation and classification: An analysis of empirical research from

- 1996 to 2010. *Eur. Manag. J.* 31, 668–681. <https://doi.org/10.1016/j.emj.2012.07.007>
- LEEF, 2012. Introduction to the London Energy Efficiency Fund (LEEF).
- Lees, E., 2006. Evaluation of energy efficiency commitment 2002-2005, Victoria.
- Lees, E.W., 2008. Evaluation of the energy efficiency commitment 2005-08 44, 105.
- LENDERS, 2017. Lenders-Improving energy costs in mortgages- Promoting energy efficiency in homes. <https://doi.org/10.1089/obe.2005.1.166>
- Lente, H. van, Hekkert, M., 2003. Roles of Systemic Intermediaries in Transition. *Int. J. ...* 7, 247–279. <https://doi.org/10.1142/S1363919603000817>
- Leventis, G., Kramer, C., Schwartz, L., Zetterberg, J., Ludwig, V., 2017. Energy Efficiency Financing for Low-and Moderate-Income Households: Current State of the Market, Issues, and Opportunities Financing Solutions Working Group FOR MORE INFORMATION.
- Lewis, J., Smith, L., 2013. Breaking the barriers: An industry review of the barriers to Whole House Energy Efficiency Retrofit and the creation of an industry action plan -Energy Efficiency Partnership for Buildings (EPPB).
- Long, T.B., Young, W., Webber, P., Gouldson, A., Harwatt, H., 2015. The impact of domestic energy efficiency retrofit schemes on householder attitudes and behaviours. *J. Environ. Plan. Manag.* 58, 1853–1876. <https://doi.org/10.1080/09640568.2014.965299>
- Lopez, F.J.D., Becker, J., Eris, B., Koers, W., Bastein, T., 2014. New business models that support resource efficiency.
- Lovell, H., 2008. Discourse and innovation journeys: the case of low energy housing in the UK. *Technol. Anal. Strateg. Manag.* 20, 613–632.
- Lowe, R., 2007. Technical options and strategies for decarbonizing UK housing. *Build. Res. Inf.* 35, 412–425. <https://doi.org/10.1080/09613210701238268>
- Maby, C., Owen, A., 2015. Installer Power - The key to unlocking low carbon retrofit in private housing.
- Mahapatra, K., Gustavsson, L., Haavik, T., Aabrekk, S., Svendsen, S., Vanhoutteghem, L., Paiho, S., Ala-Juusela, M., 2013. Business models for full service energy renovation of single-family houses in Nordic countries. *Appl. Energy* 112, 1558–1565. <https://doi.org/10.1016/j.apenergy.2013.01.010>
- Mallaburn, P.S., Eyre, N., 2014. Lessons from energy efficiency policy and programmes in the UK from 1973 to 2013. *Energy Effic.* <https://doi.org/10.1007/s12053-013-9197-7>
- Marchand, R.D., Koh, S.C.L.L., Morris, J.C., 2015. Delivering energy efficiency and carbon reduction schemes in England: Lessons from Green Deal Pioneer Places. *Energy Policy* 84, 96–106. <https://doi.org/10.1016/j.enpol.2015.04.035>
- Martiskainen, M., Kivimaa, P., 2018. Creating innovative zero carbon homes in the United Kingdom — Intermediaries and champions in building projects. *Environ. Innov. Soc. Transitions* 26, 15–31. <https://doi.org/10.1016/J.EIST.2017.08.002>
- Masini, A., Menichetti, E., 2013. Investment decisions in the renewable energy sector: An analysis of non-financial drivers. *Technol. Forecast. Soc. Change* 80, 510–524. <https://doi.org/10.1016/j.techfore.2012.08.003>
- Masini, A., Menichetti, E., 2012. The impact of behavioural factors in the renewable energy investment decision making process: Conceptual framework and empirical findings. *Energy Policy* 40, 28–38. <https://doi.org/10.1016/j.enpol.2010.06.062>
- Massa, L., Tucci, C.L., 2013. Business model innovation. *Oxford Handb. Innovafion Manag.* 27, 420–441. <https://doi.org/10.1093/oxfordhb/9780199694945.013.002>
- Maxwell, J.A., 2012. Qualitative research design: An interactive approach. Sage publications.

- Mazzucato, M., 2015. *The entrepreneurial state: Debunking public vs. private sector myths*. Anthem Press.
- Mazzucato, M., 2011. The entrepreneurial state. *Soundings* 49, 131–142.
<https://doi.org/10.3898/136266211798411183>
- Mazzucato, M., Penna, C.C.R., 2016. Beyond market failures: the market creating and shaping roles of state investment banks. *J. Econ. Policy Reform* 19, 305–326.
<https://doi.org/10.1080/17487870.2016.1216416>
- Mazzucato, M., Semieniuk, G., 2018. Financing renewable energy: Who is financing what and why it matters. *Technol. Forecast. Soc. Change* 127, 8–22.
<https://doi.org/10.1016/j.techfore.2017.05.021>
- Mazzucato, M., Semieniuk, G., 2017. Public financing of innovation: new questions. *Oxford Rev. Econ. Policy* 33, 24–48.
- McCoy, D., Lyons, S., 2017. Unintended outcomes of electricity smart-metering: trading-off consumption and investment behaviour. *Energy Effic.* 10, 299–318.
<https://doi.org/10.1007/s12053-016-9452-9>
- Mcelroy, D.J., Rosenow, J., 2018. Policy implications for the performance gap of low-carbon building technologies. *Build. Res. Inf.* 1–13.
<https://doi.org/10.1080/09613218.2018.1469285>
- McMahon, D., Thorsteinsdóttir, H., 2013. Pursuing endogenous high-tech innovation in developing countries: A look at regenerative medicine innovation in Brazil, China and India. *Res. Policy* 42, 965–974. <https://doi.org/10.1016/j.respol.2012.12.003>
- Midgley, G., Lindhult, E., 2015. What is Systemic Innovation?
- Mignon, I., Kanda, W., 2018. A typology of intermediary organizations and their impact on sustainability transition policies. *Environ. Innov. Soc. Transitions*.
<https://doi.org/10.1016/j.eist.2018.07.001>
- Miles, M.B., Huberman, A.M., Huberman, M.A., Huberman, M., 1994. *Qualitative data analysis: An expanded sourcebook*. sage.
- Milin, C., Bullier, A., 2011. Energy retrofitting of social housing through energy performance contracts. A feedback from the FRESH project : France , Italy , United Kingdom and Bulgaria, FRESH (financing energy refurbishment for social housing).
- Milsom, E., 2016. Solid wall heat losses and the potential for energy saving Consequences for consideration to maximise SWI benefits: A route-map for change. Watford.
- Mlecnik, E., 2013. Opportunities for supplier-led systemic innovation in highly energy-efficient housing. *J. Clean. Prod.* 56, 103–111.
<https://doi.org/10.1016/j.jclepro.2012.03.009>
- Mlecnik, E., Kondratenko, I., Cré, J., Vrijders, J., Degraeve, P., Van Der Have, J.A., Haavik, T., Aabrekk, S.A., Grøn, M., Hansen, S., Svendsen, S., Stenlund, O., Paiho, S., 2012. Collaboration opportunities in advanced housing renovation. *Energy Procedia* 30, 1380–1389. <https://doi.org/10.1016/j.egypro.2012.11.152>
- Mlecnik, E., Kondratenko, I., Haavik, T., n.d. Business model development for customer-oriented housing renovation.
- Mlecnik, E., Paiho, S., Cré, J., Stenlund, O., Vrijders, J., Haavik, T., Synnove, A., Vanhoutteghem, L., Hansen, S., 2011. Web Platforms Integrating Supply and Demand for Energy Renovations 1–8.
- Mlecnik, E., Straub, A., Haavik, T., 2018. Collaborative business model development for home energy renovations. *Energy Effic.* <https://doi.org/10.1007/s12053-018-9663-3>
- Modigliani, F., Miller, M.H., 1958. *The Cost of Capital, Corporation Finance and the Theory of*

- Investment. *Am. Econ. Rev.* 48, 261–297. <https://doi.org/10.4013/base.20082.07>
- Moschetti, R., Brattebø, H., 2016. Sustainable Business Models for Deep Energy Retrofitting of Buildings: State-of-the-art and Methodological Approach. *Energy Procedia* 96, 435–445. <https://doi.org/10.1016/j.egypro.2016.09.174>
- Nolden, C., Sorrell, S., 2016. The UK market for energy service contracts in 2014–2015. *Energy Effic.* 1–16. <https://doi.org/10.1007/s12053-016-9430-2>
- Nolden, C., Sorrell, S., Polzin, F., 2016. Catalysing the energy service market: The role of intermediaries. *Energy Policy* 98, 420–430. <https://doi.org/10.1016/j.enpol.2016.08.041>
- Norton, D.W., Joseph, B., Li, P., 2013. Using the customer journey to road test and refine the business model. <https://doi.org/10.1108/10878571311318196>
- Nykqvist, B., Whitmarsh, L., 2008. A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technol. Forecast. Soc. Change* 75, 1373–1387. <https://doi.org/10.1016/j.techfore.2008.05.006>
- O’Keeffe, J.M., Gilmour, D., Simpson, E., 2016. A network approach to overcoming barriers to market engagement for SMEs in energy efficiency initiatives such as the Green Deal. *Energy Policy* 97, 582–590. <https://doi.org/10.1016/j.enpol.2016.08.006>
- Odyssee, 2017. Odyssee decomposition facility [WWW Document]. URL <http://www.indicators.odyssee-mure.eu/decomposition.html> (accessed 5.12.17).
- OECD, 2015a. System Innovation: Synthesis Report 101.
- OECD, 2015b. Infrastructure Financing Instruments and Incentives.
- Ofgem, 2016. Switching Programme Design Principles V1.0 DESIGN PRINCIPLES Impacts on customers.
- Okkonen, L., Suhonen, N., 2010. Business models of heat entrepreneurship in Finland. *Energy Policy* 38, 3443–3452. <https://doi.org/10.1016/j.enpol.2010.02.018>
- Olofsson, S., Hoveskog, M., Halila, F., 2018. Journey and impact of business model innovation: The case of a social enterprise in the Scandinavian electricity retail market. *J. Clean. Prod.* 175, 70–81. <https://doi.org/10.1016/J.JCLEPRO.2017.11.081>
- Osterwalder, A., 2004. Business model ontology - PhD Thesis. l’Université de Lausanne.
- Osterwalder, A., Pigneur, Y., 2010. Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers, A handbook for visionaries, game changers, and challengers. <https://doi.org/10.1523/JNEUROSCI.0307-10.2010>
- Osterwalder, A., Pigneur, Y., Tucci, C.L., 2005. Clarifying Business Models: Origins, Present, and Future of the Concept. *Commun. Assoc. Inf. Syst.* 16, 1–25. <https://doi.org/10.1.1.83.7452>
- Owen, A., Mitchell, G., Gouldson, A., 2014. Unseen influence—The role of low carbon retrofit advisers and installers in the adoption and use of domestic energy technology. *Energy Policy* 73, 169–179. <https://doi.org/10.1016/j.enpol.2014.06.013>
- Palmer, J., Livingstone, M., Adams, A., 2017. What Does It Cost To Retrofit Homes? Updating the Cost Assumptions for BEIS’s Energy Efficiency Modelling, Department for Business, Energy and Industrial Strategy. London.
- Parker, M., Guthrie, P., 2016. Crossing the energy efficiency chasm: an assessment of the barriers to institutional investment at scale, a UK perspective. *J. Sustain. Financ. Invest.* <https://doi.org/10.1080/20430795.2016.1159650>
- Pätäri, S., Sinkkonen, K., 2014. Energy Service Companies and Energy Performance Contracting: Is there a need to renew the business model? Insights from a Delphi study. *J. Clean. Prod.* 66, 264–271. <https://doi.org/10.1016/j.jclepro.2013.10.017>
- Pelenur, M.J., Cruickshank, H.J., 2012. Closing the Energy Efficiency Gap: A study linking

- demographics with barriers to adopting energy efficiency measures in the home. *Energy* 47, 348–357. <https://doi.org/10.1016/j.energy.2012.09.058>
- Pettifor, H., Wilson, C., Chrysoschoidis, G., 2015. The appeal of the green deal: Empirical evidence for the influence of energy efficiency policy on renovating homeowners. *Energy Policy* 79, 161–176. <https://doi.org/10.1016/j.enpol.2015.01.015>
- Platt, R., Rosenow, J., 2014. Up against the (solid) wall: what changes to the eco mean for energy efficiency policy.
- Reid, G., Wynn, G., 2015. The future of solar power in the United Kingdom. *Energies* 8, 7818–7832. <https://doi.org/10.3390/en8087818>
- Rezessy, S., Bertoldi, P., 2010. Financing Energy Efficiency: Forging the link between financing and project implementation. *Environ. Plan. A* 41, 1072–1089.
- Richter, M., 2013a. Business model innovation for sustainable energy: German utilities and renewable energy. *Energy Policy* 62, 1226–1237. <https://doi.org/10.1016/j.enpol.2013.05.038>
- Richter, M., 2013b. German utilities and distributed PV: How to overcome barriers to business model innovation. *Renew. Energy* 55, 456–466. <https://doi.org/10.1016/j.renene.2012.12.052>
- Richter, M., 2012. Utilities' business models for renewable energy: A review. *Renew. Sustain. Energy Rev.* 16, 2483–2493. <https://doi.org/10.1016/j.rser.2012.01.072>
- Risholt, B., Berker, T., 2013. Success for energy efficient renovation of dwellings—Learning from private homeowners. *Energy Policy* 61, 1022–1030. <https://doi.org/10.1016/j.enpol.2013.06.011>
- Ritter, T., Lettl, C., 2018. The wider implications of business-model research. *Long Range Plann.* 51, 1–8. <https://doi.org/10.1016/j.lrp.2017.07.005>
- Roelich, K., Knoeri, C., Steinberger, J.K., Varga, L., Blythe, P.T., Butler, D., Gupta, R., Harrison, G.P., Martin, C., Purnell, P., 2015. Towards resource-efficient and service-oriented integrated infrastructure operation. *Technol. Forecast. Soc. Change* 92, 40–52. <https://doi.org/10.1016/j.techfore.2014.11.008>
- Rohrbeck, R., Konnertz, L., Knab, S., 2013. Collaborative business modelling for systemic and sustainability innovations. *Int. J. Technol. Manag.* <https://doi.org/10.1504/IJTM.2013.055577>
- Roome, N., Louche, C., 2016. Journeying toward business models for sustainability: A conceptual model found inside the black box of organisational transformation. *Organ. Environ.* 29, 11–35. <https://doi.org/10.1177/1086026615595084>
- Rosenow, J., 2013. The politics of the German CO₂-Building Rehabilitation Programme. *Energy Effic.* <https://doi.org/10.1007/s12053-012-9181-7>
- Rosenow, J., 2012. Energy savings obligations in the UK-A history of change. *Energy Policy* 49, 373–382. <https://doi.org/10.1016/j.enpol.2012.06.052>
- Rosenow, J., Cowart, R., 2017. Efficiency First : Reinventing the UK 's Energy System. Brussels.
- Rosenow, J., Eyre, N., 2016. A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. *Energy Res. Soc. Sci.* 21, 141–144. <https://doi.org/10.1016/j.erss.2016.07.005>
- Rosenow, J., Eyre, N., 2014. Re-energising the UK 's approach to domestic energy efficiency 281–289.
- Rosenow, J., Eyre, N., Bürger, V., Rohde, C., 2013a. Overcoming the Upfront Investment Barrier: Comparing the German CO₂ Building Rehabilitation Programme and the British Green Deal. *Energy Environ.* 24, 83–104. <https://doi.org/10.1260/0958-305X.24.1-2.83>

- Rosenow, J., Eyre, N., Sorrell, S., Guertler, P., 2017a. Unlocking Britain's First Fuel: The potential for energy savings in UK housing.
- Rosenow, J., Galvin, R., 2013. Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK. *Energy Build.* 62, 450–458. <https://doi.org/10.1016/j.enbuild.2013.03.021>
- Rosenow, J., Guertler, P., Sorrell, S., Eyre, N., 2018. The remaining potential for energy savings in UK households. *Energy Policy* 121, 542–552. <https://doi.org/10.1016/j.enpol.2018.06.033>
- Rosenow, J., Kern, F., Rogge, K., 2017b. The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy. *Energy Res. Soc. Sci.* 33, 95–104. <https://doi.org/10.1016/j.erss.2017.09.013>
- Rosenow, J., Platt, R., Demurtas, A., 2014. Fiscal impacts of energy efficiency programmes- The example of solid wall insulation investment in the UK. *Energy Policy* 74, 610–620. <https://doi.org/10.1016/j.enpol.2014.08.007>
- Rosenow, J., Platt, R., Flanagan, B., 2013b. Fuel poverty and energy efficiency obligations - A critical assessment of the supplier obligation in the UK. *Energy Policy* 62, 1194–1203. <https://doi.org/10.1016/j.enpol.2013.07.103>
- Rosenow, J.A.N., Leguijt, C.O.R., Pato, Z., Eyre, N., Fawcett, T., 2016. An ex-ante evaluation of the EU Energy Efficiency Directive — Article 7 5, 1–20.
- Sanchez, R., Mahoney, J.T., 1996. Modularity, flexibility, and knowledge management in product and organization design. *Strateg. Manag. J.* 17, 63–76. <https://doi.org/10.1002/smj.4250171107>
- Sarasini, S., Linder, M., 2018. Integrating a business model perspective into transition theory: The example of new mobility services. *Environ. Innov. Soc. Transitions* 27, 16–31. <https://doi.org/10.1016/j.eist.2017.09.004>
- Sayce, S., Haggett, F., 2016. Re-Value : Assessing the Value of Energy Efficient Properties in the Residential Sector.
- Schaltegger, S., Hansen, E.G., Lüdeke-Freund, F., 2016. Business Models for Sustainability: Origins, Present Research, and Future Avenues. *Organ. Environ.* 29, 3–10. <https://doi.org/10.1177/1086026615599806>
- Schröder, M., Ekins, P., Power, A., Zulauf, M., Lowe, R., 2011. The KfW experience in the reduction of energy use in and CO2 emissions from buildings : operation , impacts and lessons for the UK, Energy.
- Scottish Government, 2017. Energy Strategy – Scotland's Energy Efficiency Programme (Seep).
- Seyfang, G., Park, J.J., Smith, A., 2013. A thousand flowers blooming? An examination of community energy in the UK. *Energy Policy* 61, 977–989. <https://doi.org/10.1016/j.enpol.2013.06.030>
- Shomali, A., Pinkse, J., 2016. The consequences of smart grids for the business model of electricity firms. *J. Clean. Prod.* 112, 3830–3841. <https://doi.org/10.1016/j.jclepro.2015.07.078>
- Shove, E., 2017. What is wrong with energy efficiency? *Build. Res. Inf.* 1–11. <https://doi.org/10.1080/09613218.2017.1361746>
- Shove, E., Walker, G., 2014. What Is Energy For? Social Practice and Energy Demand. *Theory, Cult. Soc.* 31, 41–58. <https://doi.org/10.1177/0263276414536746>
- Shrubsole, C., Macmillan, A., Davies, M., May, N., 2014. 100 Unintended consequences of policies to improve the energy efficiency of the UK housing stock. *Indoor Built Environ.*

- 23, 340–352. <https://doi.org/10.1177/1420326X14524586>
- Smits, R., Kuhlmann, S., 2004. The rise of systemic instruments in innovation policy. *Int. J. Foresight Innov. Policy* 1, 4. <https://doi.org/10.1504/IJFIP.2004.004621>
- Snape, J.R.R., Boait, P.J.J., Rylatt, R.M.M., 2015. Will domestic consumers take up the renewable heat incentive? An analysis of the barriers to heat pump adoption using agent-based modelling. *Energy Policy* 85, 32–38. <https://doi.org/10.1016/j.enpol.2015.05.008>
- Sorrell, S., 2007. The economics of energy service contracts. *Energy Policy* 35, 507–521. <https://doi.org/10.1016/j.enpol.2005.12.009>
- Sorrell, S., 2005. The contribution of energy service contracting to a low carbon economy to a low carbon economy. Tyndall Cent. Tech. Rep. No. 37 Novemb. 2005 1–114.
- Sorrell, S., Dimitropoulos, J., Sommerville, M., 2009. Empirical estimates of the direct rebound effect: A review. *Energy Policy* 37, 1356–1371. <https://doi.org/10.1016/j.enpol.2008.11.026>
- Sorrell, S., Mallett, A., Nye, S., 2011. Barriers to industrial energy efficiency: a literature review. United Nations Ind. Dev. Organ. Working pa, 98. <https://doi.org/10.1016/j.rser.2015.03.002>
- Sorrell, S., Schleich, J., O'Malley, E., Scott, S., 2004. *The Economics of Energy Efficiency: Barriers to Cost-Effective Investment.*, Books. Edward Elgar, Cheltenham.
- Sovacool, B.K., 2015. Fuel poverty, affordability, and energy justice in England: Policy insights from the Warm Front Program. *Energy* 93, 361–371. <https://doi.org/10.1016/j.energy.2015.09.016>
- STBA, 2016. What is whole house retrofit ?
- STBA, 2012. *Responsible Retrofit of Traditional Buildings: Sustainable building alliance (STBA).*
- Steinberger, J.K., van Niel, J., Bourg, D., 2009. Profiting from negawatts: Reducing absolute consumption and emissions through a performance-based energy economy. *Energy Policy* 37, 361–370. <https://doi.org/10.1016/j.enpol.2008.08.030>
- Stewart, J., Hyysalo, S., 2008. Intermediaries, Users And Social Learning In Technological Innovation. *Int. J. Innov. Manag.* 12, 295–325. <https://doi.org/10.1142/S1363919608002035>
- Stieb, I., Dunkelberg, E., Stieß, I., Dunkelberg, E., 2013. Objectives, barriers and occasions for energy efficient refurbishment by private homeowners. *J. Clean. Prod.* 48, 250–259. <https://doi.org/10.1016/j.jclepro.2012.09.041>
- Stiglitz, J.E., 1993. The role of the state in financial markets. *World Bank Econ. Rev.* 7, 19–62. <https://doi.org/10.1142/S0219091508001337>
- Stone, H.B.J., 2014. *Market Development Objectives for the Energy Performance Contracting Sector in the UK.*
- Straub, A., 2016. *Cohereno: Collaboration for Housing Nearly Zero-Energy RENOVation Publishable Report.* Delft.
- Stubbs, W., Cocklin, C., 2008. Conceptualizing a “Sustainability Business Model.” *Organ. Environ.* 21, 103–127. <https://doi.org/10.1177/1086026608318042>
- Sunikka-Blank, M., Galvin, R., 2016. Irrational homeowners? How aesthetics and heritage values influence thermal retrofit decisions in the United Kingdom. *Energy Res. Soc. Sci.* 11, 97–108. <https://doi.org/10.1016/j.erss.2015.09.004>
- SUSI Partners, 2017. *SUSI Energy Efficiency Fund SUSI Energy Efficiency Fund SUSI Energy Efficiency Fund SUSI Addresses the Three Main Pillars of Energy Infrastructure.*
- Sustainable Energy Association, 2017. *Energy Efficiency – A Policy Pathway Addressing the*

Able to Pay Sector.

- Sweatman, P., 2013. Innovative Finance Mechanisms for Energy Efficient in Buildings : Finance Models from Europe , USA and Spain Specialist Consulting Firm in Low Carbon Strategy and Energy Efficiency Finance.
- Sweatman, P., 2012. Financing Mechanisms for Europe's Buildings Renovation: Assessment and Structuring Recommendations for Funding European 2020 Retrofit Targets 1–11.
- Sweatman, P., Managan, K., 2010. Financing Energy Efficiency Building Retrofits International Policy and Business Model Review and Regulatory Alternatives for Spain, Climate Strategy and Partners. Madrid.
- Tapia, J., 2012. The “duty to finance”, the cost of capital and the capital structure of regulated utilities: Lessons from the UK. *Util. Policy* 22, 8–21.
<https://doi.org/10.1016/j.jup.2012.02.003>
- Teece, D.J., 2018. Business models and dynamic capabilities. *Long Range Plann.* 51, 40–49.
<https://doi.org/10.1016/J.LRP.2017.06.007>
- Teece, D.J., 2010. Business models, business strategy and innovation. *Long Range Plann.* 43, 172–194. <https://doi.org/10.1016/j.lrp.2009.07.003>
- Teece, D.J., 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Res. Policy* 15, 285–305.
[https://doi.org/10.1016/0048-7333\(86\)90027-2](https://doi.org/10.1016/0048-7333(86)90027-2)
- The Rockefeller Foundation, DB Climate Change Advisors, 2012. United States Building Energy Efficiency Retrofits Market Sizing and Financing Models.
- Thurlwell, J., Davis, C., Mohamed, S., 2011. British Gas Home Energy Report 2011 An assessment of the drivers of domestic natural gas consumption 75.
- Treib, O., Bähr, H., Falkner, G., 2007. Modes of governance: towards a conceptual clarification. *J. Eur. Public Policy* 14, 1–20.
<https://doi.org/10.1080/135017606061071406>
- UKGBC, 2017. Regeneration and Retrofit Task Group Report.
- UKGBC, 2014. Green Deal Finance: Examining the Green Deal interest rate as a barrier to take-up 23.
- UKGBC, 2013. Retrofit Incentives, UK Green building council .
- Upward, A., Jones, P., 2015. An Ontology for Strongly Sustainable Business Models: Defining an Enterprise Framework Compatible With Natural and Social Science. *Organ. Environ.* 1–27. <https://doi.org/10.1177/1086026615592933>
- Walker, S.L., Lowery, D., Theobald, K., 2014. Low-carbon retrofits in social housing: Interaction with occupant behaviour. *Energy Res. Soc. Sci.* 2, 102–114.
<https://doi.org/10.1016/j.erss.2014.04.004>
- Washan, P., Stenning, J., Goodman, M., 2014. Building the Future: The economic and fiscal impacts of making homes energy efficient 44.
- Watson, A., 2014. To what extent has Green Deal policy facilitated energy efficiency retrofit supply chain development : A case study of Birmingham.
- Webb, J., Hawkey, D., Tingey, M., 2016. Governing cities for sustainable energy: The UK case. *Cities* 54, 28–35. <https://doi.org/10.1016/j.cities.2015.10.014>
- Webber, P., Gouldson, A., Kerr, N., 2015. The impacts of household retrofit and domestic energy efficiency schemes: A large scale, ex post evaluation. *Energy Policy* 84, 35–43.
<https://doi.org/10.1016/j.enpol.2015.04.020>
- Wells, P.E., 2013. Business models for sustainability. Edward Elgar Publishing.
- Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems:

- A framework for policy makers and innovation scholars. *Sci. Public Policy* 39, 74–87. <https://doi.org/10.1093/scipol/scr008>
- Willand, N., Ridley, I., Maller, C., 2015. Towards explaining the health impacts of residential energy efficiency interventions - A realist review. Part 1: Pathways. *Soc. Sci. Med.* 133, 191–201. <https://doi.org/10.1016/j.socscimed.2015.02.005>
- Wilson, C., Crane, L., Chrysoschoidis, G., 2015. Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Res. Soc. Sci.* 7, 12–22. <https://doi.org/10.1016/j.erss.2015.03.002>
- Winther, T., Gurigard, K., 2017. Energy performance contracting (EPC): a suitable mechanism for achieving energy savings in housing cooperatives? Results from a Norwegian pilot project. *Energy Effic.* 10, 577–596. <https://doi.org/10.1007/s12053-016-9477-0>
- Yildiz, Ö., 2014. Financing renewable energy infrastructures via financial citizen participation - The case of Germany. *Renew. Energy* 68, 677–685. <https://doi.org/10.1016/j.renene.2014.02.038>
- Yin, R.K., 1994. *Case Study Research—Design and Methods*, Sage Publications.
- Zimring, M., 2014a. Credit Enhancement Overview Guide.
- Zimring, M., 2014b. Energy Efficiency Financing Program Implementation Primer [WWW Document]. URL https://www4.eere.energy.gov/seeaction/system/files/documents/financing_primer_0.pdf (accessed 11.14.17).
- Zimring, M., Leventis, G., Borgeson, M., Thompson, P., Hoffman, I., Goldman, C., 2014a. Financing Energy Improvements on Utility Bills : Market Updates and Key Program Design Considerations for Policymakers and Administrators.
- Zimring, M., Leventis, G., Borgeson, M., Thompson, P., Hoffman, I., Goldman, C., 2014b. Financing Energy Improvements on Utility Bills: Technical Appendix — Case Studies.
- Zimring, M., Leventis, G., Goldman, C., Borgeson, M., Thompson, P., Hoffman, I., 2014c. On-Bill Finance: From Policy to Promise to Practice 1.
- Zott, C., Amit, R., 2010. Business model design: An activity system perspective. *Long Range Plann.* 43, 216–226. <https://doi.org/10.1016/j.lrp.2009.07.004>
- Zott, C., Amit, R., 2009. Business Model Innovation: Creating Value In Times Of Change. *Universia Bus. Rev.* 3, 108–121. <https://doi.org/10.2139/ssrn.1701660>
- Zott, C., Amit, R., Massa, L., 2011. The business model: Recent developments and future research. *J. Manage.* 37, 1019–1042. <https://doi.org/10.1177/0149206311406265>

Appendix A

Table A1 Consolidated interview list

Interview number	Archetype	Organisation	Actor	Date
Business model interviews				
	Expert Scoping			
#1	All	University of Oxford	Senior Research Fellow - energy efficiency policy	25/11/2016
#2		United Kingdom Green Building Council (UKGBC)	Policy Advisor	02/12/2016
#3		Energy Saving Trust (EST)	Senior Insight Manager	29/11/2016
#4		Building Research Establishment (BRE)	Director (Wales)	20/12/2016
#5		Energy Programs Consortium	Counsel and Director of Finance Programs (USA)	17/02/2017
#6		Buildings Performance Institute Europe (BPIE)/Reshape innovation	Innovation Strategist - Founder (Reshape Innovation)	01/03/2017
#7		Georgia Institute of Technology (USA)	Professor of Energy Policy	13/02/2017
#8		Association for Environmental Studies and Sciences (AESS) (USA)	Principal and Independent Consultant	14/02/2017
	Practitioner			
(#4)	Atomised market model	Building Research Establishment (BRE)	Director (Wales)	20/12/2016
#9		Sustainable Design Collective	Architect – Managing Director	17/11/2016
#10	Market intermediary model	Greater London Authority (RE:NEW)	Program Manager – Energy	01/03/2017
#11		Nottingham Energy Partnership	Contracts Manager	15/12/2016

#12		Birmingham Energy Savers (BES) (Consultant)	Sustainability Consultant	25/01/2017
#13	One-stop-shop	Retrofit works / Parity projects	Director	21/12/2016
#14		Segel AS - Norway	Business Development Consultant	2/02/2017
#15		Brighton and Hove Energy Services Company (BHESCo)	CEO	23/02/2017
(#6)	Energy Service Agreement	Energies POSIT'IF - Paris France	Innovation Strategist - Founder (Reshape innovation)	01/03/2017
#16		ICF Habitat- Paris, France	Head of Energy & Water	16/02/2017
#17		RENESCO – Riga, Latvia	Managing Director	02/02/2017
#18	Managed Energy Service Agreement	Energiesprong – UK, Netherlands	Project manager /Rainmaker	12/12/2016
Finance Mechanism Interviews				
	Expert Scoping			
#19	All	Climate Strategy and Partners	Anonymous	27/07/2017
#20		United Kingdom Green Building Council (UKGBC)	Anonymous	09/11/2017
(#4)		Building Research Establishment (BRE)	Director (Wales)	20/12/2016
(#5)		Energy Programmes Consortium (USA)	Counsel and Director of Finance Programs (USA)	17/02/2017
#21		Climate Bonds Initiative	Anonymous	08/08/2017
#22		Marksman Consulting LLP	Anonymous	14/08/2017
#23		Energy Pro Ltd	Anonymous	14/08/2017
	Practitioner			
#24	Public/ credit enhancement	Energy Saving Trust Home Energy Efficiency	Anonymous	09/10/2017

		Programme Scotland (EST-HEEPS)		
#25		Amber Infrastructure (LEEF/MEEF)	Anonymous	30/11/2017
#26	On Bill Finance and Repayment	National Conference of State Legislatures (NCSL) (USA)	Anonymous	30/11/2017
#27		Business Energy and Industrial Strategy (BEIS)	Anonymous	30/11/2017
#28	Energy Service Agreement	Servizi Energia Ambiente (SEA)	Anonymous	22/11/2017
#29		Joule Assets Europe	Anonymous	19/10/2017
(#17)		RENESCO – Riga, Latvia	Managing Director	02/02/2017
#30	Property Assessed Clean Energy (PACE)	RENEW Financial	Anonymous	17/11/2017
#31		PACE Nation	Anonymous	20/10/2017
#32	Energy Efficiency Mortgage	European Mortgage Federation (EeMAP)	Anonymous	12/10/2017
(#15)	Community Finance	Brighton and Hove Energy Services Company (BHESCo)	CEO	23/02/2017
Energiesprong case study interviews				
Interview number	Actor Type	Organisation	Actor	Date
(#18)	Intermediary	Energiesprong Market Development Team	Project Manager	12/12/2016
#33			Head of International Market Development	15/05/2018
#34			Founding Partner	20/06/2018
#35	Client	Nottingham City Homes	Head of Energy and Sustainability	29/06/2018
#36	Contractor	Melius Homes	Director	31/05/2018
#37	Policymaker (Netherlands)	Ministry of the Interior and Kingdom Relations	Director Building & Energy	20/06/2018
#38	Policymaker (UK)	Nottingham City Council	Head of Energy and Sustainability	13/06/2018

Table A2 Low energy housing intermediaries: Sequence of interviews, interviewee types and focus. (supplementary material for Article 3, not conducted by candidate)

Interview round	No. of interviews	Type of interviewees	Focus	Timing of interviews
1st	10	I1 NGO, I2 charity, I3 charity, I4 research organisation, I5 charity, I6 campaign, I7 NGO, I8 membership organisation, I9 network organisation, I10 ex-government	UK building energy efficiency policy development	July–September 2014
2nd	12	I11 social enterprise, I12 community organisation, I13 anonymous, I14 social housing fund, I15 charity, I16 research organisation, I17 social enterprise, I18 local administration, I19 social enterprise, I20 local administration, I21 social enterprise, I22 membership organisation	Developments in UK low-energy homes; activities of specific organisations	May 2015–March 2016
3rd	7	I23 membership organisation, I24 network organisation, I25 ex-government, I26 academic-practitioner, I27 network organisation, I28 academic-practitioner, I29 consultancy	Activities and influence of intermediary organisations on policy development	May 2017, February–March 2018

Appendix B

Table B1 Key financial terminology

Asset backed securities

Securities issued by a special purpose company that holds a package of low-risk assets whose cash flows are sufficient to service the bonds. Unlike covered bonds they do not remain on the balance sheet of the issuer.

Bill neutrality

Finance for energy efficiency measures whose repayments are less to or equal than the project cost savings from those measures

Capital markets

A financial market in which longer-term debt (generally with maturity of longer than one year) and equity instruments are traded

Cash flows or 'receivables'

Accounts receivable, based on future sources of income from a contract or finance repayments

Covered bonds

Unlike asset backed securities covered bonds are "covered" by both the issuer (usually a bank) and the reference portfolio of projects (assets, usually mortgages). Remaining on the balance sheet of the issuer

Credit enhancements

Broadly defined, credit enhancements are a class of tools that reduce lender or investor risk by delivering these capital providers with a level of protection against losses in the event of borrower default or delinquency

Credit rating (i.e. AAA)

Credit rating agencies typically assign letter grades to indicate ratings. These rating scale ranging from AAA (excellent) and AA+ to C and D. A debt instrument with a rating below BBB- is considered to be speculative grade or a 'junk bond', which means it is more likely to default on loans.

Factoring

Invoice Factoring is a financial transaction and a type of debt finance in which a business sells its accounts receivable (invoices) to a third party (factoring company) at a discount.

Institutional investor

Institutional investors are financial institutions that manage savings collectively on behalf of other investors such as pensions, insurance and private wealth funds. These liabilities are typically long term, and so these investors may be interested in correspondingly long-term investments.

Lien

A lien is a legal right granted by the owner of property, by a law or otherwise acquired by a creditor. A lien serves to guarantee an underlying obligation, such as the repayment of a loan. If the underlying obligation is not satisfied, the creditor may be able to seize the asset that is the subject of the lien

Liquidity

Liquidity describes the degree to which an asset or security can be quickly bought or sold in the market without affecting the asset's price.

Principal

Principal refers to the original sum of money borrowed in a loan, or put into an investment. Similarly, can also refer to the face value of a bond.

Project finance

Project finance is the financing of long-term infrastructure, industrial projects and public services based upon a non-recourse or limited recourse financial structure, in which project debt and equity used to finance the project are paid back from the cash flow generated by the project

Secondary markets

A financial market in which securities that have been previously issued (and are thus second hand) can be resold

Securitisation

Securitisation is the process of taking an illiquid asset, or group of assets, and through financial engineering, transforming it (or them) into a security

Security

A security is a negotiable financial instrument that holds some type of monetary value. It represents an ownership position in a publicly-traded corporation (via stock), a creditor relationship with a governmental body or a corporation (represented by owning that entity's bond), or rights to ownership as represented by an option

Senior debt

Senior debt is borrowed money that a company or project must repay first if it goes out of business. In this sense its repayment is senior to the junior or junior comp

Special purpose vehicle (SPV)

A special purpose vehicle is a subsidiary company with an asset/liability structure and legal status that makes its obligations secure even if the parent company goes bankrupt. They are often used to finance projects 'off balance sheet' of the participating firms

Structural funds

The Structural Funds and the Cohesion Fund are financial tools set up to implement the regional policy of the European Union. They aim to reduce regional disparities in income, wealth and opportunities. The Structural Funds are made up of the European Regional Development Fund (ERDF) and the European Social Fund (ESF)

Subordinated debt

Junior Debt is a loan or security that ranks below other loans or securities with regard to claims on assets or earnings. Junior debt is also known as a 'junior security' or junior loan. In the case of borrower default, creditors who own junior debt won't be paid out until after senior debt-holders are paid in full

Subprime mortgage

A subprime mortgage is a type of mortgage that is normally issued by a lending institution to borrowers with low credit ratings. As a result of the borrower's lower credit rating, a conventional mortgage is not offered because the lender views the borrower as having a larger-than-average risk of defaulting on the loan

Tranches

Tranches are portions of debt or securities that are structured to divide risk or group characteristics in ways that are marketable to various investors. Each portion, or tranche, is one of several related securities such as senior or junior tranches with different risks, rewards and maturities to appeal to different types of investors.

Underwriting

Involves research and assessment of the risk an application for finance presents. This helps to create the market for securities by accurately pricing risk and setting fair rates that adequately cover the true cost of lending money or providing insurance. If a specific applicant's risk is deemed too high, underwriters may refuse the offer.

Table B2 Article 2 interview quotations

Source of capital	<p><i>'this is something that should be financed by the state... I think this is the state's responsibility...by definition the state is the cheapest borrower, nobody can borrow cheaper than the state' (RENESCO -#17)</i></p> <p><i>'actually, that's considerably less risk than the government is absolutely willing bar falling over itself to take in other parts in other areas of its portfolio.'</i> (Climate Strategy and Partners-#19)</p> <p><i>'looking at something that might need to be scaled up....I guess there are other options that the government would need to look at...what budget might be necessary, where they might come from, how the government might be able to raise that kind of funding etcetera.'</i> (EST - HEEPS-#24)</p> <p><i>'PACE [is] bundled together in a way that large scale, long term investors can buy it, under the certain rules...So the vast majority of what we've done has ultimately—its funded long term by pension funds, insurance companies and money managers' (RENEW Financial-#30)</i></p> <p><i>'Look at the problem develop a solution and bring in the institutional capital ready to invest at the right time. And that would take a very small amount of public money relative to the investment' (Energy Pro-#23)</i></p> <p><i>'If you went out in the market and said, "I've got social-housing retrofit with external wall insulation"...most people would run a mile. So, we're there to alleviate that' (Amber Infrastructure-#25).</i></p>
Financial Instrument	<p><i>'One of the problems at the moment is that we've got too much equity coming in, so the equity guys want 10-15% return, the debt guys want 2-10%, the more we can make it like debt and secure it the lower the cost of the money' (Marksman Consulting-#22).</i></p> <p><i>'We can't nationalise the industry anymore, it would be way too expensive. Cooperatives represent a way of creating social enterprise for the energy industry' (BHESCO-#15)</i></p> <p><i>'Every several months...we bundle everything that we've financed using that line of credit...and we then do a rated securitisation where we sell the cash flows...as a bond into the asset backed securities market' (RENEW Financial-#30)</i></p> <p><i>'When you go in residential, first is really difficult to find big, big projects' (SEA-ESCO-#28).</i></p> <p><i>'I start to feel from investment funds [they are] interested in buildings because what they have learned from experience is that energy performance contract has a really low risk from a long payment point of view' (SEA-ESCO-#28).</i></p>

Project performance	<p><i>'[Energy performance guarantees] have the potential to make a huge difference on... [consumer] confidence.'</i> (Energy Programmes Consortium-#5)</p> <p><i>'Investors aren't going to accept an ESCO's performance guarantee at face value. They need to understand how the savings were calculated and this needs to be backed by strong financial modelling. They also need to know that the client is financially healthy, and possibly that the performance and savings are insurable.'</i> (Joule Assets Europe-#29)</p> <p><i>'One you need standardisation. And that's where the Investor Confidence Project...comes in...standardisation of everything. The whole process has to be really standardised.'</i> (Energy Pro-#23)</p> <p><i>'In the US PACE market, there is no requirement that a project reaches a savings to investment ratio greater than one. Some projects do not meet this test and still go ahead with financing'</i> (PACE Nation-#31)</p> <p><i>'anecdotally from one of the downsides we heard from industry is that actually really big-ticket stuff [doesn't happen] because of the Golden Rule cap'</i> (Policy Manager - BEIS-#27).</p> <p><i>'It is about selling health and well-being it is about creating better internal environment where people have the opportunities to live in a warmer, dryer stable building. But the mechanism is EE and carbon - it is never going to work...It is a flawed matrix for success'</i> (Director - BRE-#4).</p>
Point of sale	<p><i>'If you need to buy a car, you don't need \$30,000. You just go in...You pay a couple thousand dollars down. You drive out with the car. You're billed every month. So, you solved this upfront cost issue in like virtually every other category of things. But until...we've solved it in this residential energy sector, it's impossible to get people to do these types of projects and scale.'</i> (RENEW Financial-#30)</p> <p><i>'it was actually kind of a pain in the ass to get a Green Deal loan ... So, I'm like well then why the hell would you pay 9% for it. You know you're not gaining anything you know from that programme'</i> (Energy Programmes Consortium-#5)</p> <p><i>'That meant that literally while the [PACE] contractors was there he can get the customer approved on an iPad. And go ahead ... same day. Huge deal.'</i> (Energy Programmes Consortium-#5)</p> <p><i>'the need for an integrated business model, the need for a mechanism that fits into that, hand in glove. And then at the very end we then fill that with the appropriate financial instrument'</i> (Climate Strategy and Partners-#5)</p>
Security and underwriting	<p><i>'most commercial lenders want a lot more security as you'd expect. So, we're able to look at a non-secure position. Especially if ... we're more comfortable with the entity, just put it that way, like a major housing association or local authority'</i> (Amber Infrastructure-#5)</p> <p><i>'(In PACE) we get kind of pulled into that whole regime which means it's very secure. And if you don't pay your property taxes over time, really, really bad things happen, right?'</i> (RENEW Financial-#30)</p> <p><i>'if a household or an applicant stops making their repayment...it may be possible in certain situations, for there to be some flexibility for example,</i></p>

	<p><i>reducing monthly repayments based on the householder's affordability, or providing a repayment holiday.'</i> (EST - HEEPS-#24)</p> <p><i>'Contractors are the original points of contact for homeowners. Typically, a contractor can conduct a simple eligibility check 'over-the-kitchen-counter' and determine whether a project can go ahead or not. This can be done using PACE provider's software on a tablet. Then the contractor can guide a homeowner through the necessary improvements. The homeowner will receive a phone call from a PACE provider to confirm the project and go over the terms and conditions of PACE financing'</i> (PACE Nation-#31)</p> <p><i>'I spoke with people who used to run [Green Deal], and with people who analysed it at Brussels level...and you know, had to boil it down to one example is that, sometimes it took up to 60 days for people to get the financing, and I think that's just insanity.'</i> (PACE Nation-#31)</p>
Repayment channel	<p><i>'That's what makes it. So, when you take PACE, you get a new line item on your property tax bill ...And that is collected in the same time and in exactly the same manner with exactly all of the same rules and laws in all other parts of your property tax bill. And you can't partially pay'</i>(RENEW Financial-#30)</p> <p><i>'Something such as on bill or a performance contract can help clarify the repayment terms by adding simplicity, by including the information on a bill or combining it with energy savings as well.'</i> (Energy Policy Specialist - NCSL-#26)</p> <p><i>'So, based on the equity that house holders have in their own property, they need to be left with at least 30% equity after the loan value has been taken off'</i> (EST-HEEPS-#24)</p>

Appendix C – Appended Articles

Business models for residential retrofit in the UK: a critical assessment of five key archetypes

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Abstract The comprehensive retrofit of residential buildings has significant potential to reduce carbon emissions and provide additional health and economic benefits. However, in countries such as the UK, much of this potential is yet to be realised. This paper shows how the concept of ‘business models’ (BMs) can be a powerful tool for understanding the challenge of improving energy performance and reducing carbon emissions in residential buildings. Through a review of contemporary literature and 18 semi-structured interviews, the paper describes and compares five distinct BM archetypes: the *atomised market model*, *market intermediation model*, *one-stop-shop*, *energy services agreement* and *managed energy services agreement*. These models range from the traditional approach to highly innovative energy service contracts. The paper further illustrates how the UK and EU market for retrofitting residential buildings is beginning to trial the more innovative BMs. These emerging BMs are characterised by increasingly industrialised processes and integrated supply chains, a holistic customer offering and single point of sale, long-term energy-saving performance contracts (ESPC) and integral project finance. It is argued that whilst the traditional BM is suitable for the implementation of single or piecemeal energy-saving measures, BM innovation will be required to meet the UK’s ambitious climate change targets.

Keywords Energy efficiency · Retrofit · Housing · Business models · ESCO · ESPC · Value proposition · Supply chain · Customer interface · Financial model · Governance

Introduction

The United Kingdom (UK) has an ambitious target to reduce greenhouse gas (GHG) emissions by 80% by 2050, relative to 1990 levels (Treasury, 2008). To this end, the UK government has set legally binding, 5-year carbon budgets that include targets for reducing emissions in all sectors of the UK economy (CCC 2013). In 2016, buildings were responsible for over a third of the UK’s GHG emissions, with 22% from the residential sector alone (CCC 2016). Improving the energy efficiency of residential buildings can also improve occupant’s health (Willand et al. 2015) and reduce fuel poverty (Sovacool 2015). In the UK, the energy performance of residential buildings is measured using the ‘Standard Assessment Procedure’ (SAP),¹ where a SAP score of 100 equates to an exemplary dwelling. In 2012, the average SAP for UK homes was 59, compared to only 45 in 1996 (DECC 2015).

Progress in improving the energy performance of residential buildings has stalled since 2012 (CCC 2016). The UK still has one of the oldest and least energy efficient

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¹ SAP quantifies a dwelling’s performance in terms of energy use per unit floor area, a fuel-cost-based energy efficiency rating (the SAP Rating) and emissions of CO₂ (the Environmental Impact Rating) (GOV.UK 2017).

housing stocks in Europe, and two thirds of the existing buildings are likely to exist in 2050 (Fylan et al. 2016). Older, solid walled properties constitute around 27% of the UK stock and have a large energy-saving potential (Element Energy 2013), yet only around 4% have had solid wall insulation (SWI) installed (CCC 2016). The UK also has a high proportion (67%) of owner-occupied housing, with 19% in social housing and 14% in private rented sectors (CCC 2016). The Committee on Climate Change (CCC 2015) estimates that there is cost effective² potential to reduce direct emissions³ from all buildings by 32% to 2030, with further savings available from the implementation of onsite microgeneration, with the need to achieve near-zero emissions from the sector by 2050 (CCC 2016). A 2013 policy initiative to improve energy efficiency in this sector (the ‘Green Deal’) proved to be a high-profile failure, achieving only 15,000 installations (mostly new boilers) rather than the two million a year that were envisaged (Rosenow and Eyre 2016). Since the remaining policies for energy efficiency in housing are relatively limited in ambition and scope, the carbon targets for this sector may not be achieved (Guertler and Rosenow 2016).

Emissions from UK residential buildings largely derive from gas use for space and water heating, and electricity use for lighting and appliances. Alongside efficient appliances and behaviour changes, the majority of these emissions can be reduced by the *retrofit* of three types of measure (Mallaburn and Eyre 2014): improving the *building fabric* of properties, adopting *low-carbon heat* technologies such as heat pumps and building-integrated electricity *microgeneration*, such as solar PV (CCC 2013). The CCC projections for 2030 include 2 million SWI and 2.5 million heat pump installations. This represents a sevenfold increase in properties with SWI and a massive upscaling in low-carbon heat (CCC 2016).

The improper installation of *deeper* single measures such as SWI has, however, the potential to cause damaging unintended consequences⁴ (Davies and Oreszczyn 2012).

² The CCC defines the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes together with measures that may cost more than the projected carbon price, but are necessary in order to manage costs and risks of meeting the 2050 target (CCC 2013).

³ Those that result from heating, ventilation and cooling systems as well as and hot water. This term excludes emissions from electricity consumption.

⁴ Such as mould growth, poor air quality and interstitial condensation, due to poor detailing, and in-sufficient consideration of building physics, airtightness and ventilation (Milsom 2016)

A *comprehensive residential retrofit*, where the entire building is treated as a system rather than as individual elements or measures, is likely to mitigate such issues and achieve greater reductions in emissions (Hansford 2015). Such an approach typically involves multiple measures and strategies for insulation, draught proofing, ventilation and heating systems, and may also include microgeneration (Milsom 2016). Consequently, if the UK is to meet its ambitious climate change targets, comprehensive residential retrofit, involving multiple coordinated measures will need to become the norm (Lewis and Smith 2013).

This paper argues that despite significant policy action in this area, a major reason for the slow progress is the limitations of the traditional *business model* (BM) through which energy efficiency measures are delivered. This model is characterised by a piecemeal offering, with a fragmented supply chain, a focus on single (rather than multiple, complementary) measures, and no guarantees on performance. Yet, research that identifies how alternative BMs might be more effective in delivering comprehensive residential retrofit is largely absent from the literature.

This study addresses this gap. First, it uses the BM concept to better understand the challenge of residential retrofit; second, it identifies the range of BMs currently used for delivering residential retrofit in the UK and the EU; third, it evaluates how and why the characteristics of these BMs influence their potential in delivering comprehensive residential retrofits.

The study addresses the following research questions:

1. What insights does the BMs concept offer for the challenge of residential retrofit?
2. What BMs are currently used for residential retrofit and how do they differ?
3. How and why do the characteristics of these alternative BMs influence their potential for delivering comprehensive residential retrofit?

Through a review of the academic literature on both BMs and residential retrofit, together with semi-structured interviews with stakeholders from the residential retrofit industry, this paper explores how more innovative BMs could enable greater uptake of comprehensive residential retrofit. The paper is structured as follows: “Literature on business models, energy services and residential retrofit” section

summarises the theoretical literature on BMs and the empirical literature on residential retrofit, and outlines the value of using the former to understand the latter. “Methods” section outlines the research methodology, whilst “Retrofit business models: five key archetypes” section describes five key BM archetypes for residential retrofit. “Summary of findings” section summarises the empirical results and highlights the implications for the successful delivery of comprehensive residential retrofit. “Discussion” section places these findings in the context of the wider literature on BMs and residential retrofit. “Conclusions” section concludes and provides some suggestions for further research.

Literature on business models, energy services and residential retrofit

Literature on business models

Throughout history, the development of new BMs has been instrumental to the diffusion of innovations such as commercial aviation, modern customer electronics and the Internet (Teece 2010). Meeting the sustainability challenges of the twenty-first century is likely to require a major transition in many sectors of the economy. This transition requires the development and rapid diffusion of multiple low-carbon innovations throughout the housing sector. Thus, innovations such as distributed energy⁵ and comprehensive residential retrofit may require novel BMs before they are viable on a large scale, due to their incompatibility with existing industry practices (Hall and Roelich 2016; Winther and Gurigard 2017). Consequently, various scholars have identified how such *systemic innovations* may have specific characteristics that are more suitable to certain novel BMs (Hall and Roelich 2016; Richter 2012; Steinberger et al. 2009). In addition, new BMs for *energy services* may also enable a more comprehensive approach to improving the energy performance of buildings (Kangas et al. 2017).

The BM is therefore increasingly adopted as lens for evaluating firm strategies to address sustainability challenges (Boons et al. 2013). Yet, whilst a few key

studies provide points of reference for characterising BMs, the term remains contested, both in terms of the organisational components that are described (Osterwalder et al. 2005) and the system boundaries of individual firms or networks of firms (DaSilva and Trkman 2014; Upward and Jones 2015; Zott et al. 2011). Perhaps the most commonly used definition is from Osterwalder and Pigneur (2010) who identify four basic components: the *value proposition*, the *supply chain*, the *customer interface* and the *financial model* (Boons and Lüdeke-Freund 2013). This characterisation provides a ‘meta-model’ of features that are generic to all BMs and can thus be applied in multiple contexts (Osterwalder et al. 2005). BMs therefore incorporate the nature of the value delivered to customers, the activities involved in delivering that value and the means of capturing revenue from these activities (Boons et al. 2013).

However, the study of the BM of individual firms overlooks the interdependent and networked nature of the delivery of good and services (Hellström et al. 2015; Zott and Amit 2010). BMs thus involve a range of activities that may span the boundaries of multiple organisations (Zott and Amit 2010). This highlights the need for what has been termed a *systems perspective* on BMs (Bolton and Hannon 2016). This perspective emphasises the *governance* of BMs, both in terms of the role of different actors and the chosen mode of governance, for example, from highly integrated to highly outsourced approaches (Amit and Zott 2001).

Business models, energy services and residential retrofit

Several studies use the BM concept to describe how organisations provide *energy services* (Duplessis et al. 2012; Hannon et al. 2015; Kindström and Ottosson 2016; Labanca et al. 2014; Okkonen and Suhonen 2010). Energy service BMs move beyond the prevailing value proposition based on the sale of energy commodities (gas, electricity, fuel oil), towards an alternative value proposition based on the energy service itself (warmth, light, hot water) (Steinberger et al. 2009). This creates incentives for suppliers to reduce energy demand in order to minimise the energy cost of supplying the service (Bertoldi et al. 2006; Sorrell 2007). Where these contracts include guaranteed reductions in energy consumption or costs for the client, they are termed Energy Savings Performance Contracts (ESPC), with the relevant supplier being termed an Energy Service Company

⁵ Defined as electricity generation feeding into the local distribution network (operating from 132 kV down to 230 V), as opposed to the regional or national transmission grid (which operates from 400 kV and 275 kV).

(ESCO) (Kindström and Ottosson 2016). The market for ESPCs is largely confined to industry and non-residential buildings (Hannon and Bolton 2015; Kindström and Ottosson 2016; Okkonen and Suhonen 2010), since the transaction costs in the residential market are relatively high (Sorrell 2007). However, Bleyl-Androschin and Schinnerl (2007) propose a number of models for ESPCs that could promote building envelope refurbishment. Indeed, several residential examples of ESPCs are now emerging across the EU (Irrek et al. 2013; Labanca et al. 2014).

Relatively few academic studies investigate BMs for residential retrofit. Recent UK case studies focus on new models for distributed energy (Foxon et al. 2015; Hall and Roelich 2016; Hannon and Bolton 2015), but do not assess the specific challenges posed by residential retrofit. Gauthier and Gilomen (2016) compare two French case studies of residential retrofit BMs, but focus on individual firms within the project, rather than the overall retrofit process. Mahapatra et al. (2013) evaluate the opportunities and barriers of *one-stop-shop* BMs in Scandinavia for residential retrofit, where multiple services and finance are provided by one organisation. Winther and Gurigard (2017) explore a failed attempt to implement ESPC contracts in a Norwegian case study, whilst Moschetti and Brattebø (2016) map out possible alternative BMs for residential buildings, yet provide limited empirical examples.

Cost effective energy efficiency measures face several barriers to their implementation (Sorrell et al. 2004). These barriers can be grouped into four categories: financial, social and behavioural, supplier competence and performance risk (Fylan et al. 2016). The five components of the BM outlined in “[Literature on business models](#)” section correspond to each of these inter-related barriers. Studies identify problems with a value proposition focused on estimated, rather than guaranteed energy performance (Pettifor et al. 2015), and final energy services, such as temperature and comfort (Roelich et al. 2015). Further barriers to uptake are identified as a customer interface that is ineffective in engaging consumers (Owen et al. 2014; Wilson et al. 2015), poorly developed supply chains and retrofit performance gaps (where modelled savings are not realised) (Gupta and Chandiwalwa 2010; Kelly et al. 2012; Snape et al. 2015) and a lack of appeal in the financial model (Marchand et al. 2015). Other studies have identified the importance of *intermediary* actors in the governance of retrofit (Bleyl et al. 2013; Kivimaa

and Martiskainen 2017) and as a means of reducing transaction costs for ESCO BMs (Nolden et al. 2016). Thus, the five components of BMs provide a comprehensive framework for understanding the solutions to these barriers.

Business model framework for residential retrofit

The following section describes how a BM framework can improve understanding of the challenges in delivering residential retrofit. This framework combines the four components of BMs outlined by Boons and Lüdeke-Freund (2013) with the additional component of BM governance as described by Amit and Zott (2001) and Zott and Amit (2010). The components of a BM are therefore the value proposition, supply chain, customer interface, financial model and BM governance.

Value proposition

The value proposition refers to the value or utility from goods and services that an organisation provides to the customer (Boons and Lüdeke-Freund 2013; Engelken et al. 2016). New BMs do not necessarily provide a novel value proposition (Lopez et al. 2014), although a shift towards ESPCs may also create stronger incentives for energy efficiency improvements (Steinberger et al. 2009). Thus, the value proposition may constitute simply the implementation of energy-saving retrofit measures or a move towards some form of ESPC. Suppliers may also emphasise other sources of value for customers, such as improvements in aesthetics, comfort, health and well-being rather than energy cost savings alone (Knoeri et al. 2016). ESPCs may also enable more comprehensive residential retrofit projects (Kangas et al. 2017; Winther and Gurigard 2017).

Supply chain

The supply chain is the upstream relationships between an organisation and its suppliers (Boons and Lüdeke-Freund 2013). This comprises the logistical and technical elements that enable delivery of the value proposition (Osterwalder 2004). In the context of residential retrofit, the supply chain includes the design and delivery of the retrofit, encompassing both the installation and the operational phases, potentially across multiple suppliers and consultants. Both integration of the supply chain and improvements in project management

may enable more comprehensive residential retrofits (Mahapatra et al. 2013) increased material efficiency and quality control (Lopez et al. 2014) and industrialisation/automation of manufacturing processes and logistics, such as the use of off-site manufacture techniques (Energiesprong 2014).

Customer interface

The customer interface covers all downstream, customer-related interactions (Boons and Lüdeke-Freund 2013). This includes the relationship the customer has with the supplier organisations in terms of marketing, sales and distribution channels and the ongoing relationship with the product or service (Osterwalder and Pigneur 2010). In a retrofit context, the customer may include homeowners, landlords or social housing providers. Where customers separately source retrofit measures, finance and energy audits, they may encounter multiple interfaces and points of sale.

Financial model

The financial model constitutes the combination of an organisation's capital and operational expenditures with its means of revenue generation from business activities (Osterwalder et al. 2005). Typically, the financial objective in energy retrofits is to recover the capital costs of the measures from the saving in energy bills or from the revenues from onsite electricity generation. A range of *financing mechanisms* have thus been developed to overcome the initial capital cost, where the objective is typically to ensure that repayments are equal to or lower than the energy cost savings. A suitable finance mechanism is often the catalyst for a viable retrofit project, with the associated cost of capital being critical to the economic viability of many measures (Gouldson et al. 2015).

Business model governance

BM governance involves both the control and management of the individual components (Zott and Amit 2010) and the organisational form of the BM (Amit and Zott 2001). As such, BMs may involve a constellation of firms that interact to provide a service or product (Boons and Lüdeke-Freund 2013), leading to interdependencies between various actors in the delivery of the value proposition (Zott and

Amit 2010). Consequently, the range of governance approaches lie along a continuum, with integrated, hierarchical firms at one end, and arm's-length, market-based contractual relationships at the other (Treib et al. 2007). Where a hierarchical approach is adopted, the BM components are internal to a single organisation, whereas in a market-based approach, multiple organisations are likely to be involved. More common is a hybrid of these, with most BMs employing varying degrees of market-based, hierarchical and trust-based governance; the latter involving recurrent relationships with trusted partners (Bradach and Eccles 1989; Eriksson 2008).

In residential retrofit, managers, intermediaries and government actors may each play important roles in governance (Bolton and Hannon 2016). Governance (or lack of) becomes a particularly important consideration in highly networked arrangements where intermediaries (Bleyl et al. 2013; Kivimaa and Martiskainen 2017), such as community (Seyfang et al. 2013), municipal actors (Webb et al. 2016) work alongside private firms. In particular, innovative BMs may require these *system builders* to foster trust and coordinate the actions of multiple stakeholders (Bolton and Hannon 2016).

Methods

This study began with a comprehensive review of the academic and grey literature on retrofit BMs. The literature review identified a number of texts and reports⁶ that described the range of approaches to retrofit that are currently employed in the UK and EU (De Groote et al. 2016; Edrich et al. 2010; EST 2011; Jankel 2013; Kats et al. 2011; Kim et al. 2012; Koh et al. 2013; Mahapatra et al. 2013; Milin and Bullier 2011; Straub 2016; Sweatman and Managan 2010; The Rockefeller Foundation and DB Climate Change Advisors 2012). Five key *archetypes* of retrofit BMs were subsequently identified, summarised in Table 1 and described in detail in “Retrofit business models: five key archetypes”

⁶ These texts were identified from Google, Google Scholar and Scopus using several search terms. Search terms included retrofit BM, retrofit financial model, energy efficiency BM, retrofit intermediary, residential energy service contracts, community retrofit, cooperative retrofit, local authority retrofit, retrofit one-stop-shop, energy services agreement, residential energy performance contract and managed energy service agreement

Table 1 Business model archetypes and business model components

	'Atomised' market model	Market intermediation model	One-stop-shop	Energy services agreement (ESA)	Manged energy services agreement (MESA)
Value proposition	Single measure energy cost savings are estimated rather than guaranteed	As for 'atomised' market model	Multiple measures or comprehensive residential retrofit common energy cost savings are estimated rather than guaranteed Additional emphasis on home improvement and comfort	Multiple measures or comprehensive residential retrofit required Emphasis on energy services of temperature and hot water volume Energy savings performance contract (ESPC) including performance guarantee for heat and hot water Additional emphasis on home improvement and comfort	As for ESA but with: Additional energy services of lighting and appliances, (ESPC) including performance guarantee for electricity consumption Energy supply contract (ESC) (gas, electricity)
The bundle of products and services that create value for a specific customer segment					
Customer interface	Largely left to the market to promote and engage customers, with responsibility for the marketing and engagement for the different components (i.e. measures, finance) of the retrofit typically separated	One point of contact for the promotion, marketing and sales typically provided by an intermediary whom has no direct involvement in the retrofit itself Additional interface for finance	One point of contact for the promotion, marketing and sales of the full package necessary to achieve the retrofit, typically provided by the host company offering the retrofit package as a one-stop-shop	As for one-stop-shop and ESA but with: Potential for customer engagement through traditional energy supply retail channels	
How are downstream relationships with customers structured and managed					
Supply chain	Largely 'siloed' relationship with traditional separated trades installing the retrofit measures in sequence with limited coordination	Greater coordination of overall installation, through quality assurance vetting and scheduling by the intermediary	Highly integrated package of measures, provided in house or through trusted subcontractors, greater scope for whole house solutions Supply chain may require legal and finance skillsets	As for one-stop-shop but with: Additional contractor requirement for performance guarantee reducing likelihood of performance gap Supply chain requires legal and finance skillsets	As for ESA but with: Additional supply chain for energy supply required, can be through fully licensed supplier model or through a white label scheme
How are upstream relationships with suppliers structured and managed					

Table 1 (continued)

	'Atomised' market model	Market intermediation model	One-stop-shop	Energy services agreement (ESA)	Manged energy services agreement (MESA)
Financial Model					
How the retrofit is funded, by whom and how this is repaid to the lender	Finance is arranged via third party with little involvement in the retrofit process	As for 'atomised' market model	Finance may be provided and arranged by the retrofit provider, even where this is part of an upstream scheme	Lender developer / investor firms seeking to use ESPC/ESA structure to fund retrofits Lender captures energy savings and charges back to property owner based on historic consumption	As for ESA but: Supplier assumes responsibility for payment of energy bill.
Governance					
Are the components of the BM provided by a single organisation, or a network, how is this coordinated and by whom	Highly networked arrangement of suppliers with little co-ordination between the various elements – this is largely left to the customer to manage	A network of separate suppliers, although the intermediary provides some coordination. Customer typically left to arrange finance and may engage in multiple contracts.	The elements of the BM are delivered by a single organisation, who take responsibility for project delivery. Finance packages may also be offered by the supplier.	As for one-stop-shop but finance is included upstream within the ESPC.	As for ESA but also integrated energy procurement.

section. All these models currently exist in the EU, but some are much more widespread than others. The criteria for their differentiation were the five key BM components outlined in “[Business model framework for residential retrofit](#)” section.

The literature review was followed by scoping interviews with eight prominent experts in the residential retrofit field (see ‘Expert scoping’ in Table 3 appendix). The aim was to test the validity and representativeness of five archetypes and gain an overview of current practice in the UK and wider EU residential retrofit market. The selection of interviewees involved identification of the key organisations involved in the residential energy efficiency sector, including, academic, technical, advocacy and policy actors. Snowballing techniques were then used to develop contacts and source further interviewees (Kvale 2008).

Building on the insights from the expert interviews, the BM framework was refined, and an interview protocol developed for practitioners from each of the BM archetypes, with the aim of including at least two representatives of each archetype (see ‘Practitioners’ in Table 3). The sample was initially drawn from the UK but was expanded to include other EU Member States, including France, Latvia and the Netherlands, to obtain representatives of the more innovative and less common archetypes. The interview questions were designed to develop a detailed understanding of the structure and operation of the BM and how this influenced their success in delivering residential retrofit. Both sets of interviews were supplemented by documentary analysis of publicly available reports, where available.

Each interview was recorded, transcribed and coded using the NVivo 11™ software. This enabled detailed analysis of the responses, allowing common themes to be identified along with areas for further investigation. These methods were considered appropriate, given the need to develop a qualitative understanding of the role and importance of the different variables within the BM framework, as well to test the validity of the archetypes through discussion with expert stakeholders (Kvale 2008). The use of several case studies for each archetype allowed identification of their commonalities and to control for more idiosyncratic elements. It is recognised that this method provides less granular detail than could be obtained from in-depth case studies and provides a less

representative sample than could be obtained from a large survey. However, the chosen method is suitable for addressing the research questions given resource constraints.

Retrofit business models: five key archetypes

The following sections describe each of the five retrofit archetypes in turn. Each section provides examples of the archetype, identifies its distinguishing features and assesses how these characteristics influence the potential for delivering retrofits of residential buildings, particularly for more comprehensive approaches.

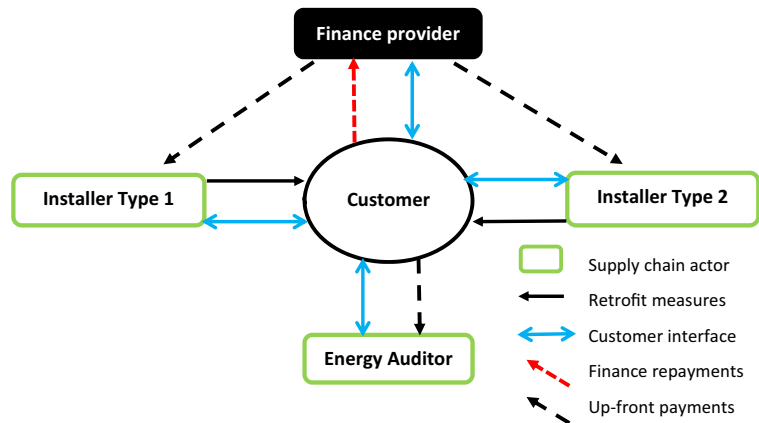
‘Atomized’ market model

The *atomized market model* continues to be the primary model delivering residential retrofit in the UK. Through an offering based on estimated energy cost and carbon savings, this model involves individual retrofit measures and technologies installed by separate contractors. Customers source the individual measures, energy audits and finance separately, with the result that multiple customer interfaces or points of contact are required for a comprehensive residential retrofit. The offer of energy savings is based on modelled impacts of measures, and no guarantees are provided. Therefore, any finance package is based on estimated rather than guaranteed cost savings. The details of the model are illustrated in Fig. 1.

Whilst a highly fragmented and market-based BM is the norm for many industries, interviewees agreed that this ‘siloed’ approach does not work well for comprehensive residential retrofit.

“[Supply chain integration] is extremely poor; there has been a focus on single measures for the last 20/25 years. It is going to be hard to make the shift to a more comprehensive approach. Single measures have their place, but you want to have mechanisms to do more comprehensive residential retrofit.” (Academic - energy efficiency policy)

This focus on single measures stems directly from the *atomised* and uncoordinated nature of the dominant model;

Fig. 1 The ‘atomized’ market model

“what we’ve got in the UK is where the customer has to be this project manager...That’s complex, it might work; for ringing somebody up when you boiler breaks down...[but] it’s not the route for a.... ramping up [off] energy efficiency measures” (Energy Saving Trust)

Such an approach has typified the delivery of the energy efficiency measures required and subsidised by UK policy, such as the Supplier Obligations and Green Deal, as well as the low-carbon heat measures subsidised by the Renewable Heat Incentive (RHI) and microgeneration Feed In Tariff (FIT). Thus, this approach has resulted in very few comprehensive residential retrofits—instead tending to deliver a succession of piecemeal interventions at different times, linked to an ever-evolving policy landscape.

“We have tended to focus in the UK on subsidy... installers, who do one thing; you can get a grant for doing x measures, get some carbon credits from the energy company...and that’s it. They don’t care about how it performs, they don’t care about how it actually impacts on the end user; they just go in and install one measure.” (Policy Advisor - UKGBC)

This model has not helped develop an effective supply chain for residential retrofit, particularly for SWI, which requires a more comprehensive approach involving additional measures such as ventilation and draught proofing.

“I’ve been around probably now over 3000 houses that have had external wall insulation and I haven’t seen any done right, and that is a fairly damning indictment of the industry...You

have got industry-standard details which introduce cold bridging. There is no assessment of ventilation it is almost inevitable it’s going to go wrong.” (Director - BRE)

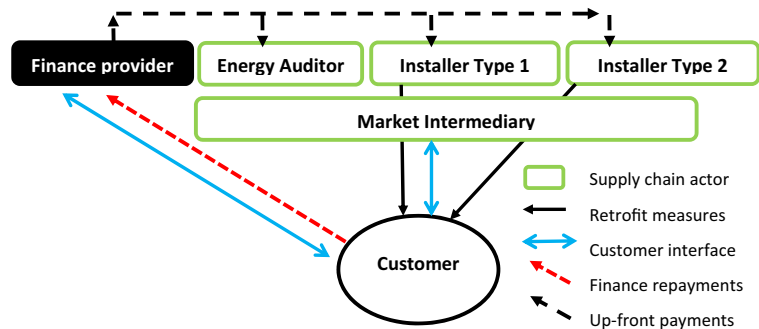
Market intermediation model

The *market intermediation model*, shown in Fig. 2, is also a relatively common delivery model for residential retrofit in the UK and the EU. This model usually involves the implementation of government subsidy schemes, focused on single measures and uses estimates of the associated energy cost and carbon savings from a basic energy audit. However, a key difference is the role of an intermediary organisation, who coordinate the supply chain and provide the customer interface through marketing activities and project management, thus, simplifying the *customer journey*. These schemes typically involve a Local Authorities (LA) or NGOs who offer information, consultancy and procurement guidance to the client and may also offer a range of specialist services and financing assistance. If the intermediary is trusted by potential customers, their involvement can lower transaction costs, facilitate project implementation and help raise awareness of retrofit opportunities in the residential sector, building upon existing trusted relationships at the area or community level.

UK examples of this model include the RE:NEW scheme implemented by the Greater London Authority (GLA), the Birmingham Energy Savers (BES) scheme, involving a partnership between Birmingham City Council and Carillion2F⁷ and the Nottingham Energy

⁷ A large international construction firm, headquartered in the UK

Fig. 2 Market intermediary model



Partnership (NEP) an NGO initiative in Nottingham. These schemes commonly utilise relationships with local housing providers and LAs. The RE:NEW scheme has focussed on the social housing sector and has facilitated the retrofit of over 127,000 London homes, saving around 46 k tonnes of carbon dioxide a year (GLA 2017). The NEP scheme focuses on the privately owned and rented sector, with an emphasis on households in fuel poverty. Both these schemes owe their success to the trusted relationships between households and their housing provider, or council; “*working with the LA, it’s that trusted brand*” (Retrofit Intermediary).

By contrast, the large-scale BES scheme was a major failure. This is in part attributed to the use of a multinational private sector partner for the marketing and delivery of measures to households, rather than using the councils branding and a local SME supply chain (Watson 2014); “*There [was] a lot of installers who don’t deserve trust, I wouldn’t touch them with a bargepole*” (Sustainability Consultant - BES).

RE:NEW has supported additional carbon savings above and beyond what would have otherwise occurred in the delivery of government and business-as-usual planned programs. “*The majority of organisations fed back [Its been] faster, deeper and with less risk involved*” (Manager- RE:NEW - GLA).

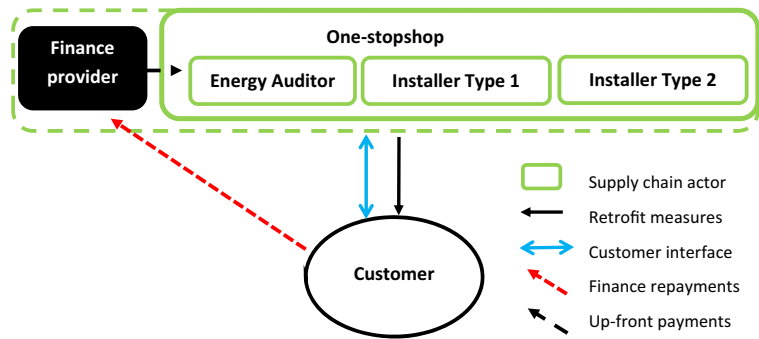
However, these programs have done little to alter the underlying model of the industry and encourage the development of comprehensive residential retrofit with an integrated supply chain; “*[in the end] it reverted to the piecemeal offer that we’ve identified is the problem*” (Sustainability Consultant - BES). The reliance on national subsidy schemes, where “*changes in policy mean that [the] model is ever changing*” (Retrofit Intermediary), also means that there is very little retrofit activity once these schemes have ended. This *stop-start* nature of funding is a key factor in the lack of a well-developed supply chain for comprehensive residential retrofit in the

UK. This may be changing, with schemes such as RE:NEW looking to support more novel value propositions and longer term finance models (e.g., the Energiesprong approach discussed below). It was argued that whilst future retrofit policy programs should recognise the importance of long-term industry led solutions, “*there is always going to be a role for intermediaries*” (Academic - energy efficiency policy) even where integrated BMs are adopted.

One-stop-shop

The *one-stop-shop* BM (Fig. 3) involves an integrated supply chain and customer interface that provides a single point of contact for the customer. The supplier offers a ‘holistic’ *design and build* including a comprehensive package of services, a more extensive modelling and design phase, the production of a comprehensive residential retrofit plan and the implementation of multiple complementary measures. Delivery of these is coordinated through either a single company or a well-integrated network of subcontractors. As shown in Fig. 3, some BMs also include finance as part of the offer, whilst several operate as cooperatives. The cooperative approach typically involves both suppliers and households as coop members, who receive dividends on their equity investment in retrofit projects.

Although more established in Scandinavia (Mahapatra et al. 2013; Straub 2016), the UK examples of this BM include the Retrofitworks project that utilises an online portal and cooperative approach to link suppliers to customers looking for retrofit and home auditing services through its sister company Parity Projects. The Brighton and Hove Energy Services Co-op (BHESCO) also uses a cooperative approach and a low-cost financing offer based on issuing shares to the local community. A key emphasis in the BM is a focus on the needs of the client and a simplification of the customer

Fig. 3 One-stop-shop

journey. Segel AS is a consultancy providing specialist guidance on the implementation of one-stop-shops in continental Europe and Scandinavia;

“The value proposition.....is a holistic retrofitting and single point of contact, easiness in the project, and project management...many of them also include help for the client in the application for grants...and confidence that the solutions chosen are right for [them]” (Segel AS - Business Consultant)

This approach typically facilitates comprehensive residential retrofits and may be applied in conjunction with other forms of renovation. In several of the Scandinavian examples, local SMEs collaborate with a larger company such as Bravida3F⁸ or national hardware chains a means of generating customers. In the case of Retrofitworks, the online portal is a key part of the customer interface where members of the cooperative can advertise works and have bids placed by the supply chain who are also cooperative members. Key to the success of these BMs is the role of specialist *retrofit coordinators* or project managers;

“a person who understands what every element of the good retrofit looks like; isn't an expert in all of them but knows when they look dodgy or when an expert is needed to be brought in on certain things. So is about the genuine coordination....so I am a massive advocate of that and its built-in within... Retrofitworks.” (Retrofitworks/Parity Projects)

Whilst not all these examples offer financing, BHESCo combines their retrofit offering with a

community share issue to provide a financing package to its customers.

“It's based on this virtuous circle, you become a member of the co-op...you invest...,you get a 5% return on investment. We invest your money into... energy efficiency, the customer pays from the savings in their energy bill” (BHESCo)

At present, the model is based on a hire purchase agreement^{4F9} or what may be termed a *capital lease*, with the assumption that if the person moves, they will see uplift in its value that will enable the lease to be paid off. However, offering competitive financing remains a challenge with considerable risk.

“Our...cost of capital is 5%, but we may have to consider whether we can offer that in the future... its very tricky and very difficult [to offer competitive finance]” (BHESCo)

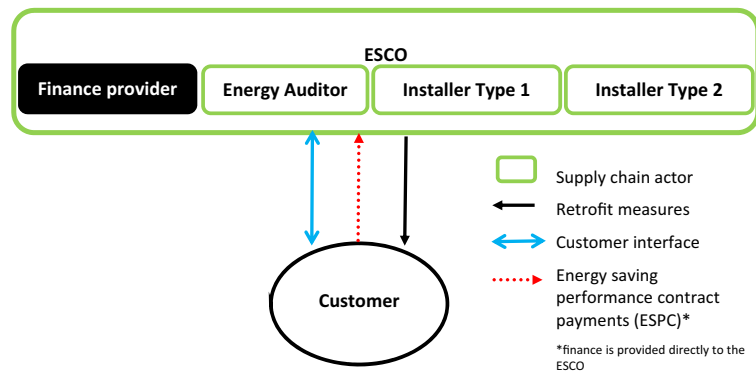
Energy services agreement (ESA)

The ESA involves a form of ESPC, where building occupants are provided with an energy performance guarantee for specific energy services, usually over a period of 15 years or more. Instead of paying for units of heating fuel, occupants are guaranteed a level of performance such as a specified internal temperature (i.e. 21 °C) and a certain volume of hot water at a specified temperature. Such an approach is synonymous with the ESCO model in that measures and the subsequent guarantee are provided by an ESCO, who are

⁸ Bravida is an installation and service company with about 9000 employees at more than 160 locations in Sweden, Norway, Denmark and Finland.

⁹ Under an HP agreement, the debtor hires the goods and then pays an agreed amount by instalments. Whilst still making payments, the debtor is not allowed to sell or dispose of the goods without the lender's permission.

Fig. 4 Energy services agreement (ESA)



engaged as part of a long-term contract, with contractual penalties for under-performance. However, this model differs from the more common examples in the public and municipal sectors (where the debt for the retrofit measures is taken on by the building occupants or tenant)¹⁰ as measures are financed directly by the ESCO or upstream through a third party financier^{5F} (The Rockefeller Foundation and DB Climate Change Advisors 2012). These projects typically consist of an integrated offering, covering a comprehensive residential retrofit of building fabric and heating measures, by a well-coordinated supply chain with *design, build and operate* phases under one contract. A comprehensive residential retrofit is a likely pre-condition to offering a temperature guarantee, thus ensuring modelled savings are realised and energy consumption is controlled (Fig. 4).

The review did not identify any examples of ESA contracts for residential retrofit in the UK, but examples exist in France and Latvia. The French state-owned railway company SNCF also manages a significant number of social housing properties under its subsidiary; ICF Habitat. ICF has undertaken several schemes based on an ESA model, focused on medium-to-high-density multifamily buildings. The Energies POSIT'IF is an ESA model for privately owned or rented multifamily buildings in greater Paris. In addition, RENESCO is a social enterprise involved in the retrofit of dilapidated multifamily buildings in former Soviet-era housing in Eastern Europe, particularly Latvia.

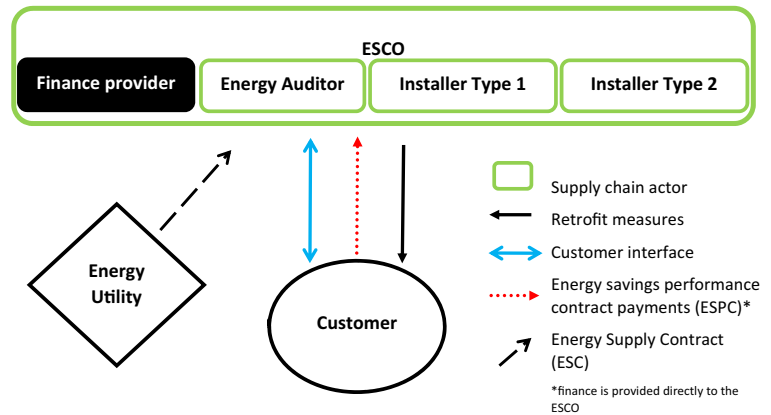
The Latvian example is notable for its value proposition involving a focus on structural improvement as a selling point.

“We are not just conserving energy, our main task is conserving the building, we are protecting the building from the elements...about 15% of our total investment has nothing to do with energy efficiency” (RENESCO).

The risk of offering the ESPC is mitigated through a well-integrated BM *“This was possible because of one entity taking a decision and co-ordinating the investments [and works]” (RENESCO)*. Such an approach means a single point of contact and recourse for the client: *“the main advantage of the [ESPC contract] is that we have only one firm to talk to” (ICF Habitat)*. The successful coordination of the model therefore relies heavily on the design of effective contracts; *“we as a buyer have to make them talk together, so we have to design a process” (ICF Habitat)*.

An important component of the ESA model is the *“bridge of finance and technology” (RENESCO)*. Under the ICF Habitat model, the capital is supplied by the housing provider, with the financial agreement upstream from the tenant. Whilst a large semi-public actor such as ICF can borrow at a relatively low cost of capital, RENESCO must source funds in private capital markets. RENESCO have chosen to use ‘on balance sheet’ finance, meaning the debt obligation is tied to the firm rather than the building owner. Based on their current cost of capital, *“the renovation can be paid by the energy efficiency alone in 15 years” (RENESCO)*. However, the economics of their offering are very sensitive to the financing terms and the size of their portfolio. Therefore, RENESCO *“hope to sell off the cash-flows of the first 15 buildings”* under a forfeiting scheme they are developing in collaboration with the European Bank for Reconstruction and Development (EBRD). This means that RENESCO can shift successful projects off their balance sheet and sell them on to investors in

¹⁰ After significant desk-based and interview research, the author could not find any examples of this BM in the UK or EU residential retrofit sector—thus, it is excluded from the paper.

Fig. 5 Managed energy services agreement (MESA)

secondary markets, improving their borrowing conditions “So, we get our equity back, we have our capital back, we can pay back the loan, we hopefully make a little bit of a profit” (RENESCO).

Managed energy services agreement (MESA)

The MESA model (Fig. 5) is like the ESA approach in that the ESCO provides guarantees for the energy performance of plant and building fabric measures, installed during a retrofit (Kim et al. 2012). However, in the MESA model, the contracting organisation also takes on responsibility for the payment of the energy bill in an energy supply contract (ESC) upstream of the customer; to provide total energy management. This requires additional capability in energy supply and procurement. This also introduces a potential role for renewable electricity, storage and demand side management as part of the MESA. This level of integration also incentivises an integrated supply chain and represents a holistic energy services offering to the customer.

Whilst the MESA is more common in the commercial or public sector, the Dutch government has funded a large-scale trial of this approach in the social housing sector, known as the *Energiesprong* or ‘energy leap’ initiative (Energiesprong 2014). The scheme has thus far delivered approximately 1800 comprehensive residential retrofits in the Netherlands, largely focusing on single family semi-detached or terraced units. At the time of writing the first UK trial is about to commence in Nottingham (Energiesprong 2017). This is the only known example of a MESA in the EU residential sector.

Energiesprong do not deliver the measures or the guarantee but instead their *market development team* acts as an intermediary between the client and

contractor, providing technical assistance in implementation. Customers are offered a comprehensive residential retrofit, based upon *net-zero energy* consumption. Typically, an *Energiesprong* retrofit involves the delivery of off-site manufactured, insulated facades, integrated with renewable heat systems and PV panels as well as lighting and controls. The contractor offers a 30-year energy performance guarantee for *net-zero* annual energy consumption, amortised over the calendar year. This is based on a guaranteed internal temperature of 21 °C in living spaces and a set allowance of hot water and electricity consumption, akin to a mobile phone contract with usage limits. A comprehensive residential retrofit, with electricity microgeneration, is a likely precondition to offering a net-zero energy guarantee, ensuring modelled savings are realised and heat and electricity consumption are controlled.

“The main premise of Energiesprong is an outcome-based procurement approach, specifying what it needs to do for the next 30 years; a long list of energy related measures; comfort, health and quality elements. So therefore, our approach is entirely technology agnostic” (Energiesprong UK)

Again, the value proposition emphasises the health, comfort and aesthetic benefits, ahead of energy cost savings.

“The quality of the design- the ‘kerbside appeal’ of the refurbished property...It is a complete envelope, so it gives an opportunity to redesign the property and uplift the value, not because of the energy efficiency economics, but the design improvements of the property” (Energiesprong UK)

The aim is to create demand through a desirable customer offering;

“it was new, it was exciting, and everybody looked at it. You had owner occupiers knocking on the door and saying, “Can I buy one of those?” So, it is really being able to see, to display the product, which is a brand new refurbished house” (Energiesprong UK)

The Energiesprong model requires significant process innovation, in the form of developing entire insulated facades using offsite manufacture techniques, to enable an installation time of less than 1 week. This process of mass production and industrialisation is key to enabling ESPCs for single family dwellings. Such an *industrialised* approach also drives down costs for SWI, which would otherwise be prohibitively expensive.

“So therefore, it is a challenge given to industry... because there is no technical specification, but an outcome-based specification it is more [like] a product design approach in industry; akin to automotive and other sectors.” (Energiesprong UK)

The Energiesprong MESA has thus far been applied in the social housing sector, and *“the financing model therefore is a combination...of maintenance, major repair works. And the additional revenue stream for thirty years from the energy plan that comes with the property.”* (Energiesprong UK). However, at present, the net-zero energy retrofit is too expensive to enable a payback within the 30-year contact. *“The [current] market price for a 3-bed terraced property of 80 m² we would be looking at £70k. As a starting point, maybe a trajectory to £40k, £35k [is needed]”*. The Energiesprong UK team are hoping to build up a large order-book that would enable industrialisation of the supply chain and economies of scale. Currently, the model is reliant on several sources of grant funding including the EU Interreg scheme. However, for long-term economic viability, a cost of capital at < 2% is also likely to be required.

Summary of findings

A summary of the five archetypes and how they differ in terms of the BM components is provided in Table 1. The results of the empirical study have provided insights into the characteristics of successful retrofit BMs, including

some generalisable findings that drawn lessons from all five archetypes, summarised in Table 2.

Discussion

The preceding sections have identified five BMs for the delivery of residential retrofit and evaluated the potential of these models based on recent cases in the UK and EU. Previous studies discuss the emergence of one-stop-shop BMs for single family homes (Mahapatra et al. 2013) and the potential of ESCO models in this sector (Moschetti and Brattebø 2016; Winther and Gurigard 2017), but have provided few empirical examples. This study builds on this work through identifying the energy service agreement (ESA) and managed energy service agreement (MESA) models involving residential ESPCs, along with the market intermediation model. These are contrasted with the incumbent ‘atomized’ market model that typifies most residential retrofits in the UK and EU. The study thus contributes to the literature on residential retrofit by identifying and evaluating the broader range of BMs in this area.

The findings in Table 2 support the argument that ESPCs have a significant potential for energy saving in residential buildings (Steinberger et al. 2009). In addition, the study demonstrates the importance of an emphasis on comfort, health and well-being and the improved condition of the property as per the value proposition (Pätäri and Sinkkonen 2014; Sunikka-Blank and Galvin 2016). Supply chain integration (where multiple measures and design services are provided by a single organisation) is shown as critical for the delivery of comprehensive residential retrofit, particularly for single-family houses. This supports previous literature on one-stop-shop retrofit BMs (Mahapatra et al. 2013; Mlecnik et al. 2012). Through this more integrated approach, performance gaps (Dowson et al. 2012) and negative unintended consequences, such as mould and poor air quality, can also be minimized (Hansford 2015). In turn, this can strengthen the reputation of the industry and further simplify the customer journey. This contrasts with the highly fragmented and ‘siloed’ supply chains that have characterised most residential retrofit delivery to date.

The inclusion of financing options as part of the retrofit package may also be a critical driver. Whilst many UK suppliers are unable to provide financing, the more integrated businesses models, such as BHESCO and the ESA and MESA models, include

Table 2 Main findings and application of business model framework

Business model component	Key findings
Value proposition: what value is embedded in the product/service offered by the firm	<ul style="list-style-type: none"> Value proposition should place less on emphasis on carbon and energy cost savings. Focus instead on comfort, health benefits, aesthetics, building longevity and uplift in value Energy performance guarantees can be more attractive to customers and can help reduce performance gaps, although they add risk and cost for contractors
Supply chain: how are upstream relationships with suppliers, structured and managed	<ul style="list-style-type: none"> Integrated supply chains can improve quality and reduce unintended consequences, but the required holistic skillset is lacking in the UK due to highly 'siloed' disciplines The role of a <i>retrofit coordinator</i> may therefore be an essential component for the successful delivery of comprehensive residential retrofit
Customer interface: how are downstream relationships with customers, structured and managed	<ul style="list-style-type: none"> A single and trusted point of contact is very important, particularly for single family schemes Cooperative and community-based approaches offer a key means of customer engagement for retrofit Integrated supply chain or one-stop-shops can help but general lack of awareness of retrofit and customer engagement at all levels
Financial model: the nature of operational expenditures, and the means of revenue generation from the business activities	<ul style="list-style-type: none"> Low cost of capital is essential for the viability of long-term comprehensive approaches due to the low rates of return Energy performance guarantees can reduce perceived risk for investors, and thereby lower cost of capital An integrated financing package provided with the retrofit is also likely to encourage customer demand
Governance: coordinating the BM may involve a multi actor network; spanning multiple organisations	<ul style="list-style-type: none"> Successful retrofits involve the coordination of the various elements of the BM; this helps both suppliers and customers Networked approaches such as the 'atomized' market model are only suitable for single measures. Comprehensive residential retrofit is better delivered through <i>integrated BMs</i>; where the supply chain, customer interface and financial model are brought together as a coordinated offering The role of intermediary organisations, i.e. municipalities or cooperatives likely to be crucial, particularly for novel BMs

long-term finance packages to cover the up-front cost of measures. However, the associated cost of capital is critical in determining the economic viability of comprehensive residential retrofit measures such as SWI (Gouldson et al. 2015). Indeed, the Energiesprong model is currently reliant on several forms of grant funding for its economic viability. Whilst the existence of an ESPC is likely to reduce the perceived risk for investors, several other factors will also be important (Donovan and Corbishley 2016).

Low customer demand is perhaps the biggest challenge for the upscaling of whole-house retrofit. A lack of visibility and knowledge of retrofit measures can be a key barrier (Marchand et al. 2015), as well as the hassle for the occupants (Snape et al. 2015). Indeed, retrofit interventions may also affect current practices in the

home (such as heating behaviour), the inherent qualities of the property and other competing needs and desires (Gram-Hanssen 2014; Wilson et al. 2015). Retrofit measures are not typically differentiated from other renovation decisions (Wilson et al. 2015). Thus, other renovations (such as bathroom replacement) may present opportunities for retrofit at certain points in a properties' life cycle (Achtnicht and Madlener 2014). Occupants may also balance potential economic benefits of retrofits against building heritage and aesthetic concerns (Sunikka-Blank and Galvin 2016).

This study shows that a BM with a simplified customer interface, with one point of contact for the retrofit process, reduces this complexity and may address barriers to uptake (Mahapatra et al. 2013). Examples, such as the Energiesprong scheme, utilise industrialised processes to

reduce retrofit timescales and the visual upgrade of external facades, and could drive increased demand through ‘kerbside appeal’. The role of intermediaries or facilitators may be particularly important in promoting the uptake of novel BMs (Bleyl et al. 2013), involving coordinated marketing efforts, capacity and trust building with energy agencies, supply chains, LAs, and the media (Long et al. 2015; Stieb and Dunkelberg 2013).

If the BM is characterised as the network through which the product or service is delivered, the governance of this network becomes critical. This builds on other work that identifies the role of network governance in delivering energy service BMs (Hellström et al. 2015). The findings suggest that integrated BMs are likely to be most suitable for comprehensive residential retrofit, where the individual components of the BM are coordinated by a single actor to provide a simple and holistic offering to the customer.

At present, these innovative BMs are relatively rare, with the ESA and MESA models largely being trialled in multifamily buildings and social housing. With the UK’s large share of private rented, owner occupier and single-family housing (Element Energy 2013), a significant challenge remains to scale up these models to impact the wider residential market. In the MESA example in this study, the ESPC is included into the rental agreement. In the owner occupier sector, this would supplant the energy supply contract and would therefore require alterations to UK legislation surrounding the energy switching rights of consumers (Ofgem 2016). The Dutch Energiesprong policy aimed to address the retrofit challenge and produce *BM innovation* (Energiesprong 2017). This included a range of regulatory changes, public funding commitments and the establishment of a ‘market development team’, to promote a radical shift in industry practice (Energiesprong 2017). Highlighting that a mix of policy solutions may be required to overcome the multifaceted challenges of comprehensive residential retrofit and promote BM innovation.

This paper described the breadth of BMs adopted for residential retrofit, including novel and innovative examples, using desk-based research and qualitative interviews. Whilst this approach enabled a detailed understanding of each archetype, the smaller number of participants involved means the results are harder to generalise than quantitative results. The pre-testing of the framework with ‘experts’ was intended to prevent key approaches and elements being missed; although it is acknowledged, this could introduce selection bias in the choice of

interviewees. Equally, the use of in-depth case studies would have provided greater depth of understanding for specific approaches, at the expense of breadth. However, acknowledging these weaknesses, the approach adopted provides a balance between these factors and is deemed appropriate for the research aims.

Conclusions

This paper has demonstrated how BMs can be a useful framework for understanding the challenges posed by residential retrofit. The paper has identified five archetypes that are currently being used for residential retrofit within the EU, compared them in terms of their value proposition, supply chain, customer interface and financial model and overall BM governance and showed how differences in these elements can help explain their relative potential in delivering comprehensive residential retrofit.

The paper has shown how more innovative BMs could expand the market for comprehensive residential retrofits in the UK. Elements of a successful BM include the following:

- A value proposition focussed primarily upon aesthetics, comfort, health and well-being and includes guaranteed rather than estimated energy performance savings
- An integrated and industrialised supply chain providing a comprehensive whole-house approach
- A simplified customer interface with a single expert point of contact
- A financial model that includes a low-cost financing mechanism integral to the offering
- Coordinated governance of these four components through an integrated BM

This is in stark contrast to the highly ‘atomized’, market-oriented approach adopted as the primary UK delivery model to date.

Two issues in particular merit further research. First, the nature of the finance mechanism remains a key challenge, so further research should aim to identify how alternative mechanisms could enable long-term finance with a low cost of capital. Second, future work should identify the challenges of BM innovation in the sector, the barriers to such innovation and how both industry and policymakers can respond to these challenges.

There are multiple gains from comprehensive residential retrofit, including health and economic benefits that go beyond energy and carbon savings. This paper has shown how viewing this challenge through the lens of BMs can provide valuable new insights. What is clear is that the incumbent approach is not delivering the scale of change needed, which necessitates the rapid growth in comprehensive whole-house retrofit in a short period. Meeting ambitious carbon targets requires a sea change in the industry and the diffusion of innovative BMs,

such as those outlined in this paper. Achieving this will require new ways of thinking in both industry and policy.

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Appendix

Table 3 Interview details

BMBM archetype	Organisation	Actor
Expert scoping		
All	University of Oxford	Senior Research Fellow - energy efficiency policy
	United Kingdom Green Building Council (UKGBC)	Policy Advisor
	Energy Saving Trust (EST)	Senior Insight Manager
	Building Research Establishment (BRE)	Director (Wales)
	Energy Programs Consortium	Counsel and Director of Finance Programs (USA)
	Buildings Performance Institute Europe (BPIE)/Reshape innovation	Innovation Strategist - Founder (Reshape Innovation)
	Georgia Institute of Technology (USA)	Professor of Energy Policy
	Association for Environmental Studies and Sciences (AESS)	Principal and Independent Consultant
Practitioner		
Atomized market model	Building Research Establishment (BRE)	Director (Wales)
	Sustainable Design Collective	Architect – Managing Director
Market intermediary model	Greater London Authority (RE:NEW)	Program Manager -Energy
	Nottingham Energy Partnership	Contracts Manager
	Birmingham Energy Savers (BES) (Consultant)	Sustainability Consultant
One-stop-shop	Retrofit works/Parity projects	Director
	Segel AS - Norway	Business Development Consultant
	Brighton and Hove Energy Services Company (BHESCo)	CEO
ESA	Energies POSIT'IF - Paris France	Innovation Strategist - Founder (Reshape innovation)
	ICF Habitat- Paris France	Head of Energy & Water
	RENESCO – Riga, Latvia	Managing Director
MESA	Energiesprong – UK, Netherlands	Project manager/Rainmaker

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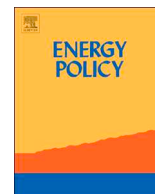
References

- Achtnicht, M., & Madlener, R. (2014). Factors influencing German house owners preferences on energy retrofits. *Energy Policy*, 68, 254–263. <https://doi.org/10.1016/j.enpol.2014.01.006>.
- Amit, R., & Zott, C. (2001). Value creation in E-business. *Strategic Management Journal*, 22(6–7), 493–520. <https://doi.org/10.1002/smj.187>.
- Bertoldi, P., Hinnells, M., & Rezessy, S. (2006). Liberating the power of Energy Services and ESCOs in a liberalised energy market. In Proceedings of the EEDAL 2006 Conference. London, UK.
- Bleil, J. W., Adilipour, N., Bareit, M., Bourgois, C.-H., & Vanstraelen Fedesco Knowledgecenter, L. (2013). ESCo market development: a role for Facilitators to play. In ECEEE Summer Studies (pp. 3–472). Belambra Presqu'île de Giens, France. Retrieved from [http://www.kompetenzzentrum-contracting.de/fileadmin/uploads_redaktion/PDF/Literatur_Download/IEADSMTask XVI_eceee_papers No. 3-472-13_ESCo_Facilitator_130322.pdf](http://www.kompetenzzentrum-contracting.de/fileadmin/uploads_redaktion/PDF/Literatur_Download/IEADSMTask_XVI_eceee_papers_No.3-472-13_ESCo_Facilitator_130322.pdf).
- Bleil-Androschin, J., & Schinnerl, D. (2007). Comprehensive refurbishment of buildings with energy services. In ECEEE 2007 summer study. Saving energy—Just do it! 817 (pp. 817–828). Retrieved from http://edit.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2007/Panel_5/5.039/paper
- Bolton, R., & Hannon, M. (2016). Governing sustainability transitions through business model innovation: towards a systems understanding. *Research Policy*, 45(9), 1731–1742. <https://doi.org/10.1016/j.respol.2016.05.003>.
- Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, 45, 9–19. <https://doi.org/10.1016/j.jclepro.2012.07.007>.
- Boons, F., Montalvo, C., Quist, J., & Wagner, M. (2013). Sustainable innovation, business models and economic performance: an overview. *Journal of Cleaner Production*, 45, 1–8. <https://doi.org/10.1016/j.jclepro.2012.08.013>.
- Bradach, J. L., & Eccles, R. G. (1989). Markets versus hierarchies: from ideal types to plural forms. *Annual Review of Sociology*, 15(Richardson 1972), 97–118. <https://doi.org/10.1146/annurev.so.15.080189.000525>.
- CCC. (2013). Committee on Climate Change. Fourth carbon budget review—part 2. Retrieved from https://www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Book_1.pdf
- CCC. (2015). The Fifth Carbon Budget—the next step towards a low-carbon economy—November 2015. Retrieved from <https://www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf>
- CCC. (2016). Meeting Carbon Budgets—2016 Progress Report to Parliament. Retrieved from <https://www.theccc.org.uk/publications/>
- DaSilva, C. M., & Trkman, P. (2014). Business model: what it is and what it is not. *Long Range Planning*, 47(6), 379–389. <https://doi.org/10.1016/j.lrp.2013.08.004>.
- Davies, M., & Oreszczyn, T. (2012). The unintended consequences of decarbonising the built environment: A UK case study. *Energy and Buildings*, 46, 80–85.
- De Groote, M., Lefever, M., & Reinaud, J. (2016). Scaling up deep energy renovation unleashing the potential through innovation & industrialisation.
- DECC (2015). Energy efficiency statistical summary 2015 Energy Efficiency Deployment Office.
- Donovan, C., & Corbishley, C. (2016). The cost of capital and how it affects climate change mitigation investment. Grantham Institute Briefing Paper, (15). Retrieved from www.imperial.ac.uk/grantham/publications
- Dowson, M., Poole, A., Harrison, D., & Susman, G. (2012). Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal. *Energy Policy*, 50, 294–305. <https://doi.org/10.1016/j.enpol.2012.07.019>.
- Duplessis, B., Adnot, J., Dupont, M., & Racapé, F. (2012). An empirical typology of energy services based on a well-developed market: France. *Energy Policy*, 45, 268–276. <https://doi.org/10.1016/j.enpol.2012.02.031>.
- Edrich, B., Beagley, K., Webber, P., & Kelling, S. (2010). Kirklees warm zone final report 2007–2010, 25.
- Element Energy (2013). Review of potential for carbon savings from residential energy efficiency. Retrieved from <https://www.theccc.org.uk/wp-content/uploads/2013/12/Review-of-potential-for-carbon-savings-from-residential-energy-efficiency-Final-report-A-160114.pdf>.
- Energiesprong (2014). Transition Zero, 1–30.
- Energiesprong (2017). United Kingdom—Energiesprong. Retrieved March 7, 2017, from <http://energiesprong.eu/country/united-kingdom/>.
- Engelken, M., Römer, B., Drescher, M., Welpé, I. M., & Picot, A. (2016). Comparing drivers, barriers, and opportunities of business models for renewable energies: a review. *Renewable and Sustainable Energy Reviews*, 60, 795–809. <https://doi.org/10.1016/j.rser.2015.12.163>.
- Eriksson, P. E. (2008). Procurement and governance management: development of a conceptual procurement model based on different types of control. *EconStor*, 91, 558–564. <https://doi.org/10.1007/s10273-011-1262-2>.
- EST (2011). Local authority large scale retrofit: a review of finance models. Retrieved from <http://www.energysavingtrust.org.uk/Publications2/Local-delivery/Funding-and-finance/Local-authority-large-scale-retrofit-A-review-of-finance-models>.
- Foxon, T. J., Bale, C. S. E., Busch, J., Bush, R., Hall, S., & Roelich, K. (2015). Low carbon infrastructure investment: extending business models for sustainability. *Infrastructure Complexity*, 2(1), 4. <https://doi.org/10.1186/s40551-015-0009-4>.
- Fylan, F., Glew, D., Smith, M., Johnston, D., Brooke-Peat, M., Miles-Shenton, D., Fletcher, M., Aloise-Young, P., & Gorse,

- C. (2016). Reflections on retrofits: overcoming barriers to energy efficiency among the fuel poor in the United Kingdom. *Energy Research & Social Science*, 21, 190–198. <https://doi.org/10.1016/j.erss.2016.08.002>.
- Gauthier, C., & Gilomen, B. (2016). Business models for sustainability: energy efficiency in urban districts. *Organization & Environment*, 29(1), 124–144. <https://doi.org/10.1177/1086026615592931>.
- GLA. (2017). RE:NEW success | London City Hall. Retrieved March 7, 2017, from <https://www.london.gov.uk/what-we-do/environment/energy/renew-0/renew-success>.
- Gouldson, A., Kerr, N., Millward-Hopkins, J., Freeman, M. C., Topi, C., & Sullivan, R. (2015). Innovative financing models for low carbon transitions: exploring the case for revolving funds for domestic energy efficiency programmes. *Energy Policy*, 86, 739–748. <https://doi.org/10.1016/j.enpol.2015.08.012>.
- GOV.UK (2017). Standard Assessment Procedure —GOV.UK. Retrieved September 28, 2017, from <https://www.gov.uk/guidance/standard-assessment-procedure>.
- Gram-Hanssen, K. (2014). Retrofitting owner-occupied housing: remember the people. *Building Research & Information*, 42(4), 393–397. <https://doi.org/10.1080/09613218.2014.911572>.
- Guertler, P., & Rosenow, J. (2016). Buildings and the 5th carbon budget. London.
- Gupta, R., & Chandiwal, S. (2010). Understanding occupants: feedback techniques for large-scale low-carbon domestic refurbishments. *Building Research & Information*, 38(5), 530–548. <https://doi.org/10.1080/09613218.2010.495216>.
- Hall, S., & Roelich, K. (2016). Business model innovation in electricity supply markets: the role of complex value in the United Kingdom. *Energy Policy*, 92, 286–298. <https://doi.org/10.1016/j.ENPOL.2016.02.019>.
- Hannon, M. J., & Bolton, R. (2015). UK Local Authority engagement with the Energy Service Company (ESCO) model: key characteristics, benefits, limitations and considerations. *Energy Policy*, 78, 198–212. <https://doi.org/10.1016/j.enpol.2014.11.016>.
- Hannon, M. J., Foxon, T. J., & Gale, W. F. (2015). “Demand pull” government policies to support Product-Service System activity: The case of Energy Service Companies (ESCOs) in the UK. *Journal of Cleaner Production*, 108, 1–16. <https://doi.org/10.1016/j.jclepro.2015.05.082>.
- Hansford, P. (2015). *Solid wall insulations: unlocking demand and driving up standards*. London.
- Hellström, M., Tsvetkova, A., Gustafsson, M., & Wikström, K. (2015). Collaboration mechanisms for business models in distributed energy ecosystems. *Journal of Cleaner Production*, 102, 226–236. <https://doi.org/10.1016/j.jclepro.2015.04.128>.
- Irrek, W., Suerkemper, F., Labanca, N., & Bertoldi, P. (2013). ESCOs for residential buildings: market situation in the European Union and policy recommendations. ECEEE Summer Study Proceedings, 1339–1347.
- Jankel, Z. (2013). Delivering and funding housing retrofit: a review of community models. Retrieved from [http://www.instituteofsustainability.co.uk/uploads/File/Delivering and Funding Housing Retrofit report March 2013.pdf](http://www.instituteofsustainability.co.uk/uploads/File/Delivering%20and%20Funding%20Housing%20Retrofit%20report%20March%202013.pdf).
- Kangas, H.-L., Lazarevic, D., & Kivimaa, P. (2017). Technical skills, disinterest and non-functional regulation: energy efficiency barriers viewed in an ecosystem of energy service companies. *Energy Policy*, 114, 63–76. <https://doi.org/10.1016/j.enpol.2017.11.060>.
- Kats, G., Menkin, A., Domm, J., & Debold, M. (2011). Energy efficiency financing—models and strategies. Capital E.
- Kelly, S., Crawford-Brown, D., & Pollitt, M. G. (2012). Building performance evaluation and certification in the UK: is SAP fit for purpose? *Renewable and Sustainable Energy Reviews*, 16(9), 6861–6878. <https://doi.org/10.1016/j.rser.2012.07.018>.
- Kim, C., O'Connor, R., & Bodden, K. (2012). Innovations and opportunities in energy efficiency finance. Wilson Sonsini Goodrich & Rosati. Retrieved from <http://www.wsgr.com/publications/pdfsearch/wsgr-ee-finance-white-paper.pdf>.
- Kindström, D., & Ottosson, M. (2016). Local and regional energy companies offering energy services: key activities and implications for the business model. *Applied Energy*, 171, 491–500. <https://doi.org/10.1016/j.apenergy.2016.03.092>.
- Kivimaa, P., & Martiskainen, M. (2017). Innovation, low energy buildings and intermediaries in Europe: systematic case study review. *Energy Efficiency*, 11(1), 31–51. <https://doi.org/10.1007/s12053-017-9547-y>.
- Knoeri, C., Steinberger, J. K., & Roelich, K. (2016). End-user centred infrastructure operation: towards integrated end-use service delivery. *Journal of Cleaner Production*, 132, 229–239. <https://doi.org/10.1016/j.jclepro.2015.08.079>.
- Koh, L., Jones, C. R., Genovese, A., Acquaye, A., Marchand, R., & Scott, F. (2013). Promoting the Green Deal to low income communities: initial insights from Yorkshire & The Humber. Sheffield.
- Kvale, S. (2008). *Doing interviews*. Sage.
- Labanca, N., Suerkemper, F., Bertoldi, P., Irrek, W., & Duplessis, B. (2014). Energy efficiency services for residential buildings: market situation and existing potentials in the European Union. *Journal of Cleaner Production*, 109, 284–295. <https://doi.org/10.1016/j.jclepro.2015.02.077>.
- Lewis, J., & Smith, L. (2013). Breaking the barriers: an industry review of the barriers to Whole House Energy Efficiency Retrofit and the creation of an industry action plan—Energy Efficiency Partnership for Buildings (EPPB) (Vol. 86).
- Long, T. B., Young, W., Webber, P., Gouldson, A., & Harwatt, H. (2015). The impact of domestic energy efficiency retrofit schemes on householder attitudes and behaviours. *Journal of Environmental Planning and Management*, 58(10), 1853–1876. <https://doi.org/10.1080/09640568.2014.965299>.
- Lopez, F. J. D., Becker, J., Eris, B., Koers, W., & Bastein, T. (2014). New business models that support resource efficiency.
- Mahapatra, K., Gustavsson, L., Haavik, T., Aabrekk, S., Svendsen, S., Vanhoutteghem, L., Paiho, S., & Ala-Juusela, M. (2013). Business models for full service energy renovation of single-family houses in Nordic countries. *Applied Energy*, 112, 1558–1565. <https://doi.org/10.1016/j.apenergy.2013.01.010>.
- Mallaburn, P. S., & Eyre, N. (2014). Lessons from energy efficiency policy and programmes in the UK from 1973 to 2013. *Energy Efficiency*, 7, 23–41. <https://doi.org/10.1007/s12053-013-9197-7>.
- Marchand, R. D., Koh, S. C. L., & Morris, J. C. (2015). Delivering energy efficiency and carbon reduction schemes in England: lessons from Green Deal Pioneer Places. *Energy Policy*,

- 84(January 2013), 96–106. <https://doi.org/10.1016/j.enpol.2015.04.035>.
- Milin, C., & Bullier, A. (2011). Energy retrofitting of social housing through energy performance contracts. A feedback from the FRESH project : France , Italy , United Kingdom and Bulgaria. FRESH (financing energy refurbishment for social housing).
- Milsom, E. (2016). Solid wall heat losses and the potential for energy saving. Consequences for consideration to maximise SWI benefits: a route-map for change. Watford. Retrieved from www.bre.co.uk
- Mlecnik, E., Kondratenko, I., Cré, J., Vrijders, J., Degraeve, P., Van Der Have, J. A., ... Paiho, S. (2012). Collaboration opportunities in advanced housing renovation. *Energy Procedia*, 30, 1380–1389. <https://doi.org/10.1016/j.egypro.2012.11.152>
- Moschetti, R., & Brattebø, H. (2016). Sustainable business models for deep energy retrofitting of buildings: state-of-the-art and methodological approach. *Energy Procedia*, 96(1876), 435–445. <https://doi.org/10.1016/j.egypro.2016.09.174>.
- Nolden, C., Sorrell, S., & Polzin, F. (2016). Catalysing the energy service market: the role of intermediaries. *Energy Policy*, 98, 420–430.
- Ofgem. (2016). Switching Programme Design Principles V1.0 DESIGN PRINCIPLES Impacts on customers. Retrieved from https://w0077w.ofgem.gov.uk/system/files/docs/2016/06/switching_programme_design_principles.pdf
- Okkonen, L., & Suhonen, N. (2010). Business models of heat entrepreneurship in Finland. *Energy Policy*, 38(7), 3443–3452. <https://doi.org/10.1016/j.enpol.2010.02.018>.
- Osterwalder, A. (2004). Business model ontology—PhD Thesis. l'Université de Lausanne.
- Osterwalder, A., & Pigneur, Y. (2010). Business model generation: a handbook for visionaries, game changers, and challengers. <https://doi.org/10.1523/JNEUROSCI.0307-10.2010>.
- Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying business models: origins, present, and future of the concept. *Communications of the Association for Information Systems*, 16(16), 1–25. <http://aisel.aisnet.org/cais/vol16/iss1/>.
- Owen, A., Mitchell, G., & Gouldson, A. (2014). Unseen influence—the role of low carbon retrofit advisers and installers in the adoption and use of domestic energy technology. *Energy Policy*, 73, 169–179. <https://doi.org/10.1016/j.enpol.2014.06.013>.
- Pätäri, S., & Sinkkonen, K. (2014). Energy service companies and energy performance contracting: is there a need to renew the business model? Insights from a Delphi study. *Journal of Cleaner Production*, 66, 264–271. <https://doi.org/10.1016/j.jclepro.2013.10.017>.
- Pettifor, H., Wilson, C., & Chrysoschoidis, G. (2015). The appeal of the green deal: empirical evidence for the influence of energy efficiency policy on renovating homeowners. *Energy Policy*, 79, 161–176. <https://doi.org/10.1016/j.enpol.2015.01.015>.
- Richter, M. (2012). Utilities' business models for renewable energy: a review. *Renewable and Sustainable Energy Reviews*, 16(5), 2483–2493. <https://doi.org/10.1016/j.rser.2012.01.072>.
- Roelich, K., Knoeri, C., Steinberger, J. K., Varga, L., Blythe, P. T., Butler, D., Gupta, R., Harrison, G. P., Martin, C., & Punell, P. (2015). Towards resource-efficient and service-oriented integrated infrastructure operation. *Technological Forecasting and Social Change*, 92, 40–52. <https://doi.org/10.1016/j.techfore.2014.11.008>.
- Rosenow, J., & Eyre, N. (2016). A post mortem of the Green Deal: austerity, energy efficiency, and failure in British energy policy. *Energy Research and Social Science*, 21, 141–144. <https://doi.org/10.1016/j.erss.2016.07.005>.
- Seyfang, G., Park, J. J., & Smith, A. (2013). A thousand flowers blooming? An examination of community energy in the UK. *Energy Policy*, 61, 977–989. <https://doi.org/10.1016/j.enpol.2013.06.030>.
- Snape, J. R., Boait, P. J., & Rylatt, R. M. (2015). Will domestic consumers take up the renewable heat incentive? An analysis of the barriers to heat pump adoption using agent-based modelling. *Energy Policy*, 85, 32–38. <https://doi.org/10.1016/j.enpol.2015.05.008>.
- Sorrell, S. (2007). The economics of energy service contracts. *Energy Policy*, 35(1), 507–521. <https://doi.org/10.1016/j.enpol.2005.12.009>.
- Sorrell, S., Schleich, J., O'Malley, E., & Scott, S. (2004). The economics of energy efficiency: barriers to cost-effective investment. Books. Cheltenham: Edward Elgar.
- Sovacool, B. K. (2015). Fuel poverty, affordability, and energy justice in England: policy insights from the Warm Front Program. *Energy*, 93, 361–371. <https://doi.org/10.1016/j.energy.2015.09.016>.
- Steinberger, J. K., van Niel, J., & Bourg, D. (2009). Profiting from negawatts: reducing absolute consumption and emissions through a performance-based energy economy. *Energy Policy*, 37(1), 361–370. <https://doi.org/10.1016/j.enpol.2008.08.030>.
- Stieb, I., & Dunkelberg, E. (2013). Objectives, barriers and occasions for energy efficient refurbishment by private homeowners. *Journal of Cleaner Production*, 48, 250–259. <https://doi.org/10.1016/j.jclepro.2012.09.041>.
- Straub, A. (2016). Cohereno: Collaboration for Housing Nearly Zero-Energy RENOVation publishable report. Delft. Retrieved from <http://www.cohereno.eu/fileadmin/media/Dateien/COHERENO-Publishable-Report-2016.pdf>
- Sunikka-Blank, M., & Galvin, R. (2016). Irrational homeowners? How aesthetics and heritage values influence thermal retrofit decisions in the United Kingdom. *Energy Research & Social Science*, 11, 97–108. <https://doi.org/10.1016/j.erss.2015.09.004>.
- Sweatman, P., & Managan, K. (2010). Financing energy efficiency building retrofits international policy and business model review and regulatory alternatives for Spain. Climate Strategy and Partners. Madrid. Retrieved from www.climatestrategy.es
- Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning*, 43(2–3), 172–194. <https://doi.org/10.1016/J.LRP.2009.07.003>.
- The Rockefeller Foundation, & DB Climate Change Advisors (2012). United States building energy efficiency retrofits market sizing and financing models.
- Treib, O., Bähr, H., & Falkner, G. (2007). Modes of governance: towards a conceptual clarification. *Journal of European Public Policy*, 14(1), 1–20. <https://doi.org/10.1080/1350176060061071406>.

- Upward, A., & Jones, P. (2015). An ontology for strongly sustainable business models: defining an enterprise framework compatible with natural and social science. *Organization & Environment*, 1–27. <https://doi.org/10.1177/1086026615592933>.
- Watson, A. (2014). To what extent has Green Deal policy facilitated energy efficiency retrofit supply chain development: a case study of Birmingham.
- Webb, J., Hawkey, D., & Tingey, M. (2016). Governing cities for sustainable energy: the UK case. *Cities*, 54, 28–35. <https://doi.org/10.1016/j.cities.2015.10.014>.
- Willand, N. ., Ridley, I. ., & Maller, C. . (2015). Towards explaining the health impacts of residential energy efficiency interventions—a realist review. Part 1: Pathways. *Social Science and Medicine*, 133, 191–201. <https://doi.org/10.1016/j.socscimed.2015.02.005>.
- Wilson, C., Crane, L., & Chrysoschoidis, G. (2015). Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research and Social Science*, 7, 12–22. <https://doi.org/10.1016/j.erss.2015.03.002>.
- Winther, T., & Gurigard, K. (2017). Energy performance contracting (EPC): a suitable mechanism for achieving energy savings in housing cooperatives? Results from a Norwegian pilot project. *Energy Efficiency*, 10(3), 577–596. <https://doi.org/10.1007/s12053-016-9477-0>.
- Zott, C., & Amit, R. (2010). Business model design: an activity system perspective. *Long Range Planning*, 43(2–3), 216–226. <https://doi.org/10.1016/j.lrp.2009.07.004>.
- Zott, C., Amit, R., & Massa, L. (2011). The business model: recent developments and future research. *Journal of Management*, 37(4), 1019–1042. <https://doi.org/10.1177/0149206311406265>.



Worth the risk? An evaluation of alternative finance mechanisms for residential retrofit

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ABSTRACT

Improving energy efficiency, de-carbonising heating and cooling, and increasing renewable microgeneration in existing residential buildings, is crucial for meeting social and climate policy objectives. This paper explores the challenges of financing this ‘retrofit’ activity. First, it develops a typology of *finance mechanisms* for residential retrofit highlighting their key design features, including: the *source of capital*; the *financial instrument(s)*; the *project performance* requirements; the *point of sale*; the nature of the *security and underwriting* the *repayment channel* and *customer journey*. Combining information from interviews and documentary sources, the paper explores how these design features influence the success of the finance mechanisms in different contexts. First, it is shown that a low *cost of capital* for retrofit finance is critical to the economic viability of whole-house retrofits. Second, by funding non-energy measures such as general improvement works, finance mechanisms can enable broader *sources of value* that are more highly prized by households. Thirdly, mechanisms that reduce complexity by simplifying the *customer journey* are likely to achieve much higher levels of uptake. Most importantly we discuss how finance alone is unlikely to be a driver of demand for whole-house retrofit, and so instead should be viewed as a necessary component of a much broader retrofit strategy.

1. Introduction

CO₂ emissions from energy used in residential buildings result from space and water heating, and electricity used for cooling, lighting and appliances. These emissions constitute a significant proportion of total emissions in advanced economies (IPCC, 2014). Aside from more efficient appliances and behavioural changes, emissions from the existing building stock can be reduced by the *retrofit* of three main types of measure: improving the energy efficiency (EE) of the building fabric; adopting low carbon heating, ventilation and cooling technologies (HVAC); and building integrated electricity microgeneration, such as solar photovoltaics (PV) (CCC, 2013). Thus, in this paper ‘retrofit’ finance potentially includes funding for all three types of intervention.

The Intergovernmental Panel on Climate Change have set ambitious goals for the retrofit of buildings (50% energy reduction from 2050 baseline scenario (IPCC, 2014)), to keep global temperature rises below 2 °C as part of the 2015 Paris agreement. Since 1970 emissions from all

buildings have more than doubled and in 2010 constituted around 19% of global carbon emissions (IPCC, 2014). Many retrofit measures deliver net cost savings or are cost effective,¹ when compared to other climate mitigation measures (CCC, 2018; IEA, 2017). However, delivering these ambitious targets, will necessitate increasingly comprehensive ‘whole-house’ retrofits, involving multiple integrated building fabric, HVAC, and microgeneration measures (Brown, 2018).

Delivering the 2 °C scenario will require an estimated \$31Tn of investment in buildings globally over the next four decades (IEA, 2013). A significant proportion of historical energy efficiency measures has involved self-financing by firms and households (IEA, 2017; Webber et al., 2015). However, an important source of EE investment in recent years in both Europe and North America (12% of total) has come from market based instruments such as supplier obligation policies, paid for by a levy on electricity and gas bills (IEA, 2017). These policies have typically delivered single home retrofit measures (Rosenow, 2012).

Achieving sufficient ‘whole house’ retrofits through supplier

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¹ The UK’s Committee on Climate Change define the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes together with measures that may cost more than the projected carbon price, but are necessary in order to manage costs and risks of meeting the 2050 target (CCC, 2013).

obligations alone could lead to significant increases in household energy bills (Kern et al., 2017), thus having a negative impact on low income households who do not undertake retrofit measures (Rosenow et al., 2013b). Whilst ‘fuel poverty’² objectives could be better achieved through general taxation (Rosenow et al., 2013b), there is a need for effective, repayable *finance mechanisms* for the ‘able-to-pay’ segments (Freehling and Stickles, 2016).

In this paper, finance mechanisms are considered distinct from targeted subsidies, supplier obligations (IEA, 2017), or fiscal incentive schemes such as property tax breaks (Rosenow et al., 2014). A finance mechanism is thus defined as the provision of capital for retrofit measures through equity and/or debt that is repaid to the lender (Leventis et al., 2017). A range of retrofit finance mechanisms have been developed, in the European Union (EU) and USA. The features of and reasons for success of these alternative approaches are the main focus of this study.

A comprehensive study of finance mechanisms for domestic retrofit is largely absent from the academic literature - with most studies published being non-academic, having limited consideration for the specific issues of residential buildings, or involving a different unit of analysis, such as supplier obligations (Rosenow, 2012). Further, an empirical investigation of factors that contribute to household appeal and the cost of capital is presently lacking. The role of different types of financing and their impact on projects remains somewhat of a ‘black box’ in the energy studies field more generally. This paper aims to open up the features of alternative finance mechanisms, and to understand the extent to which they can promote the uptake of whole-house retrofit - drawing on selected examples in Europe and North America.

This paper is structured as follows. Section 2 provides background to the context of residential retrofit and reviews the literature on retrofit finance. Section 3 introduces the conceptual framework for the features of finance mechanisms along with the cost of capital. Section 4 outlines the methodology. Section 5 introduces a new typology of retrofit finance mechanisms, while Section 6 describes how these mechanisms differ according to the framework. Section 7 discusses the findings. Section 8 concludes and provides recommendations for policy and research. A glossary of key financial terminology used in the paper is provided in Table A1 in the Appendix.

2. Background on energy efficiency, residential retrofit and finance

Residential retrofit produces a range of environmental, social and economic benefits, making it an important area for academic and policy research (Kerr et al., 2017). Energy savings from residential retrofit and a shift away from fossil fuel-based heating and cooling have the potential to significantly mitigate anthropogenic climate change. The IPCC (2014) estimate that, through improved EE, energy use from buildings could be stabilised by mid-century, compared to a current baseline where this is set to double. Thus, the EU has set a target of 27% improvement in EE by 2030 (EC, 2014) and the revised Directive for the Energy Performance of Buildings has set a near zero-energy aspiration for the existing building stock (EC, 2018). Residential retrofits have also been shown to improve occupant health and wellbeing (Curl et al., 2015; Willand et al., 2015), reduce fuel poverty (Sovacool, 2015) and lead to job creation and economic growth (EEFIG, 2015; Washan et al., 2014). Retrofit may also produce private benefits to households, including increased property value (Brounen and Kok, 2011; Fuerst et al., 2015), significant savings in energy bills and improved thermal comfort (Aravena et al., 2016; Gillingham et al., 2009). However, much of this potential remains unexploited.

The lack of investment in seemingly cost effective EE measures, is commonly termed the ‘energy efficiency gap’ (Jaffe and Stavins, 1994). Firms, public sector actors and households are seen to underinvest in EE, due to multiple ‘barriers’ that constrain uptake (Kangas et al., 2018; Sorrell et al., 2004). Although many factors that contribute to a low demand for EE are likely to be outside of what financing alone can achieve (Wilson et al., 2015), tailored financing solutions can make an important contribution to the uptake of retrofit measures (Rezessy and Bertoldi, 2010), particularly in the residential sector (Freehling and Stickles, 2016).

Historically, a large proportion of global investment in residential retrofit has involved either self-financing or energy supplier obligations (IEA, 2017). However, meeting the 2 °C target will likely require third-party sources of finance (EEFIG, 2015), particularly as energy suppliers see their market capitalisation shrink and attempt to de-leverage³ their balance sheets due to declining revenues and market share (Blyth et al., 2015; Bolton and Foxon, 2015). Incumbent energy suppliers also lack incentives to fund EE investments, as their current business model relies on increasing throughput sales of energy (Knoeri et al., 2016). Existing financial institutions, such as banks and institutional investors, also remain reticent towards such investment due to an unfamiliarity with the technologies, regulatory risk, short investment horizons, high transaction costs and a lack of suitable finance mechanisms (Bolton and Foxon, 2015; Hall et al., 2015; Stone, 2014).

The United Kingdom's (UK) ‘Green Deal’ policy provides an interesting case of an innovative finance mechanism, intended to deliver approximately 2 million retrofit installations per year and leverage billions of pounds of investment. The scheme was based on private sector lending to households, paid back through a levy on energy bills - known as ‘on-bill repayment’ (OBR). However, the scheme only achieved a fraction of its target, and resulted in a significant loss to UK taxpayers before its premature scrapping in 2015 (Rosenow and Eyre, 2016).

A range of more successful retrofit finance mechanisms, however, provide some important lessons (EEFIG, 2015). Examples include the USA's Property Assisted Clean Energy finance (PACE) programmes (Kim et al., 2012); low cost loans delivered by the German KfW state bank (Schröder et al., 2011); other forms of on-bill-financing and repayment (On-bill) (Zimring et al., 2014a); green mortgages (Ecology Building Society, 2017); and state-backed guarantee funds (Borgeson et al., 2013). In addition, energy service agreements (ESA), where finance for measures is procured upstream by an Energy Service Company (ESCO) as part of an energy saving performance contract have been used in multi-family housing and commercial buildings (Labanca et al., 2014).

Yet, academic studies on alternative approaches to EE finance are largely absent from the energy and climate journals, with leading finance journals largely silent on energy issues in general (Diaz-Rainey et al., 2017). The literature on ‘green finance’ has tended to focus on high level flows of energy finance (Mazzucato and Semieniuk, 2018), or the challenges of funding large renewable energy projects (Blyth et al., 2015). Hall et al. (2016) also highlight the challenges of financing distributed energy systems, where differing national institutional contexts influence the financial solutions available.

A handful studies have discussed the potential of alternative retrofit finance mechanisms, including potential revolving retrofit funds (Gouldson et al., 2015), the UK's Green Deal (Marchand et al., 2015; Rosenow and Eyre, 2016), and the successful German KfW programme (Rosenow et al., 2013a). Others have explored how energy performance contracts could finance residential retrofit (Winther and Gurigard, 2017) but have not foregrounded the financial component of such models. Bergman and Foxon (2017) discussed the challenges for

² The definition of fuel poverty in the UK, is where fuel costs that are above average (the national median level), and these fuel costs leave a residual income that is below the UK's official poverty line (DECC, 2013).

³ Leverage involves the use of borrowed money: typically, the use of various forms of debt. Firms or projects may be considered over leveraged when their balance sheets excessive levels of debt compared to equity.

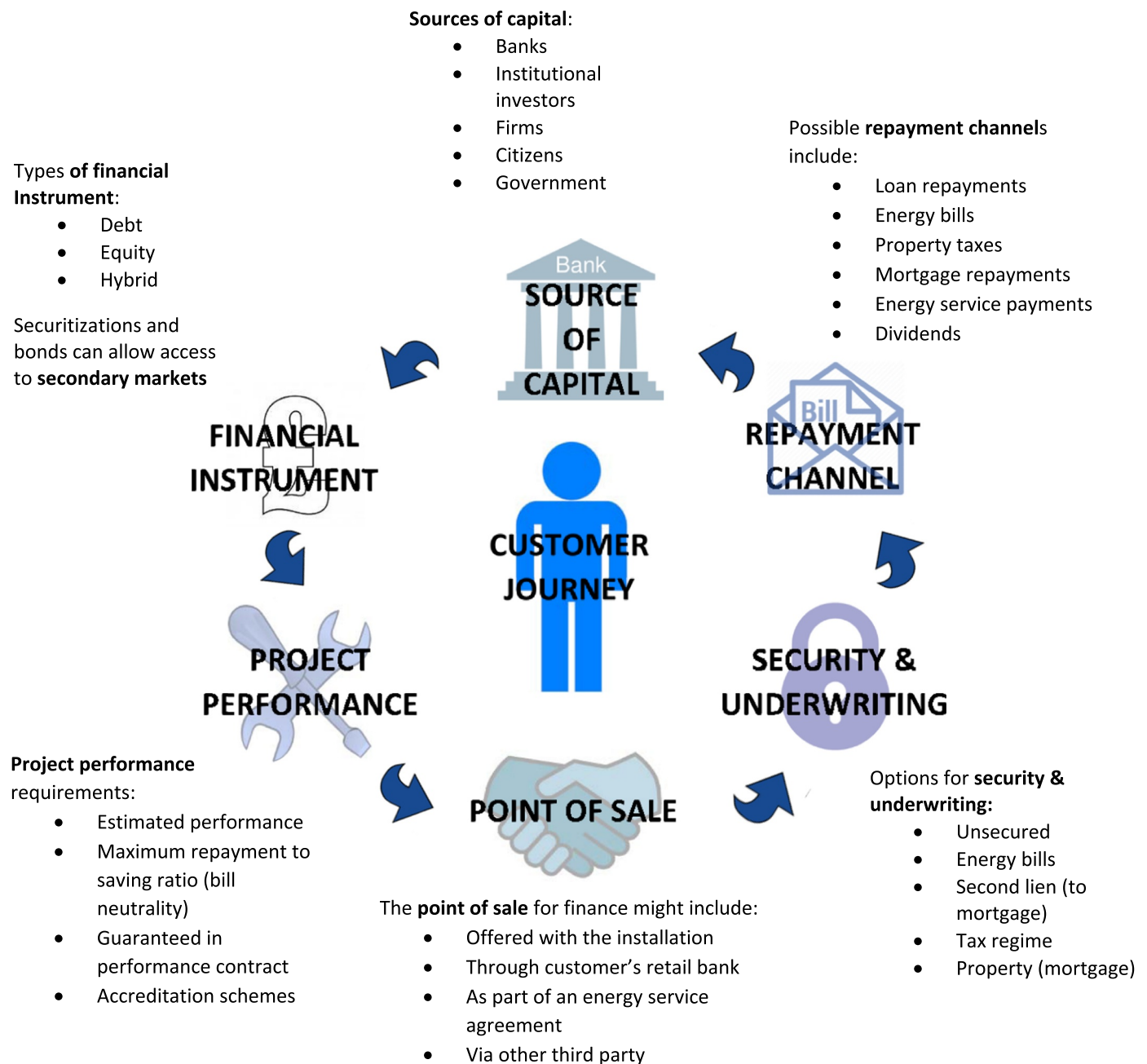


Fig. 1. Process diagram of an EE finance mechanism.

reorienting finance towards EE in the UK and argue for a re-framing of EE as infrastructure financing. Previous work has also discussed the potential of novel financing solutions for overcoming the *split incentive* barrier (Bird and Hernández, 2012). But taken together, these studies provide only limited insights into what the features of a successful finance mechanism might be. This paper seeks to address this gap in the literature.

3. Features of a finance mechanism and the cost of capital

Access to capital and *split incentives* are a significant barrier to residential retrofit. Often household savings or conventional financing solutions, such as secured and unsecured loans may be unavailable, or unsuitable (Rezessy and Bertoldi, 2010). Many also face split incentives - where the benefits of an investment do not fully accrue to the investor (Bird and Hernández, 2012). The classic example is the pervasive 'landlord tenant dilemma', where energy savings accrue to the tenant,

with the landlord making the investment. Homeowners may also face split incentives if they move out before their initial investment has been recovered and if the value of that investment cannot be capitalised in the sale price. Thus, many conventional forms of financing⁴ do not address split incentives (Bird and Hernández, 2012). In response, a range of retrofit finance mechanisms have been developed to overcome these barriers (EEFIG, 2015). Fig. 1 summarises the conceptual framework of key design features of finance mechanisms, which are described in detail in Table 1.

⁴ Conventional forms of financing such as home equity, credit cards, bank loans or conventional mortgages are excluded from this study. Whilst these approaches may be used to fund retrofit measures they are considered distinct from mechanisms designed to fund energy efficiency specifically - as the latter are designed to utilise the savings generated from the retrofit measures and in many cases to overcome specific barriers such as split incentives.

Table 1
The key design features of finance mechanisms.

Feature	Description
Source of capital	<ul style="list-style-type: none"> Investment in EE may come from single or multiple sources. Banks, institutional investors, firms, governments or even citizens may provide financing. Debt is typically provided by banks and institutional investors, whilst other non-financial corporations may also provide loans (Buchner et al., 2015b). Equity providers tend to be different (although there is often overlap) and can include project developers, ESCOs, co-operatives, private investors/citizens and venture capital funds (Buchner et al., 2015a). Public bodies may provide all of the capital, or provide <i>credit enhancements</i>^a including: junior^b (high risk) debt with private finance providers providing the senior (low risk) debt (EEFIG, 2015); interest rate reductions (Gouldson et al., 2015); or credit guarantee funds – all with the aim of reducing risk, the cost of capital and leveraging private funding (Zimring, 2014a).
Financial instrument	<ul style="list-style-type: none"> Finance may take the form of debt or equity, or a combination of the two.^c Debt finance typically consists of loans provided by financial institutions or equipment providers in the form of leases (Sorrell, 2005). Debt may be issued directly to the homeowner or upstream to energy suppliers, ESCOs or to a special purpose vehicle (SPV)^d (Rezessy and Bertoldi, 2010). Securitisation^e involves aggregating loans into tradeable ‘securities’, thus drawing in sources of capital who would normally only invest in larger projects (OECD, 2015). Small scale loans to households can be aggregated and <i>securitised</i> and sold into secondary markets,^f often in the form of bonds (Borgeson et al., 2013). Equity takes the form of part ownership or share issues. Stakeholder models such as cooperatives adopt largely equity based approaches (Walker, 2008), although in commercial finance equity tends to be costlier^g than debt (Tapia, 2012), despite its theoretical equivalence (Modigliani and Miller, 1958). The majority of domestic retrofit schemes are debt-financed, although ESCOs may use their own equity to finance projects, as part of energy performance contracts (Leventis et al., 2017).
Project performance	<ul style="list-style-type: none"> The post intervention performance of EE retrofits is of critical importance to both financiers and building occupants. Evaluating the potential of a retrofit is likely to require an energy model and audit and ideally data on past energy consumption (Rezessy and Bertoldi, 2010). Financiers may place a range of requirements on project performance. This may include requirements that measures are ‘cash-flow positive’ meaning that finance repayments are less than or equal to energy bill savings – often referred to as <i>energy bill neutrality</i> (Borgeson et al., 2013). Savings-backed arrangements such as energy performance contracts include requirements for <i>actual</i> energy performance outcomes, such as kWh savings, guaranteed cost reductions or even guaranteed temperatures (Sorrell, 2005). Financiers may also require projects to be standardised to best practice guidelines (Investor Confidence Project, 2015) or be accredited to industry quality standards (Bonfield, 2016). Alternatively, funders may place less strict requirements on energy performance outcomes, or enable wider non-energy measures to be funded (Borgeson et al., 2013).
Point of sale	<ul style="list-style-type: none"> The point of sale is the interface through which the customer accesses finance. The nature of this interface has important implications for the <i>customer journey</i>^h (Norton et al., 2013) for a retrofit project. In many cases, finance has a separate point of sale from the contractor providing the retrofit measures. This may include the use of the customer's existing bank (Schröder et al., 2011), a special mortgage product (Ecology Building Society, 2017) or an additional third party provider. In other cases the retrofit provider may offer an integrated finance package as part of the retrofit, or as part of an energy performance contract (Borgeson et al., 2013). Previous studies have shown that the uptake of retrofit schemes is strongly influenced by how information is presented (Hoicka et al., 2014; Long et al., 2015); the nature of the financial rewards (upfront payments or long term savings) (Collins et al., 2018); and the channels through which the scheme is promoted (Mahapatra et al., 2013; Mlecnik et al., 2011).
Security and Underwriting	<ul style="list-style-type: none"> Mortgages are secured by the financial institution's ability to repossess the home should a customer default on their loan (Borgeson et al., 2013). Other forms of security include property taxes or energy bills, meaning the threat of court proceedings or disconnection can be applied (Zimring, 2014b). The <i>underwriting</i> process is how financiers determine the underlying credit-worthiness of the asset or borrower. Underwriting may be focussed upon the asset to which finance is secured (i.e. the historic repayments of property taxes or energy bills), or upon the borrower through metrics such as personal credit ratings (Leventis et al., 2017). Publicly funded programmes may place less emphasis on security and underwriting, particularly if they are targeting low-income households (EEFIG, 2015).
Repayment channel	<ul style="list-style-type: none"> The repayment channel is how funds are repaid to the creditor or shareholders. A range of repayment channels exist for EE projects and are an important area for new policy and legal frameworks (EEFIG, 2015). Repayments can be made through conventional personal or corporate loan repayments, through energy bills, service charges, collected via property taxes or through rent or mortgage repayments. Equity returns are then distributed through dividends, although these may be contingent on the performance of the asset or company (EEFIG, 2015). Further, equity release models may only require payment once the property is sold (Scottish Government, 2017). Where repayments are linked to the underlying asset such as with property taxes or energy bills, this can enable transferability of the retrofit finance from one occupant to the next, thereby addressing split incentive problems (Borgeson et al., 2013).
Customer Journey	<ul style="list-style-type: none"> The customer journey is defined as the sequence of events that customers experience to learn about, purchase and interact with products and services (Norton et al., 2013). Although individual elements of a finance mechanism influence the customer journey, the concept summarizes the household's experience of how these elements are integrated. Complex or lengthy customer journeys have been shown to negatively impact the uptake of residential retrofit finance (O'Keeffe et al., 2016). Specific issues include poor integration with the timing of wider renovations (Fawcett, 2014), complex applications and limited information (Marchand et al., 2015), low trust in the provider (Risholt and Berker, 2013), and a lack of co-ordination with the supply chain (Brown, 2018).

^a Credit enhancements are a set of approaches usually offered by public actors, which reduce lender or investor risk by providing some form of protection or guarantee in the event of default, bankruptcy or delinquency.

^b Junior Debt is a loan or security that ranks below other loans or securities with regard to claims on assets or earnings. Junior debt is also known as a ‘Subordinated debt’ or subordinated loan. In the case of borrower default, creditors who own subordinated debt won't be paid out until after senior debtholders are paid in full.

^c Many retrofit programmes may be partly based on grants or other public subsidies, however the focus of this study is to analyse the dynamics of the finance mechanisms, rather than the influence of grants or subsidy instruments on the underlying economic viability of retrofit measures.

^d A special purpose vehicle (SPV) is a company with a specific and often short-term purpose, with a structure and legal status that allows the SPV to fail or go bankrupt without bringing down the wider organisations involved the transaction. They are designed isolate risk and allow organisations to finance projects ‘off balance sheet’.

^e Securitisation is a form of financial engineering where groups of illiquid assets are bundled together, often by aggregating multiple smaller securities, and transforming them into a tradable security in secondary markets.

^f A secondary market allows for securities (such as loans) to be resold, often in aggregation and are thus second hand.

^g Debt is senior to equity, so in a bankruptcy, the debt holders get paid before the equity holders. Therefore, equity providers (shareholders) require dividends that tend to reflect these higher risks with higher associated rewards and are often linked to project profitability.

^h The customer journey is defined as the sequence of events that customers experience in order to learn about, purchase and interact with products and services (Norton et al., 2013).

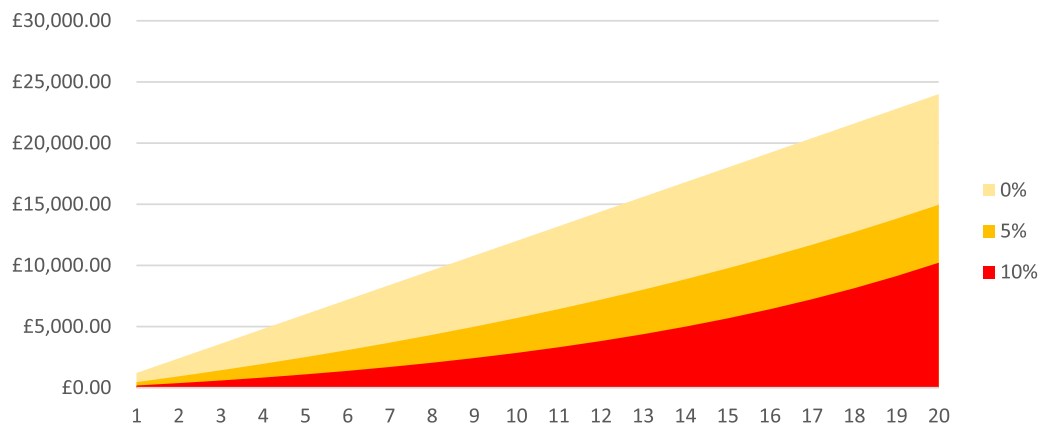


Fig. 2. The impact of the interest rate on borrowing potential, assuming a fixed repayment and term.

3.1. The features of a finance mechanism and the customer journey

See Fig. 1 and Table 1.

3.2. The cost of capital

The cost of capital is of critical importance for determining the economics of capital-intensive investments, such as retrofit (Donovan and Corbishley, 2016). The cost of capital consists of the weighted average cost of debt (e.g. the interest rates attached to a bank loan) and equity (e.g. the returns required by shareholders). Due to the effects of compound interest, the cost of capital has increasing significance for long term, capital-intensive investments (Donovan and Corbishley, 2016).

Fig. 2 provides a simple illustration. Assuming a fixed repayment of £100/month and a loan maturity of 20 years, the figure shows the total amount that can be borrowed at 0%, 5% and 10% interest rates respectively. Whilst a household could borrow £24,000 (the principal) at 0%, this reduces to £14,954.65 at 5%, and only £10,216.27 at 10% – where at 10% the total interest is higher than the principal. Consequently, assuming fixed payments and loan term, the cost of capital limits the amount that can be borrowed and in turn the extent of the retrofit measures funded.

Previous studies show that the interest rates on loans can limit the appeal of retrofit finance mechanisms such as the UK's Green Deal (Marchand et al., 2015; Rosenow and Eyre, 2016), whilst low interest rates were an important success factor in Germany's KfW scheme (Rosenow et al., 2013a; Schröder et al., 2011). This high cost of capital is also likely to significantly limit the feasible range of retrofit measures that can be funded (UKGBC, 2014). However, Borgeson et al. (2014) question the extent to which the cost of capital is a barrier, emphasising how high interest credit card financing for retrofit remains prevalent in the USA.

4. Methods

This study takes a qualitative approach, involving analysis of interviews and secondary data, including a comprehensive review of the 'grey literature' on EE finance. Whilst there are few academic studies on the topic, numerous policy briefs, publicly commissioned studies and consultancy reports exist from a range of public, private and third sector sources. This review identified several texts with recurring descriptions of the key approaches to retrofit finance in both domestic and commercial buildings (EEFIG, 2015; EST, 2011; Investor Confidence Project, 2015; Kats et al., 2011; Kim et al., 2012; Sweatman, 2012; Sweatman and Managan, 2010; The Rockefeller Foundation and DB Climate Change Advisors, 2012; Zimring, 2014b). Examination of this literature led to the development of a typology of six archetypes of

finance mechanisms used to fund residential retrofit in the EU and USA. For simplicity, some archetypes, such as public guarantee funds and state bank loans were aggregated under a single heading, whilst others, such as leasing, were excluded due to limited examples being available in the residential sector. This typology is summarised in Table 2 and described in detail in Section 5.

Subsequently, eighteen semi structured interviews were carried out, split into two phases: 'expert scoping' and 'practitioner' interviews. During Spring/Summer 2017, eight prominent experts (Table B1) in the EE finance community were interviewed. Several interviewees were authors in the key texts described above, notably the European Commission funded Energy Efficiency Finance Group report (EEFIG, 2015), whilst others were selected through personal contacts and snowballing techniques (Yin, 1994). The aim was to understand the key drivers and barriers for residential EE financing; which design features of a finance mechanism are most important; and why certain approaches are more effective. Information was also sought on how the policy and institutional context shapes the preference for and viability of different approaches.

Building on the insights from the expert interviews, a protocol was developed to interview practitioners pertaining to each of the six finance mechanisms in the proposed typology. The aim was to include at least two representatives of each type, with the sample drawn from the EU and the USA. Many of the mechanisms under study, such as PACE, have only been adopted in certain USA states, notably California. Understanding both the mechanism's features and the policy and institutional context in which they operate is therefore important. Questions were designed to probe each of the design features of finance mechanisms (described in Section 3), and the drivers and barriers to the adoption of those mechanisms, including broader contextual factors. During Summer/Autumn 2017, ten semi-structured practitioner interviews (Table A1) were conducted.

Interviews were coded using the NVivo 11™ software, allowing common themes to be identified along with areas for further investigation. This qualitative approach was considered appropriate, given the need to develop a rich understanding of the role and importance of different features of finance mechanisms, and their broader contextual setting (Yin, 1994). The pre-testing of the framework with 'experts' was intended to prevent key approaches and elements being missed, although it is acknowledged this could introduce bias in the selection of interviewees.

5. Typology of retrofit finance mechanisms

Building on the review of grey literature, a number of distinct finance mechanisms can be identified. These approaches are distinguished by variations in the key features identified in Section 3. The range of approaches to financing residential retrofit was discussed

Table 2

The key features of six archetypes of finance mechanism for residential retrofit.

TYPE OF FINANCE MECHANISM	EXAMPLE SCHEMES	SOURCE OF CAPITAL	FINANCIAL INSTRUMENT	FEATURE OF FINANCE MECHANISM			
				PROJECT PERFORMANCE	POINT OF SALE	SECURITY AND UNDERWRITING	REPAYMENT CHANNEL
PUBLIC LOAN/ CREDIT ENHANCEMENT	HES and HEEPS equity loan (Scotland)	Government spending	Debt	Minimum CO ₂ saving	Third party finance provider	No security - basic credit check	Unsecured Loan/ equity release
	KfW CBRP (Germany)	Public Bank	Debt (bonds)		Retail bank	No security - basic credit check	Unsecured Loan
	JESSICA-> LEEF (EU-> London, UK)	Hybrid – EIB, LEEF & Private lender	Debt		Housing provider	Varies	Revolving phase then full repayment
ON BILL FINANCING/ ON BILL REPAYMENT	UK (OBR) Green Deal	Third party private Sector	Debt	Bill neutrality (Golden rule)	Third party finance provider	Energy meter & bill history	Energy Bills
	USA & Canada (OBF) schemes	Energy Utility & public/ credit enhancements	Debt (some securitised examples)	Often Bill neutrality	Energy utility		
PROPERTY ASSESSED CLEAN ENERGY (PACE)	RE:NEW Financial (US)	Municipal bond -> private capital	Debt (bonds)	None - approved contractor schemes	Contractor	Lien on property & tax bill-based underwriting	Property taxes
GREEN MORTGAGE	EMF Green mortgage project (EU)	Covered Bond market	Mortgage (equity & debt)	EPC improvement	Mortgage provider	Detailed credit check	Mortgage payments
	Ecology Building society (UK)	Member deposits	Equity				
ENERGY SERVICES AGREEMENT	RENESCO (Latvia)	ESCO -> Public Bank	Debt & Equity	Energy Performance Guarantee	Contractor	Based on ESCO	Energy performance contract
	SEA (Italy)	ESCO -> Institutional investor				Based on ESCO & bill payment history	
COMMUNITY FINANCING	BHESCo (Brighton, UK)	Member share issue	Equity	None	Contractor	Credit check	Hire Purchase agreement-> dividends

during the expert scoping interviews, leading to the development of a typology of six archetypes of finance mechanism, namely, *public loan/ credit enhancement*, *on-bill finance and repayment*, *property assessed clean energy financing*, *green mortgages*, *energy service agreement financing*, and *community financing*. The typology is described in this section and summarised in Table 2. The following types are drawn from prominent contemporary examples and their nomenclature reflects common terminology within the industry. The typology is ordered from the more widespread publicly funded approaches, to the more niche community financing.

Some overlap exists between the different archetypes, with the possibility that hybrid forms may emerge.

5.1. Public loan/ credit enhancement

Public retrofit finance mechanisms typically involve low cost loans provided by governments, but may also include a range of credit enhancements to be blended with private capital (EEFIG, 2015). The most prominent example is Germany's CO₂ Building Rehabilitation Programme (CBRP). Germany's state bank, the KfW, provides loans to households arranged through commercial banks. Funds are raised on capital markets,⁵ and offered at very low rates of interest (> 2%) (Rosenow et al., 2013a). The bank is able to offer these low rates primarily due to its AAA rating; a product of its public status, with additional state funding to further subsidise interest rates (Schröder et al., 2011). In 2007, the CBRP issued €5bn in loans, and the programme is estimated to have reduced carbon emissions from the existing building

stock by 24% between 1990 and 2006, with an average of a 59% reduction per property in 2006 (Schröder et al., 2011).

Less well-known schemes are the Home Energy Scotland (HES) loan and Home Energy Efficiency Programme for Scotland (HEEPS) equity loans, funded by the Scottish government. Both programmes offer 0%⁶ interest loans. The HEEPS equity loan is repaid upon the sale of the property. However, it is more common for public funded programmes, such as the HES and KfW loans, to be unsecured and linked to the individual rather than the property (Zimring et al., 2014a). Both the CBRP and the HEEPS equity loan schemes allow funding for wider renovation measures (Schröder et al., 2011), with the HEEPS equity loan allowing 45% of the maximum £40,000 to be spent on non-efficiency measures (EST, 2017).

Credit enhancements blend public money with private capital in a single fund. For example, the Joint European Support for Sustainable Investment in City Areas (JESSICA) programme, administered by the European Investment Bank, mobilises grants from European structural funds⁷ (Rezessy and Bertoldi, 2010). Such mechanisms typically involve the low cost public capital occupying the junior (high risk) tranche⁸ of a fund, which is then blended with private sources (Zimring, 2014b). This

⁶ A small administration fee and inflation index linking is applied.

⁷ The European Structural Funds are a set of financial tools designed to address inequalities in income, wealth and economic opportunities within the Member states of the European Union.

⁸ Tranches are different portions of debt within the capital structure of a fund or project finance structure that are designed to divide risk or group different characteristics such as rewards, maturity and size in ways that are marketable to various classes of investor. This typically includes equity components, junior and senior debt but may also include mezzanine and other hybrid forms of finance.

⁵ Generally, these markets involve the trading of longer-term debt and equity instruments, typically with a maturity of a year or more.

reduces risk for the private providers, with the public money absorbing the first losses should customers default. A prominent example is the London & Mayors EE Funds (LEEF & MEEF) (LEEF, 2012). Such schemes aim to leverage high ratios of private to public capital for EE investments with LEEF and MEEF raising £100 m (50:50 private/public ratio) and £1 bn respectively (70:30 private/public ratio) (Amber Infrastructure). Other examples may include loan loss reserve funds and guarantees⁹ or direct interest rate subsidies (Zimring, 2014a).

5.2. On-bill finance and repayment (On-bill)

On-bill mechanisms involve the repayment of loans via the energy bill (electricity, gas or dual-fuel). The investment is typically secured by the right to disconnect supply, if left unpaid (Zimring et al., 2014a). These approaches are divided into two types, with different sources of capital. On-bill financing (OBF) involves energy bill-payer or public funds, whilst on-bill repayment (OBR) refers to the use of third party, private capital (Zimring, 2014b). In the USA, UK and Canada over 20 on-bill programmes have provided over \$1.05Bn of financing to households for EE improvements, delivering \$76 m in 2014 alone (Zimring et al., 2014a).

The UK's Green Deal is probably the most well-known example of OBR and included requirements for *energy bill neutrality* as part of its 'Golden rule', meaning savings had to be equal to or greater than loan repayments. The Green Deal also precluded non-energy measures from financing (7–11% interest rate). The scheme had very limited uptake. Of the 614,383 assessments undertaken, only 15,138 households adopted a Green Deal plan by October 2015 (DECC, 2015), far less than the millions of installations that were hoped for (Rosenow and Eyre, 2016). However, in many cases these assessments may have led to self-financing (Webber et al., 2015).

A range of other on-bill programmes in North America have been more successful. Manitoba Hydro's public OBF scheme has funded almost \$300 m in efficiency improvements in single-family residences since 2001, although 95% of the loans have funded single-measure window, door or furnace replacements (Zimring et al., 2014a). Some smaller scale programmes, such as Clean Energy Works Oregon (CEWO) OBR private finance, have funded whole-house retrofits with loans of up-to \$30,000 (Zimring et al., 2014b). Several of these programmes offer reduced interest rates (0–5%) through public funds and credit enhancements, and have very low rates of default (0–3%) (Zimring et al., 2014a).

5.3. Property assessed clean energy (PACE)

PACE was developed in 2007 and allows municipalities in the USA to fund home and commercial retrofit using land-secured special improvement districts (Kim et al., 2012). These are debt instruments linked to a specific geographical area and secured by land or property. Traditionally they are a means of funding municipal infrastructure investments, through an additional charge on the property tax bill, common in the USA. The assessment districts were devised by Benjamin Franklin in the 17th century as a means to fund improvements that meet a 'valid public purpose'. (Energy Pro). Originally in PACE, local governments funded retrofit measures and attached a tax lien¹⁰ (a form of security that allows claims on tax payments) to properties that benefit from the improvement works. Most PACE funding now comes

from the private sector, although still uses the bond issuance and tax collection powers of municipal or local governments (Kim et al., 2012). The PACE financing is secured as a senior lien on the property and is repayed along with other municipal charges and assessments, on the property tax bill - which provides investors with robust repayment security¹¹ (DOE, 2016).

Most residential PACE projects have been concentrated in California, with private providers such as RENEW Financial securitising PACE debt for re-sale to capital markets (RENEW Financial). Residential PACE financing has risen dramatically in recent years, facilitating more than \$4 billion in clean energy investments (Leventis et al., 2017), with RENEW Financial achieving an average 28–27% reduction in home energy use on their projects (RENEW Financial). There is currently no national or state requirement for energy bill neutrality within PACE schemes.

5.4. Green mortgages

Mortgage or home equity financing provides the mainstay of extension and renovation funding to existing homes, usually through a mortgage-extension or re-mortgage. Loans are secured to the property and typically have a duration of 25 years or more. However, some mortgage providers offer a range of Green or EE mortgage products designed to provide lending specifically for retrofit.

Mortgage underwriting is based on the applicant's ability to repay. Whilst a significant proportion of outgoings relate to energy costs, current underwriting methods use arbitrary techniques to determine these costs. Initiatives including the UK LENDERS (2017) and EU EeMap (2017) projects are seeking to promote actual energy usage data in these underwriting calculations. Thus, lenders may provide increased lending for more efficient properties at reduced interest rates—as the higher disposable income reduces the risk of default (EeMap, 2017). The LENDERS project estimates that monthly savings equivalent to two Energy Performance Certificate (EPC)¹² bands, could equate to around £4000 in additional mortgage finance (LENDERS, 2017). Eventually this may create a modest 'green premium', increasing property values for the most efficient properties (EeMap, 2017), also providing additional borrowing for retrofit measures.

Whilst mainstream European mortgage lenders are yet to offer EE mortgage products, some specialist lenders such as the UK's Ecology Building Society offer both additional lending for retrofit projects and also interest rate discounts of 0.25% for each EPC improvement level (Ecology Building Society, 2017). In the USA, the Fannie Mae mortgage company's Green financing for multi-family buildings reached \$3.6 billion in 2016, involving preferential interest rates and additional borrowing for energy and water efficiency property improvements (Leventis et al., 2017). The UK government is now looking to promote 'innovative green mortgage products' as part of its Clean Growth Plan (HM Government, 2017).

5.5. Energy service agreement (ESA) financing

Energy service agreements (ESAs) are a form of financing to fund energy performance contracts. In a traditional energy performance contract,¹³ the ESCO implements a retrofit and provides an energy

⁹ A loan loss reserve or guarantee sets aside a limited pool of funds from which financial institutions can recover a portion of their losses in the event of borrower defaults. Several examples exist in the US including the MichiganSaves single family loan loss reserve scheme (Zimring, 2014a).

¹⁰ A lien is a legal right granted by the owner of property to a creditor to claim rights to or seize an asset that is the subject of the lien. The lien guarantees the underlying obligation to repay the creditor, such as claims against residential property for repayment of a loan.

¹¹ "Subject to the structure of a state's PACE statute...the PACE obligation may result in a property tax lien on the property. If applicable...the failure to pay property taxes, including PACE assessments, could trigger foreclosure and property loss even if the property owner is current on other mortgage lien(s)" (DOE, 2016).

¹² EPCs are a measure of a buildings energy efficiency and running costs, based on a standardised assessment procedure. Most EU member states employ some form of EPC and they are typically rated from A to G, with A being an exemplary dwelling.

¹³ In an energy performance contract without a financing package from the ESCO, the client will need to find other forms of capital to fund the retrofit.

performance guarantee and a commitment to maintain the assets under the contract for a given period. Energy performance contracts have been most common in the public sector, where public actors can access cheap capital and, thus, ESCOs typically provide engineering services without any financial component (Nolden and Sorrell, 2016). Recently energy performance contract and ESCO models have been growing in the small commercial and residential sectors (Labanca et al., 2014). Under an ESA, a finance provider will arrange financing directly with the ESCO or SPV (typically 7–10% interest), with the end user or household paying for measured performance improvements - usually derived from a baseline of past consumption (Kim et al., 2012). This effectively shifts the financing upstream from the household to provide an integrated offer of finance and measures through an energy service charge. In some models the ESCO will initially use its own funds and then sell on the cash flows or ‘receivables’ of proven projects to a third-party financier in a process known as ‘factoring’¹⁴ (EEFIG, 2015). In a pure ESA, the third-party financier will fund projects from the beginning, usually via an SPV, where projects are aggregated and sold into secondary markets to institutional investors (SUSI Partners, 2017).

Although in 2014, over \$150 m of USA ESCO revenues were generated through projects in public housing, most this was funded using working capital from the housing provider rather than an ESA structure. However, since 2011 PosiGen have offered an ESA for residential solar and EE and completed 8400 projects in the USA (Leventis et al., 2017). The model has also been gaining traction in Europe in the multi-family sector. RENESCO provide an ESA for the deep retrofit and renovation of dilapidated eastern European housing, while Servizi Energia Ambiente (SEA) offers ESAs and energy performance contracts to the Italian multi-family market. RENESCO have invested over €4 m in 15 Soviet-era blocks and are developing a factoring fund with the European Bank for Reconstruction and Development (EBRD) (RENESCO 2015). SEA are currently negotiating to refinance several projects, with financing partners (SUSI Partners, 2017). Several large investment funds are now beginning to become involved in the ESA market, including the UK’s Green Investment Group (2017).

5.6. Community financing

Community financing mechanisms use equity capital from multiple individuals, each providing a small component of funding for a project. Often this involves groups organised around a local geographical area, adopting ‘co-operative type’ legal structures. Typically the number of shares (and votes) an individual can hold is limited (Yildiz, 2014). Projects are funded through a share issue. However, often these shares cannot be easily sold on, requiring long term commitment from project investors, who may value wider community benefits (Yildiz, 2014).

Community finance mechanisms are common for renewable energy, where in Germany, over 500 energy co-operatives with 80,000+ members have invested up to €800 million in solar PV (EEFIG, 2015). Yet, there are a growing number of examples of this being used to fund residential EE projects. The Brighton and Hove Energy Services Co-op (BHESCO) in the UK use a co-operative approach and a low-cost financing offer (5%) to fund retrofits, based on issuing shares to the local community with an annual return of 5% (BHESCO). A number of examples also exist in Germany (EEFIG, 2015).

(footnote continued)

Therefore, this model is not considered a standalone finance mechanism and is not included in the study.

¹⁴ Invoice Factoring involves the sale of project accounts and revenues (receivables) to a third party at a discount. This allows the issuing company to shift these projects with corresponding debt and future cash flows off their balance sheet - enabling them to deleverage and take on additional projects.

6. Key features of retrofit finance mechanisms

The following section outlines the key findings from both sets of stakeholder interviews in relation to the *features* of these finance mechanisms as outlined in Section 3. The discussion draws upon insights from each of the *archetypes* of finance mechanisms described in the previous section, with the aim of identifying some more generalizable findings. A summary of relevant interview quotes for each feature of is provided in Table A2 in the Appendix.

6.1. Source of capital

Two interviewees felt that government should be the primary source of capital for residential retrofit. It was argued that the multiple social and environmental benefits of retrofits are ‘public goods’, justifying state financing. Equally, government bodies typically have the lowest cost of borrowing and are able to offer the longest term, lowest interest loans to the widest range of customers. It was emphasised that governments already absorbed significant risk in other areas, providing credit guarantees and low-cost loans for a range of sectors from infrastructure to first time house purchases.

However, most interviewees (eleven out of eighteen) considered that the required investment (~ \$1.3 trillion to 2035 in the EU (EEFIG, 2015)) could not be met from public sources alone. Indeed, whilst many small publicly funded programmes utilised day-to-day government spending, (such as the HES and HEEPS loans in Scotland), scaling this up could be a challenge. Therefore, many stressed the need to bring in low-cost institutional capital.¹⁵ The only scheme to have achieved this at significant scale has been PACE in California, with ESA models being better developed in the commercial sector. Crucial to accessing these sources of capital is project standardisation and the use of aggregation or securitisation techniques discussed in the following sections.

Aside from PACE, leveraging significant private capital for residential retrofit has involved public co-financing and credit enhancement approaches. Programmes such as LEEF/MEEF and some on-bill schemes in the USA use public money to reduce risk for private investors. Through provision of the ‘at risk’ or junior tranche of a fund or project finance structure, these approaches are able to leverage significant sums of private capital and achieve high ratios of private to public investment.

Germany’s CBRP programme is able to overcome the constraints on day-to-day public spending through the use of the borrowing powers of the KfW state bank. Thus, the programme is able to access large amounts of low-cost funding via the capital markets. However, five interviewees described how this approach owes a lot to the specific institutional context in Germany and similar approaches would require significant institutional change in countries such as the USA or UK, where no equivalent banks exist.

6.2. Financial instruments and secondary markets

Most of those interviewed agreed that the long term, low yield nature of retrofit investments lends itself to debt financing. However, BHESCO co-operative emphasised that community equity finance mechanisms could also play an important role in empowering citizens to engage in retrofit at a local level. Community shareholders may also accept lower returns in exchange for local community and environmental benefits.

EnergyPro in particular emphasised that accessing institutional investor capital is likely to require aggregated financial instruments, such

¹⁵ Institutional investors are a class of investor who trade in securities of sufficient scale and quantity that they qualify for preferential treatment and lower commissions. Typical institutional investors include pension funds and life insurance companies.

as bonds enabling small loans to be pooled and traded in capital markets. Unlike central governments, state banks such as KfW are less constrained by national fiscal policy and deficit reduction as they are able to issue bonds directly into capital markets (Schröder et al., 2011). Equally EE mortgages can utilise the well-established ‘covered bonds’¹⁶ markets, which are used for trading mortgage securities (European Mortgage Federation). Private sector PACE programmes in the USA, have successfully aggregated multiple retrofit loans through securitisation and sold them as PACE bonds into the asset-backed securities market (RENEW Financial).

Achieving sufficient *scale* was described by six respondents as the key challenge in accessing these secondary markets. Most institutional investors require minimum investments of at least £2m. Several examples of the ESA/energy performance contract approach have successfully sold on project receivables, often by aggregating several projects once the revenue streams or cash flows had been proven. Therefore, ESA models are an attractive means of bringing in institutional investors, although these models have so far only been used for the non-residential and multi-family markets. To appeal to institutional investors, achieving standardised projects, that can be aggregated and securitised was identified as a key challenge by both Energy Pro and the European Mortgage Federation. Ensuring and demonstrating project quality is therefore important for reassuring both investors and households, mitigating the issues associated with the securitisations of sub-prime mortgages during the 2008 financial crisis.

6.3. Project performance

Long-term performance contracts as part of ESA financing structures provide a clear revenue stream that can appeal to investors in a similar way to power purchase agreements for renewable generation. Whilst it was recognised that energy performance guarantees could also be a key driver for households, Joule Assets Europe emphasised, this alone would not be sufficient to reassure private investors. Therefore, standardised procurement and quality assurance frameworks, such as the [Investor Confidence Project \(2015\)](#) for commercial buildings, were seen as important for attracting finance into residential retrofit.

However, requirements for energy bill neutrality such as the Green Deal’s ‘Golden Rule’ was criticised by several interviewees. Such requirements prevent non-energy measures from being funded and obstruct deeper retrofits, particularly at high interest rates (Fig. 2). For example, measures such as solid wall insulation could not be funded under the Green Deal. Restricting the focus to carbon and energy savings was also seen as a major constraint on household demand. Since customers value funding for general renovation work and aesthetic improvements, restricting funding to efficiency measures alone limits the appeal of the finance package. Mechanisms, such as the CBRP and the HEEPS equity loan and PACE to a lesser extent, allow for wider renovation measures to be funded. These schemes also do not impose strict requirements for energy bill neutrality. However, it was noted that this needs to be balanced against affordability concerns for repayments significantly above current energy bills.

6.4. Point of sale

The point of sale for finance, and the ease and availability of procuring financing alongside the retrofit was viewed as critical by all interviewees. The analogy of the purchase of a car or mobile phone was used by several interviewees. In these mature sectors, suppliers provide a financing package as part of their offer to customers, whereas many retrofit programmes, require a separate interface, involving a long and

complex application process. This is also usually separated from the process of actually procuring the retrofit measures.

The complexity of schemes such as the Green Deal, with a separate point of sale, is considered to be a major barrier. The success of PACE is partly attributed to the fact that approved contractors can offer financing through the scheme at the point of sale of the retrofit. This means that customers are able to procure the retrofit measures and financing on the same day and from the same person. This simplicity can dramatically increase uptake, although it requires a streamlined underwriting and approval process from the PACE loan provider, usually initially over the telephone. However, challenges remain with contractors’ lack of literacy in financing, and financiers’ lack of literacy in energy efficiency. Equally, Energy Programmes Consortium (USA) emphasised that whilst USA contractors are able to promote certain financing packages, UK contractors must be accredited with the Financial Conduct Authority before they can provide such advice. Similar arrangements exist in other EU countries. These findings highlight the importance of the presentation of the finance offering to prospective households, the levels of trust in the finance provider and quality of information provided.

6.5. Security and underwriting

Different mechanisms require different forms of security and underwriting processes, whilst most public mechanisms are unsecured. Although there are some examples of private unsecured lending, this typically involves a high cost of capital for what is perceived as a high-risk loan without collateral. Both PACE and on-bill approaches involve novel forms of security, tied to the property tax regime and energy bills respectively. Theoretically this leads to streamlined underwriting and draws in people with lower credit ratings – as the debt is secured to the underlying asset, rather than the individual. However, this is not always the case, with one interviewee describing how it could take up to 60 days to get a Green Deal loan. Rapid underwriting and unconventional security can also raise concerns about the appropriateness of offering finance to vulnerable households who would otherwise not qualify for credit. EE mortgage models also require the inclusion of EPCs as part of the underwriting, although is unlikely to add a significant burden on already extensive mortgage eligibility assessments.

Thus, private sector funded mechanisms are likely to require a robust form of security or collateral in order to provide lending at lower interest rates (< 10%). Publicly funded approaches offer greater flexibility on both underwriting and repayment terms so could therefore provide a good option for those in rented accommodation, on low incomes, with a poor credit history, or some combination thereof.

6.6. Repayment channel

The use of an existing repayment channel was viewed as a key benefit of the PACE, on-bill and mortgage-based approaches. Thus, adopting an existing bill that customers are unable to partially pay or refuse to pay the retrofit component of.

Both PACE and on-bill approaches are theoretically transferable to the new occupier of a property, addressing the split incentive issue – although currently PACE finance is only available to homeowners. Equally, mortgage or equity-release approaches such as HEEPS in Scotland, see the remaining debt resolved once the property is sold, through the equity share. Therefore, finance for measures that add value to the property strengthens the case for using mortgage-based financing. However, case studies from the USA have shown that the debt from PACE and On-bill schemes is transferred to the new occupant only about 50% of the time, thus requiring the outstanding payment on sale (Leventis et al., 2017). Further, both Energy Pro and PACE Nation highlighted how the PACE approach would be particularly challenging for the UK given its different system of property taxation and municipal finance.

¹⁶ Covered bonds are backed both by the issuer – usually a bank and the portfolio of projects – typically mortgages. Unlike asset backed securities they remain on the balance sheet of the issuer and are thus considered very secure.

7. Discussion

This paper introduced a typology of six financing mechanisms currently adopted for residential retrofit across the EU and USA. Developing a novel framework, the paper has further identified six key features of these mechanisms and shown how these contribute to the success or failure of the mechanism. The following section discusses the findings in the context of the literature on residential retrofit and EE finance. It is shown how the six features influence three outcomes that are critical for the successful uptake of residential retrofit: *cost of capital*, *source of value* and *customer journey*. The paper then discusses how the institutional and policy context of different states is likely to shape the viability of these approaches and the policy solutions required.

7.1. Cost of capital

The stakeholder interviews explored the significance of the cost of capital for the financing of residential retrofit projects, particular for more expensive, ‘whole house’ approaches. The impact of the interest rate on household appeal has previously been highlighted by several studies on retrofit finance (Marchand et al., 2015; Rosenow and Eyre, 2016). Typically, deeper retrofits require capital expenditure of at least £15–20,000 (BEIS, 2017) and have payback periods of 20 years or more. Thus, in combination with requirements for energy bill neutrality, higher interest rates may prevent deeper (but ultimately necessary) measures like solid wall insulation from being financed. Although those with sufficient access to capital, or other forms of household borrowing may continue to self-finance retrofits (Webber et al., 2015), a lack of access to low cost finance remains a key barrier the uptake of residential retrofit. These higher costs may be offset by private benefits such as higher house prices (Brounen and Kok, 2011). However, the findings presented here suggest the customer journey and source of value have a greater impact on household appeal.

The results support the view that the state's ability to borrow cheaply, absorb risks and deliver social and environmental benefits, provides a strong justification for public funding of investments such as residential retrofit (Stiglitz, 1993). However, given the scale of investment required, the extent to which day-to-day government spending alone can deliver this may be limited (Blyth et al., 2015). Therefore, countries such as Germany have funded large scale investment through public banks, offering very low interest rates and favourable loan terms. This builds on previous research on the market-creating and shaping role that state investment banks can play (Mazzucato and Penna, 2016), particularly where such investments are seen as high risk by private finance (Mazzucato and Semieniuk, 2018).

However, in countries without state investment banks, more ‘market led’ solutions are often favoured (Hall et al., 2016). This paper has described several examples of using public money to leverage significant private finance and reduce the cost of capital through tools such as credit enhancements (see Zimring, 2014a). These approaches can also bring in customers who would otherwise not qualify for credit (Zimring et al., 2014c). Whilst this may leverage limited public funds and reduce the cost of capital, some argue that this represents a public subsidy to private capital (Bergman and Foxon, 2017) or a socialisation of risk and a privatisation of rewards (Mazzucato, 2011). However, some form of public support is likely to be required for those with difficulty in accessing low-cost capital or in rented accommodation and fuel poverty (Sovacool, 2015).

Privately funded mechanisms are likely to require robust forms of security or collateral such as mortgage eligibility and repossession (EE Mortgages), property tax default (PACE) and energy disconnection (On-bill). These findings support work such as Blyth et al. (2015) and Hall et al. (2015) on the potential role of institutional investors, such as pension funds in the energy system. Securitisation enables small loans to be pooled and sold through financial instruments such as PACE bonds in capital markets. However, this requires sufficient scale and

standardised project performance protocols currently only widespread in the PACE market and ESA's in the non-residential sector. Therefore, widespread institutional financing of EE retrofit remains largely aspirational at present (Hall et al., 2015).

7.2. Customer journey

In interpreting the findings, this paper draws on the concept of the *customer journey* (Norton et al., 2013). Whilst the previous section largely concerned with how the features of finance mechanisms affect their appeal to investors, this research suggests the nature of customer journey has a greater impact on household appeal.

A key finding is that the success of schemes such as PACE and KfW's CBRP owe a lot to the ease of the customer journey in procuring retrofit financing. PACE loans are often sold by the contractor, at the point of sale of the retrofit. The streamlined underwriting of PACE programmes has enabled loans to be approved over the telephone, during the contractor's sales visit. Equally EE mortgages utilise a well-established process, which is usually essential when purchasing a property, whilst the KfW approach uses the customers' existing bank and support from accredited project managers. This simplicity is often valued ahead of a low cost of capital by households – helping to explain why expensive credit card retrofit financing remains prevalent (Zimring et al., 2014a).

These findings support previous critiques of the UK's Green Deal which involved a complex vetting and application process, requiring a separate interface with a third-party provider (O'Keeffe et al., 2016; Rosenow and Eyre, 2016). This complexity may be further compounded when additional policy measures interact with retrofit programmes, such as the smart meter rollout (McCoy and Lyons, 2017) reducing household uptake. This supports arguments for *integrated business models* for residential retrofit (Brown, 2018), including a financing offer to households alongside retrofit measures (Mahapatra et al., 2013). In an ESA, financing is fully integrated into the energy performance contract, effectively upstream of the client (Brown, 2018).

An important dimension of the customer journey relates to how the information is presented to households and by whom. This research identifies the point of sale as the critical juncture in the customer journey in which to promote both the retrofit measures and the financing package in a clear and compelling way to households. This supports previous research which identifies the significance of how costs and benefits of retrofit are presented to households (Hoicka et al., 2014) and the importance of a trusted and competent advisor in disseminating this information (O'Keeffe et al., 2016; Risholt and Berker, 2013). Our findings therefore suggest that schemes are most successful, when the technical and financial elements of the customer offering are integrated by a single competent advisor – as is the case in the German KfW scheme (Rosenow et al., 2013a).

Adopting a repayment channel, and form of security that is tied to the underlying asset, theoretically enables PACE, on-bill and Green mortgage/equity release approaches to address split incentive barriers (Bird and Hernández, 2012). However, only on-bill mechanisms address the landlord-tenant dilemma. Yet, in many examples from the USA this has not been the case. Outstanding debt on properties with PACE or on-bill loans may need to be settled when homes change hands (Zimring et al., 2014a), although can be partially offset by increased property values (Sayce and Haggett, 2016). The latter, in turn, requires credible labelling schemes to allow the energy efficiency properties to be identified by potential buyers, together with more widespread appreciation of the benefits of energy efficiency for mortgage repayments.

7.3. Source of value

The study demonstrates how successful retrofit finance mechanisms typically involve funding for wider renovation and enabling works as part of the finance package. This builds on contemporary research on residential retrofit, where broader motivations such as environmental

concerns, improved comfort and living standards, property longevity and aesthetics are often valued more highly than cost savings (Fawcett and Killip, 2014), or at least act as important drivers for retrofit projects (Kivimaa and Martiskainen, 2018). Thus, in many cases, financing provides a means of ‘addressing a problem’, such as a broken boiler or low levels of thermal comfort. Whilst the desire to save money is often a driver (Marchand et al., 2015), households may be willing to spend more to finance these broader sources of value.

Consequently, mechanisms that have requirements for energy bill neutrality, or only fund energy measures are likely to undermine these motivations. Many of those interviewed regarded the ‘Golden Rule’ element of the Green Deal as a mistake and pointed out that no such requirements are in place for other forms of consumer finance. Equally the narrow focus on energy measures alone, may leave a finance gap for important enabling works. However, there is a need to balance these issues with concerns over affordability (Leventis et al., 2017). Other forms of project performance guarantees such as energy performance contracts, or warranties are however, likely to be valued by both households and finance providers. This supports recent work on the potential for energy performance contracts to be a demand driver for residential retrofit (Brown, 2018; Winther and Gurigard, 2017).

Critically, all those interviewed agreed that barriers for retrofit financing were of secondary importance for driving demand for residential retrofit. Indeed Borgeson et al. (2014) describe: ‘*lack of financing is seldom the primary reason that efficiency projects do not happen.*’ Thus, financing should be seen as an *enabler* rather than a driver of demand, with the analogy that in the Green Deal ‘*people were sold the loan instead of the car*’ (Rosenow and Eyre, 2016).

8. Conclusions and policy implications

This paper presented a typology of finance mechanisms for residential retrofit, including examples that are delivering at scale. The paper develops a novel framework to understand the features of these mechanisms, including; the *source of capital*; *financial instrument(s)*, *project performance*; *point of sale*; *security and underwriting* and the *re-payment channel*.

These features are shown to implicate three outcomes that affect the success of these finance mechanisms. Firstly, it is shown that a low *cost of capital* is key to the current economic viability of whole-house retrofits, such as those involving solid wall insulation. This can be achieved through public finance through state investment banks, municipal authorities or the blending of public and private sources through a range of credit enhancements. Alternatively, low cost private financing is likely to require robust forms of security, standardised project performance protocols and access to secondary markets through the aggregation of multiple projects into trade-able financial instruments. Secondly, and perhaps more significantly, mechanisms that reduce complexity by simplifying the *customer journey* are likely to achieve much higher levels of uptake. Thirdly, by enabling non-energy measures such as general improvement works, schemes can appeal to broader *sources of value* that are more highly valued by households, often ‘addressing a problem’, such as broken boiler or low levels of comfort.

Most importantly, the paper outlines how the finance mechanism alone is unlikely to be a driver of demand for whole-house retrofit, and so instead should be viewed as a necessary *enabler* of a much broader strategy. Thus, integrated business models that enable the wider benefits of whole-house retrofits, alongside a range of up-front incentives and minimum standards are likely to be pre-requisites of a successful, ambitious retrofit programme. Consequently, a review of different retrofit incentives and investigation of how policy can support business model innovation, seem important avenues for further research.

This paper has emphasised the scale and importance of financing the low carbon retrofit of residential buildings. Different countries and regions may adopt different approaches based on their specific

institutional context, with different approaches serving certain market segments. However, this goal is unlikely to be achieved without a broad strategy to promote demand and build supply chain capacity – only then requiring appropriate financing solutions. This paper presents a template of how this can be done effectively and provides lessons from where it has not.

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Conflict of interest statement

The authors declare that they have no conflict of interest.

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.enpol.2018.12.033.

References

- Aravena, C., Riquelme, A., Denny, E., Denny, E., 2016. Money, comfort or environment? Priorities and determinants of energy efficiency investments in Irish households. *J. Consum. Policy* 39, 159–186. <https://doi.org/10.1007/s10603-016-9311-2>.
- BEIS, 2017. Energy Consumption in the UK. Department for Business, Energy and Industrial Strategy.
- Bergman, N., Foxon, T.J., 2017. Reorienting finance towards energy efficiency in the UK. In: *eccee 2017 Summer Study Proceedings*, 1–11.
- Bird, S., Hernández, D., 2012. Policy options for the split incentive: increasing energy efficiency for low-income renters. *Energy Policy* 48, 506–514. <https://doi.org/10.1016/j.enpol.2012.05.053>.
- Blyth, W.W., McCarthy, R., Gross, R., 2015. Financing the UK power sector: is the money available? *Energy Policy* 87, 607–622. <https://doi.org/10.1016/j.enpol.2015.08.028>.
- Bolton, R., Foxon, T.J., 2015. A socio-technical perspective on low carbon investment challenges – insights for UK energy policy. *Environ. Innov. Soc. Transit.* 14, 165–181. <https://doi.org/10.1016/j.eist.2014.07.005>.
- Bonfield, P., 2016. Each Home Counts – An Independent Review of Consumer Advice, Protection, Standards and Enforcement for Energy Efficiency and Renewable Energy. Department for Business, Energy and Industrial Strategy (BEIS) and Department for Communities and Local Government (DCLG), Watford, UK.
- Borgeson, M., Todd, A., Goldman, C., 2013. Getting the Biggest Bang for the Buck Exploring the Rationales and Design Options for Energy Efficiency Financing Programs.
- Borgeson, M., Zimring, M., Goldman, C., 2014. The Limits of Financing for Energy Efficiency.
- Brounen, D., Kok, N., 2011. On the economics of energy labels in the housing market. *J. Real Estate Finance* 32, 1–15. <https://doi.org/10.1016/j.jreem.2010.11.006>.
- Brown, D., 2018. Business models for residential retrofit in the UK: a critical assessment of five key archetypes. *Energy Effic.* <https://doi.org/10.1007/s12053-018-9629-5>.
- Buchner, B.K., Trabacchi, C., Mazza, F., Abramskiehn, D., Wang, D., 2015a. A Closer Look at the Landscape 2015 Methodology. Climate Policy Initiative, Venice, Italy.
- Buchner, B.K., Trabacchi, C., Mazza, F., Abramskiehn, D., Wang, D., Frenk, C.A., Atteridge, A., Barnard, S., Banton, G., Bird, N., Christianson, G., Clifford, H., Cochran, I., Cronenberg, C., Cummings, M., Cruz, R., Dela, Ellis, J., Ferreira, E., Gjonaj, M., Hainaut, H., Haites, E., Ishii, Y., Jachnik, R., Javier, E., Kawamura, M., Kerres, M., Lauridsen, R., Martins, G., Uwell, D.M., Mills, L., Ruffing, M., Saich, N., Sato, I., Schneider, H., Spannenberg, S., 2015b. Global Landscape of Climate Finance 2015. CCC, 2018. Reducing UK Emissions – 2018 Progress Report to Parliament.
- CCC, 2013. Committee on Climate Change. Fourth Carbon Budget Review – Part 2.
- Collins, M., Dempsey, S., Curtis, J., 2018. Householder preferences for the design of an energy efficiency retrofit subsidy in Ireland. *Econ. Soc. Rev.* 49, 145–172.
- Curl, A., Kearns, A., Mason, P., 2015. Physical and mental health outcomes following housing improvements: evidence from the GoWell study. *J. Epidemiol. Community Heal.* 69, 12–19. <https://doi.org/10.1136/jech-2014-204064>.
- DECC, 2015. Domestic Green Deal and Energy Company Obligation in Great Britain, Headline Report.

- DECC, 2013. Fuel Poverty: A Framework for Future Action.
- Diaz-Rainey, I., Robertson, B., Wilson, C., 2017. Stranded research? Leading finance journals are silent on climate change. *Clim. Change* 143, 243–260.
- DOE, 2016. Best Practice Guidelines for Residential PACE Financing Programs. DOE, Washington DC, USA.
- Donovan, C., Corbishley, C., 2016. The cost of capital and how it affects climate change mitigation investment. Grantham Inst. Brief. Pap.
- EC, 2018. Directive (EU) 2018/ of the European Parliament and of the Council of 30 May 2018 amending directive 2010/31/EU on the energy performance of buildings and directive 2012/27/EU on energy efficiency. Off. J. Eur. Union.
- EC, 2014. A Policy Framework for Climate and Energy in the Period from 2020 to 2030. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Publication Office of the European Union, Brussels, Belgium. <https://doi.org/10.1017/CBO9781107415324.004>.
- Ecology Building Society, 2017. C-Change Mortgage Discounts | Ecology Building Society [WWW Document]. <https://www.ecology.co.uk/mortgages/c-change-discounts/>, (Accessed 15 June 2017).
- EEFIG, 2015. Energy Efficiency – the first fuel for the EU Economy. <https://doi.org/10.1021/ja982781y>.
- EeMap, 2017. Energy Efficient Mortgages Action Plan (Eemap) Initiative Eemap Energy Efficiency (EE) Financing: Emerging Analysis. Brussels.
- EST, 2017. HEEPS Equity Loan | Energy Saving Trust [WWW Document]. <http://www.energysavingtrust.org.uk/scotland/grants-loans/heeps/heeps-equity-loan-scheme>, (Accessed 21 December 2017).
- EST, 2011. Local Authority Large Scale Retrofit: A Review of Finance Models.
- Fawcett, T., 2014. Exploring the time dimension of low carbon retrofit: owner-occupied housing. *Build. Res. Inf.* 42, 477–488. <https://doi.org/10.1080/09613218.2013.804769>.
- Fawcett, T., Killip, G., 2014. Anatomy of low carbon retrofits: evidence from owner-occupied Superhomes. *Build. Res. Inf.* 42, 434–445. <https://doi.org/10.1080/09613218.2014.893162>.
- Freehling, J., Stickles, B., 2016. Energy Efficiency Finance: A Market Reassessment (An ACEE White Paper).
- Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2015. Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. *Energy Econ.* 48. <https://doi.org/10.1016/j.eneco.2014.12.012>.
- Gillingham, K., Newell, R.G., Palmer, K., 2009. Energy Effic. Econ. Policy. <https://doi.org/10.1146/annurev.resource.102308.124234>.
- Gouldson, A., Kerr, N., Millward-Hopkins, J., Freeman, M.C., Topi, C., Sullivan, R., 2015. Innovative financing models for low carbon transitions: exploring the case for revolving funds for domestic energy efficiency programmes. *Energy Policy* 86, 739–748. <https://doi.org/10.1016/j.enpol.2015.08.012>.
- Green Investment Group, 2017. Energy solutions – making energy work harder. In: SEAF Investor Forum.
- Hall, S., Foxon, T.J., Bolton, R., 2016. Financing the civic energy sector: how financial institutions affect ownership models in Germany and the United Kingdom. *Energy Res. Social Sci.* 12, 5–15. <https://doi.org/10.1016/j.erss.2015.11.004>.
- Hall, S., Foxon, T.J., Bolton, R., 2015. Investing in low-carbon transitions: energy finance as an adaptive market. *Clim. Policy* 3062, 1–19. <https://doi.org/10.1080/14693062.2015.1094731>.
- HM Government, 2017. The Clean Growth Strategy Leading the way to a low carbon future.
- Hoicka, C.E., Parker, P., Andrey, J., 2014. Residential energy efficiency retrofits: how program design affects participation and outcomes. *Energy Policy* 65, 594–607. <https://doi.org/10.1016/J.ENPOL.2013.10.053>.
- IEA, 2017. Market-Based Instruments for Energy Efficiency.
- IEA, 2013. Transition to Sustainable Buildings: Strategies and Opportunities to 2050. OECD, Paris, France. <https://doi.org/10.1787/9789264202955-en>.
- Investor Confidence Project, 2015. Fueling Investment in Energy Efficiency.
- IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Summary for Policymakers and Technical Summary, Climate Change 2014: Mitigation of Climate Change. Part of the Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. <https://doi.org/10.1017/CBO9781107415416.005>.
- Jaffe, A.B., Stavins, R.N., 1994. The energy-efficiency gap What does it mean? *Energy Policy* 22, 804–810. [https://doi.org/10.1016/0301-4215\(94\)90138-4](https://doi.org/10.1016/0301-4215(94)90138-4).
- Kangas, H.-L., Lazarevic, D., Kivimaa, P., 2018. Technical skills, disinterest and non-functional regulation: barriers to building energy efficiency in Finland viewed by energy service companies. *Energy Policy* 114, 63–76. <https://doi.org/10.1016/j.enpol.2017.11.060>.
- Kats, G., Menkin, A., Domm, J., Debold, M., 2011. Energy Efficiency Financing – Models and Strategies. Capital E.
- Kern, F., Kivimaa, P., Martiskainen, M., 2017. Policy packaging or policy patching? The development of complex energy efficiency policy mixes. *Energy Res. Social Sci.* 23, 11–25. <https://doi.org/10.1016/j.erss.2016.11.002>.
- Kerr, N., Gouldson, A., Barrett, J., 2017. The rationale for energy efficiency policy: assessing the recognition of the multiple benefits of energy efficiency retrofit policy. *Energy Policy*. <https://doi.org/10.1016/j.enpol.2017.03.053>.
- Kim, C., O'Connor, R., Bodden, K., 2012. Innovations and Opportunities in Energy Efficiency Finance. Wilson Sonsini Goodrich & Rosati, New York; San Francisco; Washington DC, USA.
- Kivimaa, P., Martiskainen, M., 2018. Innovation, low energy buildings and intermediaries in Europe: systematic case study review. *Energy Effic.* 11, 31–51. <https://doi.org/10.1007/s12053-017-9547-y>.
- Knoeri, C., Steinberger, J.K., Roelich, K., 2016. End-user centred infrastructure operation: towards integrated end-use service delivery. *J. Clean. Prod.* 132, 229–239. <https://doi.org/10.1016/j.jclepro.2015.08.079>.
- Labanca, N., Suierkemper, F., Bertoldi, P., Irrek, W., Duplessis, B., 2014. Energy efficiency services for residential buildings: market situation and existing potentials in the European Union. *J. Clean. Prod.* 109, 284–295. <https://doi.org/10.1016/j.jclepro.2015.02.077>.
- LEEF, 2012. Introduction to the London Energy Efficiency Fund (LEEF).
- LENDERS, 2017. Lenders-Improving energy costs in mortgages – promoting energy efficiency in homes. <https://doi.org/10.1089/obe.2005.1.166>.
- Leventis, G., Kramer, C., Schwartz, L., Zetterberg, J., Ludwig, V., 2017. Energy Efficiency Financing for Low-and Moderate-Income Households: Current State of the Market, Issues, and Opportunities. Financing Solutions Working Group FOR MORE INFORMATION.
- Long, T.B., Young, W., Webber, P., Gouldson, A., Harwatt, H., 2015. The impact of domestic energy efficiency retrofit schemes on householder attitudes and behaviours. *J. Environ. Plan. Manag.* 58, 1853–1876. <https://doi.org/10.1080/09640568.2014.965299>.
- Mahapatra, K., Gustavsson, L., Haavik, T., Aabrekk, S., Svendsen, S., Vanhoutteghem, L., Paiho, S., Ala-Juusela, M., 2013. Business models for full service energy renovation of single-family houses in Nordic countries. *Appl. Energy* 112, 1558–1565. <https://doi.org/10.1016/j.apenergy.2013.01.010>.
- Marchand, R.D., Koh, S.C.L.L., Morris, J.C., 2015. Delivering energy efficiency and carbon reduction schemes in England: lessons from Green Deal Pioneer Places. *Energy Policy* 84, 96–106. <https://doi.org/10.1016/j.enpol.2015.04.035>.
- Mazzucato, M., 2011. The entrepreneurial state. *Soundings* 49, 131–142. <https://doi.org/10.3898/136266211798411183>.
- Mazzucato, M., Penna, C.C.R., 2016. Beyond market failures: the market creating and shaping roles of state investment banks. *J. Econ. Policy Reform* 19, 305–326. <https://doi.org/10.1080/17487870.2016.1216416>.
- Mazzucato, M., Semieniuk, G., 2018. Financing renewable energy: who is financing what and why it matters. *Technol. Forecast. Social Change* 127, 8–22. <https://doi.org/10.1016/j.techfore.2017.05.021>.
- McCoy, D., Lyons, S., 2017. Unintended outcomes of electricity smart-metering: trading-off consumption and investment behaviour. *Energy Effic.* 10, 299–318. <https://doi.org/10.1007/s12053-016-9452-9>.
- Mlecnik, E., Paiho, S., Cré, J., Stenlund, O., Vrijders, J., Haavik, T., Synnove, A., Vanhoutteghem, L., Hansen, S., 2011. Web Platforms Integrating Supply and Demand for Energy Renovations. pp. 1–8.
- Modigliani, F., Miller, M.H., 1958. The cost of capital, corporation finance and the theory of investment. *Am. Econ. Rev.* 48, 261–297. <https://doi.org/10.4013/base.20082.07>.
- Nolden, C., Sorrell, S., 2016. The UK market for energy service contracts in 2014–2015. *Energy Effic.* 1–16. <https://doi.org/10.1007/s12053-016-9430-2>.
- Norton, D.W., Joseph, B., II, P., 2013. Using the customer journey to road test and refine the business model. <https://doi.org/10.1108/10878571311318196>.
- O'Keeffe, J.M., Gilmour, D., Simpson, E., 2016. A network approach to overcoming barriers to market engagement for SMEs in energy efficiency initiatives such as the Green Deal. *Energy Policy* 97, 582–590. <https://doi.org/10.1016/j.enpol.2016.08.006>.
- OECD, 2015. Infrastructure Financing Instruments and Incentives.
- Rezessy, S., Bertoldi, P., 2010. Financing energy efficiency: forging the link between financing and project implementation. *Environ. Plan. A* 41, 1072–1089.
- Risholt, B., Berker, T., 2013. Success for energy efficient renovation of dwellings – learning from private homeowners. *Energy Policy* 61, 1022–1030. <https://doi.org/10.1016/j.enpol.2013.06.011>.
- Rosenow, J., 2012. Energy savings obligations in the UK – a history of change. *Energy Policy* 49, 373–382. <https://doi.org/10.1016/j.enpol.2012.06.052>.
- Rosenow, J., Eyre, N., 2016. A post mortem of the Green Deal: austerity, energy efficiency, and failure in British energy policy. *Energy Res. Social Sci.* 21, 141–144. <https://doi.org/10.1016/j.erss.2016.07.005>.
- Rosenow, J., Eyre, N., Bürger, V., Rohde, C., 2013a. Overcoming the upfront investment barrier: comparing the German CO₂ building rehabilitation programme and the British Green Deal. *Energy Environ.* 24, 83–104. <https://doi.org/10.1260/0958-305X.24.1-2.83>.
- Rosenow, J., Platt, R., Demurtas, A., 2014. Fiscal impacts of energy efficiency programmes – the example of solid wall insulation investment in the UK. *Energy Policy* 74, 610–620. <https://doi.org/10.1016/j.enpol.2014.08.007>.
- Rosenow, J., Platt, R., Flanagan, B., 2013b. Fuel poverty and energy efficiency obligations – a critical assessment of the supplier obligation in the UK. *Energy Policy* 62, 1194–1203. <https://doi.org/10.1016/j.enpol.2013.07.103>.
- Sayce, S., Haggett, F., 2016. Re-Value: Assessing the Value of Energy Efficient Properties in the Residential Sector.
- Schröder, M., Ekins, P., Power, A., Zulauf, M., Lowe, R., 2011. The KfW experience in the reduction of energy use in and CO₂ emissions from buildings: operation, impacts and lessons for the UK. Energy.
- Scottish Government, 2017. Energy Strategy – Scotland's Energy Efficiency Programme (Seep).
- Sorrell, S., 2005. The Contribution of Energy Service Contracting to a Low Carbon Economy to a Low Carbon Economy (Tyndall Cent. Tech. Rep. No. 37). pp. 1–114.
- Sorrell, S., Schleich, J., O'Malley, E., Scott, S., 2004. The Economics of Energy Efficiency: Barriers to Cost-Effective Investment. Books. Edward Elgar, Cheltenham.
- Sovacool, B.K., 2015. Fuel poverty, affordability, and energy justice in England: policy insights from the Warm Front programme. *Energy* 93, 361–371. <https://doi.org/10.1016/j.energy.2015.09.016>.
- Stiglitz, J.E., 1993. The role of the state in financial markets. *World Bank Econ. Rev.* 7, 19–62. <https://doi.org/10.1142/S0219091508001337>.
- Stone, H.B.J., 2014. Market Development Objectives for the Energy Performance

- Contracting Sector in the UK.
- SUSI Partners, 2017. SUSI Energy Efficiency Fund SUSI Energy Efficiency Fund SUSI Energy Efficiency Fund SUSI Addresses the Three Main Pillars of Energy Infrastructure.
- Sweatman, P., 2012. *Financing Mechanisms for Europe's Buildings Renovation: Assessment and Structuring Recommendations for Funding European 2020 Retrofit Targets*. pp. 1–11.
- Sweatman, P., Managan, K., 2010. *Financing Energy Efficiency Building Retrofits International Policy and Business Model Review and Regulatory Alternatives for Spain*. Climate Strategy and Partners. Madrid.
- The Rockefeller Foundation, DB Climate Change Advisors, 2012. *United States Building Energy Efficiency Retrofits Market Sizing and Financing Models*.
- UKGBC, 2014. Green Deal Finance: Examining the Green Deal interest rate as a barrier to take-up 23.
- Walker, G., 2008. What are the barriers and incentives for community-owned means of energy production and use? *Energy Policy* 36, 4401–4405. <https://doi.org/10.1016/J.ENPOL.2008.09.032>.
- Washan, P., Stenning, J., Goodman, M., 2014. *Building the Future: The Economic and Fiscal Impacts of Making Homes Energy Efficient*.
- Webber, P., Gouldson, A., Kerr, N., 2015. The impacts of household retrofit and domestic energy efficiency schemes: a large scale, ex post evaluation. *Energy Policy* 84, 35–43. <https://doi.org/10.1016/j.enpol.2015.04.020>.
- Willand, N., Ridley, I., Maller, C., 2015. Towards explaining the health impacts of residential energy efficiency interventions – a realist review. Part 1: pathways. *Social Sci. Med.* 133, 191–201. <https://doi.org/10.1016/j.socscimed.2015.02.005>.
- Wilson, C., Crane, L., Chrysoschoidis, G., 2015. Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Res. Social Sci.* 7, 12–22. <https://doi.org/10.1016/j.erss.2015.03.002>.
- Winther, T., Gurigard, K., 2017. Energy performance contracting (EPC): a suitable mechanism for achieving energy savings in housing cooperatives? Results from a Norwegian pilot project. *Energy Effic.* 10, 577–596. <https://doi.org/10.1007/s12053-016-9477-0>.
- Yildiz, Ö., 2014. Financing renewable energy infrastructures via financial citizen participation – the case of Germany. *Renew. Energy* 68, 677–685. <https://doi.org/10.1016/j.renene.2014.02.038>.
- Yin, R.K., 1994. *Case Study Research—Design and Methods*. Sage Publications.
- Zimring, M., 2014a. *Credit Enhancement Overview Guide*.
- Zimring, M., 2014b. *Energy Efficiency Financing Program Implementation Primer* [WWW Document]. https://www4.eere.energy.gov/seeaction/system/files/documents/financing_primer_0.pdf, (Accessed 14 November 2017).
- Zimring, M., Leventis, G., Borgeson, M., Thompson, P., Hoffman, I., Goldman, C., 2014a. *Financing Energy Improvements on Utility Bills: Market Updates and Key Program Design Considerations for Policymakers and Administrators*.
- Zimring, M., Leventis, G., Borgeson, M., Thompson, P., Hoffman, I., Goldman, C., 2014b. *Financing Energy Improvements on Utility Bills: Technical Appendix — Case Studies*.
- Zimring, M., Leventis, G., Goldman, C., Borgeson, M., Thompson, P., Hoffman, I., 2014c. *On-Bill Finance: From Policy to Promise to Practice*. 1.



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How can intermediaries promote business model innovation: the case of ‘Energiesprong’ whole-house retrofits in the United Kingdom (UK) and the Netherlands

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Abstract

Business model innovation is increasingly important for the diffusion of sustainable innovations - particularly those that are *systemic* in nature. In this paper we outline how systemic innovations, such as whole-house energy ‘retrofit’, may require new business models before they gain widespread adoption. Through a series of semi-structured interviews and document analysis, we undertake a case study of the ‘Energiesprong’ retrofit business model - contrasting this with the incumbent ‘atomised’ market model. We highlight the central role of an *innovation intermediary* - the Energiesprong ‘market development team’, in this business model innovation, and how Dutch policymakers sought to promote business model innovation through creation of this intermediary. In doing so we develop a novel framework - combining the components of business models with the functions of intermediaries to illustrate this case. Finally, the paper suggests this case and framework could provide lessons for how intermediaries and in turn policymakers might foster business model innovation in other sectors.

Keywords

- Business models
- Energy efficiency retrofit
- Systemic innovation
- Business model innovation
- Intermediaries
- Innovation policy

1. Introduction

The concept of the ‘business model’ has gained widespread use: as a means of classifying different businesses; a lens for academic research; and as an entrepreneurial tool for management practitioners (Baden-Fuller and Morgan, 2010). Increasingly the role of the business model is seen as critical for the diffusion of technological innovations (Baden-Fuller and Haefliger, 2013; Teece, 2010) and for ‘sustainability transitions’ (Bidmon and Knab, 2018; Bolton and Hannon, 2016). This has led to a focus on ‘business model innovation’ as an important area for both incumbent and entrepreneurial firms (Chesbrough, 2010), in promoting sustainability, and in addressing climate change (Boons and Lüdeke-Freund, 2013; Sarasini and Linder, 2018). Thus, the governance of sustainability transitions may require new policies that foster business model innovation (Bolton and Hannon, 2016). However, very little has been written on how policymakers might actually promote business model innovation. We argue that one such approach is the support of innovation intermediaries (Kivimaa, 2014; Mignon and Kanda, 2018).

In this paper, we make three propositions. First, we argue that business model innovation may be particularly important for ‘systemic innovations’ – those which require integration and configuration with other complementary processes, practices and technologies, within a system that spans the boundaries of individual organisations (Midgley and Lindhult, 2015). Second, we build on the literature on innovation intermediaries (Kivimaa and Martiskainen, 2018a; Stewart and Hyysalo, 2008), and highlight the important role that these actors can play in business model innovation. Third, by developing a novel framework we suggest that policymakers can promote business model innovation through intermediaries to facilitate systemic change (Lente and Hekkert, 2003). We illustrate these ideas through the case of the Dutch Energiesprong initiative for whole-house retrofit, addressing the following research questions:

1. How can business model innovation enable the diffusion of systemic innovations such as whole-house retrofit?
2. How did an innovation intermediary promote the Energiesprong business model?
3. How might policymakers promote business model innovation for sustainability through innovation intermediaries?

Buildings, especially homes, are the largest single consumer of energy and producer of carbon emissions in most advanced economies (IPCC, 2014). These emissions can be reduced¹ by the ‘retrofit’ of three types of measure: energy efficiency improvements to the building fabric; the adoption of low carbon heating technologies; and electricity microgeneration such as solar photovoltaics (PV). Thus far, significant savings in the European Union have been achieved through incremental measures such as fluorescent lightbulbs, loft insulation and efficient boilers (Rosenow et al., 2016). These measures have been implemented through existing supply chains, requiring limited changes in consumer and industry practices.

However, it is increasingly recognised that this approach will be insufficient to achieve the savings required to meet climate change targets (CCC, 2018; IPCC, 2014). Instead, emphasis is placed on the need for ‘*whole-house retrofits*’ involving multiple measures (Lewis and Smith, 2013). This involves the effective integration of multiple measures and systems and consideration of how they interact within a specific building - whether installed at once or over time (Fawcett, 2014). Thus, having the features of ‘integrative’ as opposed to ‘modular’ technologies (Sanchez and Mahoney, 1996). Recent research indicates that the diffusion of whole-house retrofit may therefore require business model innovation (Mlecnik et al., 2018) as well as significant policy support (Rosenow et al., 2017).

In this paper, we contrast the incumbent ‘atomised’ market model with the innovative ‘Energiesprong’ business model – considered to have greater potential for the delivery of whole-house retrofit. Drawing on in-depth interviews conducted in the UK and the Netherlands to formulate a case study; we outline how the Energiesprong business model was developed by an *innovation intermediary* or ‘market development team’. Initially created by the Dutch government, although now operating independently internationally. We suggest this

¹ Aside from more efficient appliances and behavioural changes

approach could provide a template for policymakers looking to promote business model innovation in other sectors – requiring further research to other contexts.

This paper is structured as follows. Section 2 reviews the literature on systemic innovation, business models and innovation intermediaries, emphasising the lack of research on policy support for business model innovation, before outlining the conceptual framework. Section 3 summarises our case study methodology. Section 4 describes the operation and potential of the atomised market and Energiesprong business models and assesses the role of the innovation intermediary in the emergence of Energiesprong. Section 5 discusses these findings in light of the existing literature on business model innovation, systemic intermediaries and innovation policy, while Section 6 concludes and provides recommendations for further research.

2. Systemic innovation, business models and innovation intermediaries

2.1. Systemic innovation and whole-house retrofit

The literature on systemic innovation is increasingly the point of departure for scholars grappling with the innovation policy challenges of the 21st century. Systemic innovations require complementary changes in supporting technologies, technical skills, cultural norms, user competences, organisational practices and regulations (Midgley and Lindhult, 2015). Systemic innovation may therefore result in entirely new ‘socio-technical systems’ - where technological, social and institutional elements co-evolve; resulting in whole system change (Foxon, 2011; Midgley and Lindhult, 2015). The importance of systemic innovation and its role in economic and sustainable development is recognised by the Organisation for Economic Co-operation and Development (OECD), who provide the following definition:

“System innovations...alter existing system dynamics...entailing changes in both the components and the architecture of systems. They are characterised by three main features:

- 1) disrupting or complementary types of knowledge and technical capabilities;*
- 2) fundamental changes in consumer practices and markets; and*
- 3) novel types of infrastructures, institutional rules and skill sets.” (OECD, 2015).*

Systemic innovations contrast with incremental innovations; where gradual improvements in current technologies, processes or infrastructures can be easily adopted by incumbent actors, with little change required in underlying processes and practices (Mlecnik, 2013). Many of the sustainability challenges facing policy makers in a range of systems from: food and agriculture (Klerkx and Leeuwis, 2009); healthcare (McMahon and Thorsteinsdóttir, 2013); transport (Nykqvist and Whitmarsh, 2008); buildings (Mlecnik, 2013); and energy provision (Foxon et al., 2005) – require such systemic innovation (OECD, 2015).

Whole-house retrofit is perhaps an archetypal example of a systemic innovation (Mlecnik, 2013) - needing complementary developments in regulations, financing, supply chain

competences and household practices (Wilson et al., 2015), all requiring policy and institutional changes to be fully and effectively realised (Brown et al., 2018).

2.2. Business model innovation and sustainability

Business models² describe of the nature of value delivered to customers, how organisations and networks create value and the means of capturing revenues from that value (Hellström et al., 2015; Teece, 2018). Whilst the innovation studies literature focusses primarily on technological artefacts, there is growing recognition of the integral role of accompanying business models - particularly for radical, path breaking or systemic innovations (Chesbrough, 2010). Although the majority of studies on business model innovation originate from the business and management literature (Massa and Tucci, 2013), the concept is increasingly prevalent in sustainability research (Boons et al., 2013). The importance of sustainable business model innovation is emphasised by Budde Christensen et al., (2012, p. 499):

“it might be that innovative technologies that have the potential to meet key sustainability targets are not easily introduced by existing business models within a sector, and that only by changes to the business model would such technologies become commercially viable.”

Hence, the economic, environmental and social value of innovation often remains latent, until commercialised through a complementary business model (Bohnsack et al., 2014). Radical innovations, which present challenges in capturing revenues, often pose the greatest need for new business models (Teece, 2010). Thus, business model innovation may be a particularly important component of systemic innovation (Boons et al., 2013). Incumbent business models may also be incompatible with long term sustainability and the direction of technological change (Roome and Louche, 2016). Business model innovation therefore presents two key opportunities; first to enable the diffusion of sustainable innovations, and second to reconfigure existing industries towards more sustainable practices (Massa and Tucci, 2013; Schaltegger et al., 2016). Recent studies therefore highlight the potential for integrated retrofit business models (Brown, 2018; Mahapatra et al., 2013; Mlecnik et al., 2018) and energy performance contracts³ in the residential sector (Brown, 2018; Mcelroy and Rosenow, 2018; Winther and Gurigard, 2017).

However, organisations may face a range of barriers to business model innovation (Stubbs and Cocklin, 2008), including the ‘dominant logic’ of a firm or industry (Chesbrough, 2010) and wider cultural and structural barriers which have ‘co-evolved’ with incumbent business models (Bohnsack et al., 2014; Hannon et al., 2013). Organisations may thus lack the necessary knowledge, capabilities or complementary assets to innovate their existing business models, or enter new markets with new business models (Teece, 2018, 2010, 1986). These barriers and benefits may provide a rationale for policy intervention (Jaffe et al., 2005).

Yet, existing literature provides limited insight as to how business model innovation might be governed (Bolton and Hannon, 2016). Innovation intermediaries have been shown to

² A more detailed definition used in this paper is provided in Section 3.

³ Energy performance contracts include guaranteed reductions in energy consumption or costs for the client

overcome barriers to systemic innovation (Lente and Hekkert, 2003) with authors emphasising policies to promote these intermediaries (Kivimaa, 2014). Although some authors have studied intermediation in the retrofit context (Kivimaa and Martiskainen, 2018b) few have linked these ideas to business models.

2.3. Intermediation for business model innovation

In this section we integrate the literature on business models, with that on innovation intermediaries to develop a new conceptual framework. We first outline the detailed components of business models before introducing the literature on innovation intermediaries. Due to the challenges of business model innovation, we argue that innovation intermediaries may be important in the creation and adoption of new business models.

2.3.1. Components of a business model

Following Boons and Lüdeke-Freund (2013), we identify the key components of a business model as the *value proposition*, *supply chain*, *customer interface*, and *financial model*. To this we add the *governance* dimension described by Zott and Amit (2010). This approach captures both the *content* of the business model (Osterwalder and Pigneur, 2010) and its mode of *governance* within organisations and wider networks (Hellström et al., 2015; Zott and Amit, 2010). These components are integrated by Brown (2018) and summarised in Table 1.

Table 1 Key components of a business model (Brown, 2018)

Component	Definition
Value proposition	The <i>value proposition</i> refers to the value or utility from goods and services that an organisation or network provides to the customer (Boons and Lüdeke-Freund, 2013; Engelken et al., 2016).
Supply chain	The <i>supply chain</i> describes the upstream relationships between an organisation and its suppliers (Boons and Lüdeke-Freund, 2013). This comprises the logistical and technical elements that enable delivery of the value proposition (Osterwalder, 2004).
Customer interface	The <i>customer interface</i> covers all downstream, customer-related interactions (Boons and Lüdeke-Freund, 2013). This includes the relationship the customer has with the supplier organisations in terms of marketing, sales and distribution channels and the ongoing relationship with the product or service (Osterwalder and Pigneur, 2010).
Financial model	The <i>financial model</i> constitutes the combination of an organisation's capital and operational expenditures with its means of revenue generation (Osterwalder et al., 2005). This is linked to the value proposition, in terms of what products and services customers pay for and how revenues are collected and distributed.
Governance	Business model <i>governance</i> involves both the co-ordination and management of the other components and the organisational form of the business model (Amit and Zott, 2001; Zott and Amit, 2010). As such, business models may involve a single organisation or a network of interdependent firms that interact to provide a service or product (Hellström et al., 2015). The range of governance approaches lie along a continuum, with integrated, hierarchical firms at one end,

	and arm's-length, market-based contractual relationships at the other (Treib et al., 2007).
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2.3.2. Innovation intermediaries and business models

A range of policy instruments to promote innovation are identified by Edler and Fagerberg (2017). These are grouped into six types; various stages of *research, development and deployment (R&D&D) funding*; policies to develop *capabilities and skills*; policies to promote *interaction and learning across networks*; *procurement policies* to generate demand; *regulations and standards*; and *missions and foresight policies* which envisage future needs and set the direction of change. Recently scholars have emphasised the need for systemic innovation policies, which move beyond a focus on individual instruments and technologies - instead seeking to promote whole system change (Wieczorek and Hekkert, 2012). Kivimaa (2014) therefore emphasises how government affiliated intermediaries may constitute a form of systemic innovation policy (Smits and Kuhlmann, 2004).

Innovation intermediaries have been studied in multiple contexts since the 1990s (Bessant and Rush, 1995), covering a huge array of activities from technology transfer to innovation management and systems of innovation (Howells, 2006). Intermediaries can be characterised by their intermediation functions: for innovation in general (Howells, 2006), or in the context of sustainability transitions (Kivimaa et al., 2018; Mignon and Kanda, 2018). They can be grouped into specific types of actors based on the level and scale in which they operate, their mandate and normative orientation (Kivimaa et al., 2018). These actors may be key bridges or brokers in innovation systems, providing linkages, advocacy or technical services between multiple stakeholders, including suppliers and end-users (Howells, 2006; Hyysalo et al., 2018). Kivimaa et al., (2018) define innovation intermediaries for sustainability as:

“actors and platforms that positively influence sustainability transition processes by linking actors and activities, and their related skills and resources”

Van Lente et al (2003) contrast ‘systemic’ intermediaries, with those that have a more bi-lateral, or single technology focus (Klerkx and Leeuwis, 2009). The actions of these intermediaries may therefore play a crucial role in facilitating the emergence, development and diffusion of systemic innovations (Lente and Hekkert, 2003) - such as whole-house retrofit (Martiskainen and Kivimaa, 2018). In the retrofit context, intermediaries may include local authority agents, charities or NGOs, third sector or individual actors who facilitate projects (Kivimaa and Martiskainen, 2018).

We argue that innovation intermediaries may also play a role in promoting business model innovation. In their seminal work, Stewart and Hyysalo (2008) describe innovation intermediaries having three core roles: *facilitating, configuring and brokering* - which have been extensively applied in subsequent studies (Barnes, 2016; Kivimaa, 2014; Kivimaa et al., 2018). In Table 2 we develop these ideas and apply them to the context of business model innovation.

Table 2 Key functions of an innovation intermediary in business model innovation

Function	Definition
Facilitating	Facilitating enables networking and collaboration as well as knowledge dissemination and learning (Howells, 2006). In the context of business model innovation this involves the support and co-ordination of the networks involved in the delivery of the value proposition (Hellström et al., 2015). Thus, potentially facilitating new approaches to business model governance, towards integrated or more networked arrangements (Treib et al., 2007).
Configuring	Configuration involves the design and modification of technological, social and organisational innovations, to promote their appropriation and adoption among key stakeholders (Howells, 2006). Therefore, this involves the design, modification and testing of new business models with relevant users, suppliers and the wider regulatory environment. This is likely to include developing novel value propositions and financial models (Chesbrough, 2010), such as energy performance contracts (Nolden et al., 2016) but also capabilities in supply chains and the customer interface (Boons and Lüdeke-Freund, 2013).
Brokering	Innovation intermediaries may provide support through negotiation and representation with external sponsors or regulators (Stewart and Hyysalo, 2008). Thus, intermediaries may seek to raise financial or human resources to sustain and develop innovative activity or undertake advocacy or lobbying activities to alter the legal or policy environment (Howells, 2006). Intermediaries may also seek to create demand for the combination of products and services embedded within the business model they are seeking to promote (Klerkx and Leeuwis, 2009), what could be termed 'market formation' (Kivimaa et al., 2018).

Table 3 presents our conceptual framework used for examining the Energisprong case in Section 4. It connects Stewart and Hyysalo's (2008) innovation intermediary roles with business model components (Brown, 2018) highlighting the role they play in business model innovation.

Table 3 Conceptual framework linking innovation intermediation to business model components

	Facilitating – network formation and collaboration	Configuring – business model design	Brokering - advocacy and resource raising
Value proposition	Creating opportunities for new value propositions, by bringing new actors together-supporting and coordinating networks (Hellström et al., 2015).	Configuring the mix of products and services which form the new value proposition (Chesbrough, 2010). Includes testing of alternative value propositions with users, suppliers and regulators.	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new value propositions.
Supply chain	Creating opportunities for new supply chain interactions - developing the relationship between the core firm/businesses and their suppliers, which can be more complex in the case of systemic innovation (Mlecnik, 2013).	Setting rules and contract terms for suppliers, as well as training and capacity building (Mlecnik, 2013).	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new supply chain configurations.
Customer interface	Creating new connections to potential customers, interfacing between customer expectations and new business model designs.	Developing marketing and sales channels as well as new forms of customer engagement – including the use of new media (Brown, 2018).	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new customer interfaces. Creating new markets by influencing regulations or local rules (Martiskainen and Kivimaa, 2017).
Financial model	Creating links to new financial actors to develop new financial models through new sources of capital or revenue streams.	Developing new financial models – often linked to new value propositions, requiring interaction with finance providers and customers.	Advocacy and lobbying to modify regulatory or policy environment to be more favourable to new financial models. Seeking new financial resources such as research and development (R&D) funding or other private sector fundraising activities.
Governance	By facilitating new networks and links between the other business model components this may lead to new modes of governance, towards more integrated or networked arrangements (Treib et al., 2007).	Developing the linkages between different actors involved in business model governance. This may include an active role in organisational management and ‘system building’ activities during the early phases of business model development (Bolton and Hannon, 2016).	Advocacy and lobbying with regulators to overcome potential barriers to business model integration or outsourcing (Howells, 2006; Klerkx & Leeuwis, 2009; Kivimaa, 2014).

The combined business model and intermediation framework is shown in Figure 1 and illustrates how these elements work together to produce business model innovation.

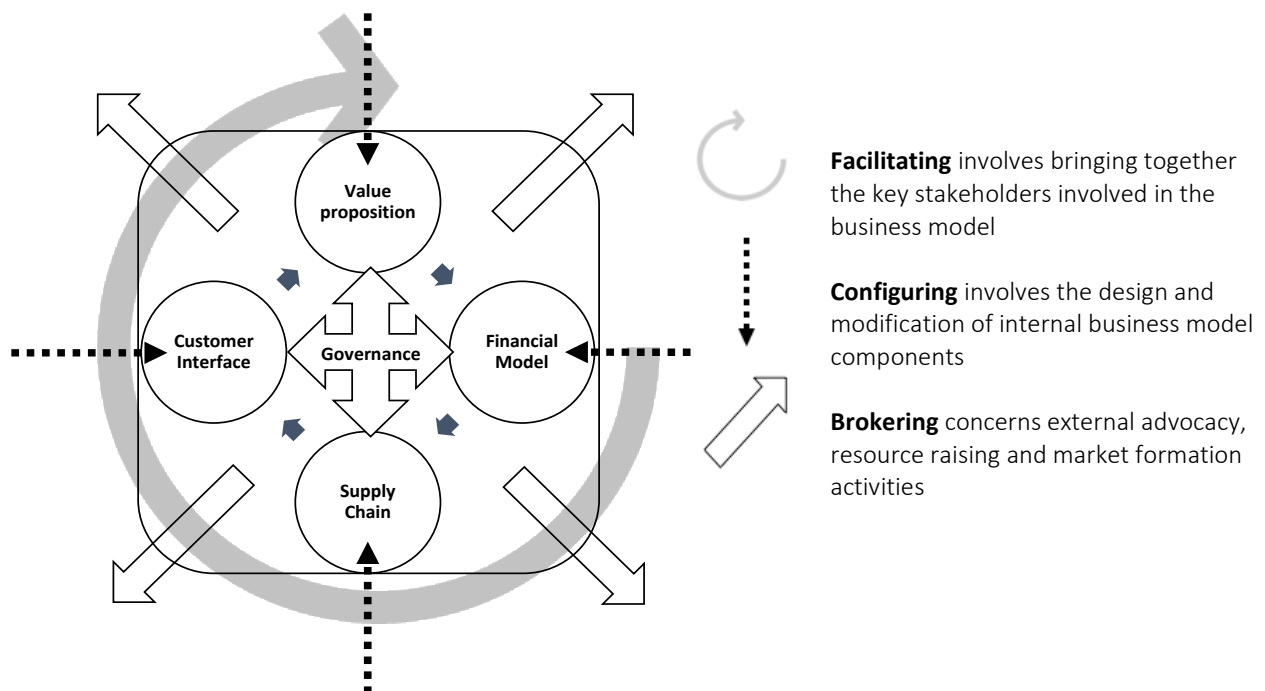


Figure 1 Business model innovation and intermediation framework

3. Methodology

This research involved a qualitative case study of a policy initiative to promote business model innovation for whole-house retrofit; the Energiesprong initiative. We draw on insights and empirical context from two wider research projects focussed on both (1) business models and finance mechanisms for residential retrofit and (2) the role of intermediaries in low energy housing innovation. Each project involved a total of thirty-nine and twenty-nine semi-structured interviews⁴ respectively, conducted between November 2016 and June 2018. This included seven interviews with actors directly involved in the Energiesprong initiative. Other interviews provided background both on the range of business model archetypes and financing mechanisms adopted as well as the nature of intermediation in the sector. A qualitative case study approach was considered appropriate given the need to develop an in-depth understanding of these relatively understudied processes in the retrofit context, to answer ‘how’ or ‘why’ questions (Yin, 1994) that contribute to theory development (Flyvbjerg, 2006). In building this picture, the research was undertaken in three parts.

Part one focussed on the diversity of business models and finance mechanisms adopted for residential retrofit. This initially involved nine scoping interviews with key ‘experts’ in the retrofit space in the UK, EU and USA (see Appendix A, Table A1). These experts were selected on the basis of their technical, academic and policy eminence within the retrofit sector, with further interviewees sourced through snowballing techniques (Yin, 1994). This was

⁴ The interviews were a mix of face to face and video conference calls

supplemented by extensive document analysis and attendance of industry events and seminars. The objective was to develop a typology of business models and finance mechanisms and understand how their design features contributed to their success in different contexts. The scoping interviews were followed by twenty-four interviews with key practitioners across the key business model and finance mechanism archetypes, to develop a rich understanding of their operation and the advantages and disadvantages of each approach. This identified two contrasting business model archetypes, which are explored in detail in this study. The ‘atomised’ market model that has typified the delivery of single residential retrofit measures, and highly innovative net-zero energy performance contracts; with the ‘Energiesprong’ initiative the only known residential example.

Part two provided context on intermediation in the UK low energy housing sector (see (Kivimaa and Martiskainen, 2018b, 2018a; Martiskainen and Kivimaa, 2017)) and provided a background setting for analysis of intermediation in this case study. This included twenty-nine in-depth interviews and a workshop organised with stakeholders in February 2017, in which Energiesprong were a speaker (see Appendix B, Table B1).

Part three involved an in-depth case study⁵ of the Energiesprong initiative. This phase involved six⁶ interviews during spring and summer 2018 with various actors in both the UK and the Netherlands. This included the *client* or housing provider; the construction *industry* partner; supporting *policymakers*, as well as the Energiesprong market development team *intermediary* themselves (see Appendix C, Table C1). The interviews focussed on understanding whole-house retrofit as a systemic innovation; the nature of the Energiesprong business model; the role of the market development team in enabling business model innovation; the policy approach that brought it into being and the ongoing interaction between the intermediary, policymakers and other stakeholders. Again, these interviews were supplemented by document analysis and attendance of relevant industry events and seminars.

Each interview was digitally recorded and transcribed and analysed using the NVivo™ qualitative analysis software. Interviewees were offered options as to the level of disclosure and anonymity (reflected in the appendices). Interview data was coded and analysed based on the framework outlined in Section 2.3.2. This also involved triangulating these findings with public available reports such as Energiesprong (2018, 2017, 2014), to add validity to the claims made in the following sections.

4. Business model incumbency and innovation intermediation in residential retrofit

The following section explores two contrasting business models and the role of an innovation intermediary; based on the framework outlined in Section 2.3.2. This section first outlines the ‘atomised’ market, business model - considered typical retrofit practice. We then introduce the Energiesprong initiative, as a case study of retrofit business model innovation, delivered through a government funded intermediary.

⁵ Phase one provided sufficient detail on the atomised market model

⁶ One Energiesprong interview already took place in phase one

4.1. The 'atomised' market model

The majority of EU low carbon retrofit has involved single measures delivered by separate contractors, without guarantees on energy saving performance. This has typically required multiple points of contact and has tended to be funded by a number of changing subsidy regimes such as energy supplier obligations, tax breaks or feed in tariff type schemes. Although this approach has been fairly successful for incremental single measures (Rosenow and Eyre, 2014); this 'atomised market model' is considered problematic for undertaking whole-house retrofits. Creating issues for project co-ordination, energy performance gaps and unintended consequences such as air quality and damp issues - limiting consumer appeal.

4.1.1. Value proposition

The traditional offer to households has been framed in terms of energy cost savings, rather than home improvement or increasing comfort. This was considered to be a mistake by many of those interviewed:

"For most people ... it's not the economics that's driving them, it really isn't. First and foremost, its comfort, its often aesthetics, what you perceive as aspirational... It's all these subtle things that are more cultural I think." (Academic - Energy Efficiency Policy)

The focus on energy cost savings is especially problematic, given that energy savings are typically based on estimated rather than guaranteed performance:

"to guarantee you performance...that's a different mind-set...and...selling performance is good because it puts a line of blame and accountability, which is what we don't have at the moment" (Director – BRE)

Therefore, the narrow offer of estimated energy cost savings without any guarantees or warranties on the work, severely limits the appeal of a whole-house retrofit. It was also commented that this approach results in poor-quality installations, with limited liability or recourse potential due to the lack of aftercare or performance guarantees.

4.1.2. Supply chain

The typical retrofit supply chain consists of multiple, fragmented installers, suppliers and consultants. It was discussed by several interviewees, that this is largely a reflection of the wider construction industry; typified by specialised subcontractors, each with their own division of labour and industry culture:

"Solid wall insulation it's like an...artisanal, industry...Rather than something which is at industrial scale, and those economies of scale are never going to happen, until you got the whole supply chain working" (Energy Saving Trust)

This supply chain fragmentation, the lack of assured performance, measurement and verification alongside a skills gap were all seen to contribute to low quality retrofits, particularly for deeper measures such as solid wall insulation:

“we’ve got issues around external wall insulation ... we’ve got ... green algae growing on the outside...we’ve got so many complaints coming in from private residents” (Social Housing Provider)

4.1.3. Customer interface

In the atomised market model, consumer engagement⁷ has typically involved single measures, leaving the customer to seek out and project manage more comprehensive work “largely the onus is on them at the moment” (Energy Saving Trust). In procuring multiple retrofit measures, customers therefore need to engage multiple consultants and contractors, each with their own marketing channels and points of sale:

“[referring to the UK’s Green Deal⁸] what actually happened was the customer journey was a lot longer than expected.” (Energy Efficiency Consultant).

This lack of co-ordination between different suppliers is therefore seen as complex, and likely to deter all but the most committed households. Without a trusted intermediary or a single point of contact, some interviewees also felt this made customers vulnerable to unscrupulous contractors *“if Mrs Jones goes direct to the company, the company can tell her anything can’t they”* (Energy Efficiency Consultant).

4.1.4. Financial model

Specific financial models are not intrinsic to the atomised market model. However, this approach is synonymous with government grant and supplier obligation schemes; typified by stop start funding for single measures. Thus, many interviewees felt that this approach had resulted in a marketplace that was very grant dependent. It was further discussed that this policy approach had contributed to the piecemeal nature of installations and the very limited diffusion of whole-house retrofits. Whilst the UK’s recent Green Deal financing mechanism was intended to fund multiple measures, it still applied an incremental logic to financing:

“Green Deal was set up to fund things on a measure by measure basis. So, you have this, then you have this, then you have this. ... With the supplier obligations we worked on things ...in the order of cost-effectiveness; in an ‘incrementalist’ approach” (Energy Saving Trust)

4.1.5. Governance

The atomised market model is associated with a market-based mode of governance, characterised by limited integration between the different elements of the business model:

⁷ Largely through the energy supplier obligations

⁸ The Green Deal was a voluntary UK policy program based on a private sector finance mechanism, repaid on energy bills

“at the moment there is no integration in the retrofit market ...somebody goes out and gets a lead ...they may get £50...they then come up with ‘yes it's got a solid wall yes it needs windows’ it becomes a sum of parts without...a plan” (Director - BRE)

This mode of governance may be effective for large organisations, able to manage complex supply chains, multiple interfaces with suppliers and compare different financing options. However, it is considered a poor means of delivering whole-house retrofits for time poor households, who may have limited knowledge of the options available or the ability to undertake due diligence.

4.2. Case study: The Energiesprong initiative

In 2013, the Dutch government funded a large-scale (€45 million) market led initiative to achieve net-zero energy homes known as the ‘Energiesprong’ or ‘energy leap’ initiative (Energiesprong, 2014). The aim was to overcome many of the issues identified in the previous section, thus, facilitating a self-sustaining market for net-zero energy homes⁹, through a new type of policy - delivered by a market intermediary. The Energiesprong market development team developed a radical solution based around a highly innovative business model involving: a net-zero energy performance contract; an integrated and industrialised supply chain; a single customer interface; a financial model based on the performance contract, and co-ordinated governance of these elements aided by the market development intermediary.

The Energiesprong initiative, since emerging from its pilot phase, has now begun a period of growth and expansion to other national contexts - having signed a deal with 175 housing industry partners in the Netherlands to deliver 110,000 net-zero energy homes by 2020 (Energiesprong, 2014). This included the creation of market development teams in the UK, France, Germany and in North America, building on the Dutch experience (Energiesprong, 2017). Thus far, 4,500 net-zero energy homes (a mix of new-build and retrofit) have been delivered in the Netherlands, with 10 and 24 retrofits completed in the UK and France respectively - with many more planned (Energiesprong, 2018). Initially entirely state funded, the initiative is now supported by national and European Union innovation funds and a range of local authority, industry and public sector partners in these respective countries. The following section explores the Energiesprong business model in more detail including its Dutch origins and recent translation to the UK market.

4.2.1. Value proposition

In the Energiesprong model, customers are offered a comprehensive whole-house retrofit, based on guaranteed net-zero energy consumption. This typically involves offsite manufactured, insulated facades, integrated with renewable heat sources and PV panels. The contractor offers a 30-year energy performance guarantee for net-zero annual energy consumption amortised over the calendar year. This is based on a guaranteed internal temperature of 21°C in living spaces, and a set allowance of hot water and electricity consumption; analogous to a mobile phone contract with usage limits. The aim is also to reduce

⁹ The program is focused both on net-zero-energy whole-house retrofit and new build

the duration of the retrofit to under one week using offsite manufacture and modularisation. However, the model does not proscribe any specific measures but rather the performance outcome:

“This is a balanced scorecard...of outcomes, so that's energy, that's cost, that's overheating, that's noise, that's indoor air quality that do get genuinely measured, has sanctions if you do not meet them and it is over the long term” (Energiesprong Contractor)

Another key aspect of the Energiesprong offering is the emphasis on the home improvement value of the whole-house retrofit. Homes are given a visual uplift and the retrofit typically includes a number of non-energy-based maintenance measures. Unlike the atomised market model, less emphasis is placed on energy costs savings, and instead on health and comfort benefits alongside property improvement value:

“I think...in terms of desirability...the push for such a scalable solution also needs to come from an angle where people actually want to have it.” (Energiesprong International Market Development)

4.2.2. Supply chain

The Energiesprong business model specifies performance rather than technical solutions. However, delivery of a net-zero energy retrofit requires an integrated supply chain, typically with a single ‘solution provider’. The Energiesprong model is also driving a move to industrialisation and offsite manufacture; with integrated energy modules that can be miniaturised, and mass-produced. It is thought that this process innovation will drive down costs and installation times through economies of scale; with one-day retrofits now being achieved in the Netherlands – despite each retrofit being bespoke. The Energiesprong model therefore adopts a performance-based approach to procurement:

“In the past they would come up with a technical specification, price it up and invite competition on price. We are completely turning that round and saying you ask for a product performance to a fixed price point” (Energiesprong Project Manager)

Moreover, this procurement route is seen to improve quality and collaboration between the client and contractor:

“Energiesprong however, has real teeth, so therefore the quality is driven up because we are concerned to get it right.” (Energiesprong Contractor)

4.2.3. Customer interface

In the Energiesprong initiative, the initial target market has been the social housing sector. Achieving scale is considered to be easier in this market where multiple homes can be retrofitted under a single deal, also tending to have a more uniform housing stock.

Interviewees felt that breaking into the owner occupier market would be much more challenging:

“They are managing larger volumes; it is much easier to converse with a provider who is managing 50, 60, 70,000 homes, than to talk to individual private landlords of one or two flats.” (Energiesprong Project Manager)

The customer interface involves a single product offering, rather than separate, sales, audit, measures and financing from different providers. Whilst for social housing this interface is initially with the housing provider, significant emphasis is placed on household engagement:

“there was quite an intensive consumer engagement process, which involved workshops with the tenants...in the local pub...so that the tenants could directly import what they wanted out of the scheme... It did genuinely make a difference” (Local Authority Partner)

Moreover, a key marketing tool of the Energiesprong approach is the visual impact of the newly renovated house, creating what is termed ‘kerbside appeal’.

4.2.4. Financial model

As with other forms of energy performance contract, the financial model relies on realised energy savings to fund the cost of the measures. Given the retrofit results in net-zero energy, the entire energy bill can be used to recover these costs. The model has thus far been adopted in the social housing sector, and benefits from the rolling up of future maintenance¹⁰ from the housing providers’ asset management budget:

“The financing model therefore is...the aggregation of maintenance, major repair works and the additional revenue stream for thirty years from the energy plan that comes with the property.” (Energiesprong Project Manager)

The strategy hinges on achieving economies of scale and learning rates, so that the financial model is viable based on energy costs savings and maintenance budgets alone - rather than reliant on subsidy as at present:

“the way I see it...is...this massive prize of a self-financing business model, if we achieve that then there are millions and millions of homes that could be retrofitted” (Social Housing Provider)

However, for the model to become viable in the private housing sector, third party sources of finance are likely to be necessary. The Dutch government is therefore exploring the use of mortgage financing and performance-based energy service agreements tied to the property. Critical to this is the cost of capital; *“what we see now is cost of financing, structural cost of borrowing money is high in the UK, because it's fully commercial”* (Energiesprong International

¹⁰ Such as those for wall and roofing repairs

Market Development). Therefore, several interviewees saw an ongoing role for government in bridging the funding gap and ensuring low interest rates.

4.2.5. Governance

The Energiesprong business model adopts an integrated mode of governance. Central to this has been the market development team, who have brought together the key stakeholders and facilitated collaboration and innovation towards a common goal:

“We’ve made an innovation of the Energiesprong, and I guess this is one of the biggest things...it’s the way, more the governance...the way it was organised” (Dutch Energy Policymaker)

“So, there was quite a lot of collaboration...when we were developing our tender we could do some market testing through Energiesprong, through the market development team” (Social Housing Provider)

This ‘partnership approach’ has been central to developing a business model where customer interface, supply chain, financing and net-zero energy retrofit are integrated into an offering from a single solution provider - which can be easily understood by the customer. Thus, simplifying the customer journey, improving quality and is potentially scalable to create a mass market for whole-house retrofit.

Table 4 compares the atomised market model and Energiesprong business model, illustrating the difference across the components of the respective business models.

Table 4 Comparison of the atomised market model and Energiesprong business models.
Adapted from: (Brown, 2018)

	'Atomised' market model	'Energiesprong' energy performance contract
Value proposition	<ul style="list-style-type: none"> • Single measures • Emphasis on energy cost savings • Savings are estimated rather than guaranteed 	<ul style="list-style-type: none"> • Multiple measures or whole-house approach • Emphasis on home improvement and comfort • Energy performance contract • Energy service guarantee of temperature (21°C), hot water volume (150L/day) and electricity (fixed kWh/year) • Energy supply contract subsumed in energy service agreement
Customer interface	<ul style="list-style-type: none"> • Largely left to the market to promote and engage customers, with responsibility for the marketing and engagement for the different components (i.e. measures, audit, finance) of the retrofit typically separated 	<ul style="list-style-type: none"> • One point of contact for the promotion, marketing and sales of the full package necessary to achieve the retrofit, provided by the host company as a one-stop-shop • Emphasis on customer engagement through housing provider and face to face workshops
Supply chain	<ul style="list-style-type: none"> • Fragmented relationship with traditional separated trades (plumbers, carpenters etc.) installing the retrofit measures in sequence with limited co-ordination 	<ul style="list-style-type: none"> • Highly integrated package of measures, using offsite manufacture techniques - provided in house or through trusted subcontractors • Supply chain may require legal and finance skillsets • Additional supply chain for electricity supply required, can be through fully licensed supplier model or through a white label scheme
Financial Model	<ul style="list-style-type: none"> • Finance is arranged via third party with little involvement in the retrofit process 	<ul style="list-style-type: none"> • Lender developer / investor seeking to use energy performance contract structure to fund retrofits • Lender captures energy savings and charges back to property owner based on historic consumption • Retrofit supplier assumes responsibility for payment of energy bill

	'Atomised' market model	'Energiesprong' energy performance contract
Governance	<ul style="list-style-type: none"> Highly fragmented arrangement of suppliers with little co-ordination between the various elements – project management is left to the customer 	<ul style="list-style-type: none"> Integrated mode of governance where components of the business model are delivered and co-ordinated by a single organisation, who take responsibility for project delivery.

4.3. Innovation intermediary

The Energiesprong market development team was funded by a €45 million grant from the Dutch government, as an arm's length, market-led initiative; considered a radical step change in both innovation and energy efficiency policy in the Netherlands:

"There was a strong belief here in this ministry that we should not do this... ourselves. This is not [what] we are good at. [We] had to bring out new people with knowledge of the market to make a connection with the market... We are making policy... we're not judging business plans" (Dutch Energy Policymaker)

To achieve its goals, the market development team performs three key forms of intermediation; *facilitating*, *configuring* and *brokering* that are crucial to business model innovation, and market formation.

4.3.1. Facilitating

The overarching role of the market development team is to co-coordinate the key stakeholders of the housing provider, the construction industry and policymakers, facilitating collaboration and learning.

"So, what we saw is that it's much easier if you put an interlocutor or a catalyst in the middle that understands where the market needs to go ...what the financing conditions need to be, what the regulatory conditions need to be, that you organise some demand, and then the market is right there." (Energiesprong International Market Development)

This has involved multiple project partners including large construction companies, social housing providers, local authorities and municipalities. The aim has been to create a shared vision for net-zero energy buildings and develop a diverse skillset and knowledge base through events, publications and pilot projects. Interestingly, the market development team sees this role as temporary. It is hoped that over time and with sufficient experience, its role would become obsolete as the business model becomes mainstream.

4.3.2. Configuring

The Energiesprong market development team were tasked to develop a novel solution that would overcome many of the issues surrounding the traditional atomised market model. Whilst funded by a large government grant in the Netherlands, it was effectively independent of the ministry that created it. This provided significant autonomy to fundamentally redesign the business model through which retrofit was delivered:

"In the beginning... were able to do pretty radical things, right? Because there was nothing out there yet. Performance guarantees for 30 years, energy service plans, retrofit solution in a week? Nobody had...there was no example to look at the time... So, we really had to do a lot of activation. That budget allowed us to do that." (Energiesprong International Market Development)

This involved intensive innovation in partnership with contractors to determine what was technically possible, and extensive legal and policy work to develop the procurement approach and energy performance contracts. The Energiesprong team thus draws on extensive expertise, crucial in moving from concept to reality. However, the model has required re-configuration to the UK context due to the different regulatory environment, industry culture and consumer expectations:

"It was about promoting what had been done in the Netherlands, and saying, "This is how it works." I think what we've ended up with understanding... "It doesn't really work like that here." (Social Housing Provider)

4.3.3. Brokering

The market development team has also played a critical advocacy role - brokering policy changes, procurement volumes and raising financial and human resources. This included lobbying the Dutch government to allow placement of energy service charges on rents, performance-based efficiency subsidies, and mortgage eligibility assessments to account for net-zero-energy performance. This was made possible, because despite its independence Energiesprong was essentially an arm's length government programme:

"Interesting, why could we play this role? We were funded by the government. So, the fact that we brought together these organisations and we always said.... we're going to work on the supply side. We're going to work on the demonstrable goal. Also, we're going to work with the legislator." (Energiesprong founding partner)

The UK team have also secured innovation funding through various European Union grants and are now seeking a large UK government grant of over £150 million - for thousands of homes. It is hoped this scale will enable the financial model to be fully commercial. Critical to this is also securing demand volume; where in the Netherlands housing providers have agreed to retrofit 110,000 homes to net-zero standards (Energiesprong, 2014). However, significant work remains for the model to become self-sustaining:

“after you know, 45 million.... the idea was always that after that, the market would it do itself. That is still not the case here [Netherlands] and it's also not in the UK.” (Dutch Energy Policymaker)

A summary of these intermediation activities and how they relate to the components of the Energiesprong business model is provided in Table 5.

Table 5 Intermediation activities for the Energiesprong business model

	Facilitating – network formation and collaboration	Configuring – business model design	Brokering - advocacy and resource raising
Value proposition	Bringing together the necessary skillsets for energy performance contracts including expertise in offsite manufacture, asset and energy management, law and finance.	Designing performance contracts and developing the customer offer through collaborative design with the stakeholders in the network. Testing the customer offer through small scale trials and feedback with the end user.	In the Netherlands the intermediary secured regulatory changes surrounding energy service charges on social rents.
Supply chain	Co-ordinating actors within the supply chain to deliver net-zero energy retrofits through greater integration – facilitating learning and adoption of offsite manufacture techniques and modular solutions through collaborative procurement.	Managing procurement, tender process and contract terms with suppliers, as well as training and capacity building with SMEs in the retrofit supply chain.	Securing agreement from housing providers for large order volumes for net-zero energy homes – providing security for the supply chain to scale up operations.
Customer interface	Network formation and involvement of local community actors as well as public and private sector partners, holding regular events and outreach activities.	Developing marketing materials and customer outreach in collaboration with the housing provider or other representatives of residents. This included social media channels as well as more conventional forms of engagement, including focus groups.	Recruitment of housing association executives into the market development team to lobby for procurement of large numbers of net-zero energy retrofits within their host firms.
Financial model	Incorporating key financial stakeholders from both the private sector and government into the consortium from the earliest stages.	Mobilising financial resources and designing contracts, building on dedicated financial and legal expertise to develop the financial model.	In the Netherlands securing policy changes: for both efficiency subsidies and mortgage eligibility to be based on energy performance. UK and EU level: lobbying for innovation funding under EPRD; Interreg; and UK Industrial Strategy Challenge Fund.
Governance	A system building role – improving the links and between the elements of the business model towards an integrated mode of governance, ideally through a single solution provider.	Formalising the links within the supply chain and wider network. In the UK, case this involved the creation of a new business venture ‘Melius Homes’ which will act as an integrated solution provider.	Widespread PR and advocacy campaign across UK and EU to promote the Energiesprong business model with business leaders, local authorities and the Industry. With the aim of creating a network of ‘advocates’.

5. Discussion

The goal of this paper was to understand how and why intermediaries - and in turn policymakers, might support business model innovation. We illustrate this through the case of an innovative business model for whole-house residential retrofit: the Energiesprong approach.

In understanding the role of new business models in systemic innovation, the case of whole-house retrofit is particularly instructive. Whole-house retrofit involves the assemblage and co-ordination of a complex mix of technologies, processes, human and financial resources which interface both user *and* industry practices. Among these groups the imperative of saving energy remains a low priority. Equally, the wider regulatory and institutional environment remains poorly aligned to achieving this, particularly as it also constitutes a shift toward a more distributed energy supply system (Richter, 2013). Whole-house retrofit thus represents an archetypal example of a systemic innovation (Mlecnik, 2013).

This paper builds on an earlier phase of research involving a systematic comparison of alternative retrofit business models (Brown, 2018). We show that the traditional atomised market business model, whilst suitable for the delivery of single retrofit measures is poorly suited to whole-house retrofit and is a weak driver of demand. The Energiesprong initiative radically overhauls this approach, through an integrated business model.

Thus, our findings support recent research on the potential for supply chain integration (Mahapatra et al., 2013; Mlecnik et al., 2018, 2012, n.d.) and energy performance contracts for promoting whole-house retrofit (Brown, 2018; Winther and Gurigard, 2017). Therefore, these findings emphasise how the 'integrative technologies' - which characterise whole-house retrofit are best suited to hierarchical or integrated modes of governance (Hoetker, 2006; Sanchez and Mahoney, 1996).

Consequently, business model innovation is able to exploit the added value of systemic innovations like whole-house retrofit - such as improved energy services and household comfort (Roelich et al., 2015). New business models achieve this by reconfiguring relationships within supply chains, mobilising financial resources and engaging customers in new or improved ways (Boons et al., 2013). Our case further emphasises how the *governance* of the business model is critical for the integration and management of these components, and the impact this has on the customer (Hellström et al., 2015). Business model innovation thus reconfigures organisational practices and their management to enable systemic innovations to become viable:

"of significance is the business model's ability to create a fit between technology characteristics and (new) commercialisation approaches that both can succeed on given and new markets." (Boons and Lüdeke-Freund, 2013)

However, the adoption of innovative business models, such as the Energiesprong approach remains challenging - due to a range of cultural and structural barriers (Stubbs and Cocklin, 2008). Our findings show how the incumbent business model is a product of the wider construction industry - characterised by fragmentation, lowest cost procurement, and few

guarantees on performance. This reflects established ways of undertaking construction work and contract design, based on the 'dominant logic' of the industry (Chesbrough, 2010). Many SMEs lack the necessary knowledge for whole-house retrofits, capabilities such as energy monitoring and finance, or complementary assets such as energy management ventures - preventing them from offering long term energy performance contracts (Teece, 2018, 2010, 1986). As identified by Budde Christensen et al., (2012) incumbent firms may thus be locked into a path dependent business model, with a limited demand for whole-house retrofit, providing few incentives to change.

Crucial to overcoming these barriers has been an open approach to innovation, where learning is widely disseminated rather than held within individual firms (Chesbrough, 2006). Thus, the market development team created standardised contracts and procurement processes, critical in reducing transaction costs for energy service contracts (Nolden et al., 2016). The intermediary also played an instrumental role in lobbying for policy changes and financial resources. Moreover, the negotiation of delivery volumes and the targeting of the social housing market is ostensibly an organisational 'strategy' rather than a business model (Teece, 2010). Thus, the intermediary roles of configuring, facilitating and brokering (Stewart and Hyysalo, 2008) were critical for business model innovation, market formation *and* strategy for the diffusion of whole-house retrofit. Interestingly, the temporary nature of the market development team was also observed in Kivimaa's (2014) study of two Finnish innovation agencies. Both studies emphasise the risks of too short an intervention and the importance of maintaining neutrality whilst retaining policy influence - a challenging balancing act (Kivimaa and Martiskainen, 2016; Klerkx and Leeuwis, 2009).

Where this study breaks new ground is by highlighting the role of an innovation intermediary in overcoming these barriers to business model innovation. We develop a novel framework (Table 3 and Figure 1) which integrates the components of the business model with intermediation functions for the first time. The Energiesprong market development team is therefore shown to be instrumental in developing the concept of a net-zero energy retrofit, engaging the supply chain to develop innovative approaches, as well as developing the legal and policy framework necessary for it to work. By highlighting the specific processes by which intermediaries can support business model innovation; these findings are an important contribution to the literature on innovation intermediaries (Klerkx and Leeuwis, 2009), and business model innovation (Bolton and Hannon, 2016) – emphasising how one can promote the other.

Our case study also contributes to understanding the role of intermediaries and business model innovation in innovation policy. Drawing on Edler and Fagerberg's (2017) typology; the formation of the market development team was primarily a policy to promote *interaction and learning across networks*. What is interesting is that the intermediary was able to engage with the market and influence policy in a range of other areas. This included: securing *R&D&D funding* in the form of European Union grants as well as changes to the energy efficiency subsidy regime; *procurement policies* to generate demand through volume agreements with public housing providers; changes in *regulations and standards* to allow energy service charges to be bundled with rent; *and missions and foresight policies* including the goal for net zero energy homes by 2050 and the gradual disconnection of neighbourhoods from the natural gas grid in the Netherlands.

The catalytic role of the intermediary can thus be seen both in terms of market *and* policy formation. Recognising the limited generalisability of our case study approach, we suggest that by bringing together the literature on systemic innovation, business models and innovation intermediaries - our findings and framework (Table 3 and Figure 1) provide some transferable theoretical insights. We demonstrate how government affiliated intermediaries like the Energiesprong market development team can be viewed as a decentralised and highly effective form of innovation policy (Kivimaa, 2014). This policy created an intermediary who facilitated business model innovation, which in turn has enabled systemic innovation in the form of whole-house retrofit. Accordingly, policymakers wishing to promote business model innovation in other sectors, may achieve these aims through the creation of innovation intermediaries such as the market development team.

However, the transferability and wider significance of these findings, both for the empirical context of retrofitting and intermediation for business model innovation, requires qualification. For now, the Energiesprong business model requires significant scale before it is viable without subsidy; thus, contingent on promising but as yet unrealised learning rates (Energiesprong, 2017). The findings also emphasise the greater challenges in entering the owner occupier market, where diversity of building forms and consumer preferences make mass produced solutions more challenging (Haines and Mitchell, 2014). Equally, these findings highlight issues of compatibility for the transfer of radical business models to new contexts. The absence of 'net metering' for renewable microgeneration, the lack of public financing support through low cost loans, or a general unwillingness for policymakers to promote specific technological solutions are all significant challenges for the UK. Therefore, these findings highlight the difficulty in transferring systemic innovations and new business models to different institutional contexts (Hall et al., 2016) and political economies (Baker et al., 2014).

6. Conclusion

In this paper we advanced three related propositions. First, we outline how business model innovation may play a key role in unlocking the potential of systemic innovations. We illustrate how the radical 'Energiesprong' business model, based on zero-energy performance contracts, an industrialised supply chain, integrated governance and a simple customer offer, could greatly improve the appeal, delivery and scalability of whole-house energy retrofit.

Second, we show how a range of barriers to business model innovation may be overcome through an innovation intermediary; in our case the Energiesprong market development team. This intermediary has played an instrumental and catalytic role, facilitating stakeholder collaboration, configuring the design of the business model, and brokering the policy changes, financial resources and procurement volumes needed for the business model to be viable.

Third, we described how such entities can be created by policy, and in turn shape the policy and institutional landscape towards new business models. Our case demonstrates how the creation of a market facing intermediary enabled the Dutch government to achieve its policy aims through a decentralised body - the Energiesprong market development team. This intermediary's role in market formation and business model innovation could thus present a

template for both policymakers and academics looking to facilitate and study systemic innovation in a range of other sectors.

Concisely, these findings show how policymakers can promote business model innovation through the creation and support of innovation intermediaries. These organisations may further shape the policy and institutional landscape, in a process of feedback between policy and market design in ways that market or government actors alone cannot.

Given the limited generalisability of this single case study, future research could incorporate this framework into a more representative cross-sectional research design of the sector at large. Future research could also explore these processes in other sectors such as food, transport, healthcare or manufacturing - using the theoretical links we make in this paper. Future research on business models for whole-house retrofit could also incorporate quantitative methods, such as on project performance or customer satisfaction to add validity to the claims made here.

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8. References

- Amit, R., Zott, C., 2001. Value creation in E-business. *Strateg. Manag. J.* 22, 493–520. <https://doi.org/10.1002/smj.187>
- Baden-Fuller, C., Haefliger, S., 2013. Business Models and Technological Innovation. *Long Range Plann.* 46, 419–426. <https://doi.org/10.1016/j.lrp.2013.08.023>
- Baden-Fuller, C., Morgan, M.S., 2010. Business models as models. *Long Range Plann.* 43, 156–171. <https://doi.org/10.1016/j.lrp.2010.02.005>
- Baker, L., Newell, P., Phillips, J., 2014. The Political Economy of Energy Transitions: The Case of South Africa. *New Polit. Econ.* 19, 791–818. <https://doi.org/10.1080/13563467.2013.849674>
- Barnes, J.P., 2016. The local embedding of technologies through community-led initiatives: the case of sustainable energy.
- Bessant, J., Rush, H., 1995. Building bridges for innovation: the role of consultants in technology transfer. *Res. Policy* 24, 97–114.
- Bidmon, C.M., Knab, S.F., 2018. The three roles of business models in societal transitions: New linkages between business model and transition research. *J. Clean. Prod.* 178, 903–916. <https://doi.org/10.1016/J.JCLEPRO.2017.12.198>
- Bohnsack, R., Pinkse, J., Kolk, A., 2014. Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. *Res. Policy* 43, 284–300. <https://doi.org/10.1016/j.respol.2013.10.014>
- Bolton, R., Hannon, M., 2016. Governing sustainability transitions through business model innovation: Towards a systems understanding. *Res. Policy* 45, 1731–1742. <https://doi.org/10.1016/J.RESPOL.2016.05.003>
- Boons, F., Lüdeke-Freund, F., 2013. Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. *J. Clean. Prod.* 45, 9–19. <https://doi.org/10.1016/j.jclepro.2012.07.007>
- Boons, F., Montalvo, C., Quist, J., Wagner, M., 2013. Sustainable innovation, business models and economic performance: An overview. *J. Clean. Prod.* 45, 1–8. <https://doi.org/10.1016/j.jclepro.2012.08.013>
- Brown, D., 2018. Business models for residential retrofit in the UK: a critical assessment of five key archetypes. *Energy Effic.* 1–26. <https://doi.org/10.1007/s12053-018-9629-5>
- Brown, D., Kivimaa, P., Rosenow, J., Martiskainen, M., Bird, J., 2018. *Warm Homes for All*. Brighton, UK.
- Budde Christensen, T., Wells, P., Cipcigan, L., 2012. Can innovative business models overcome resistance to electric vehicles? Better Place and battery electric cars in Denmark. *Energy Policy* 48, 498–505. <https://doi.org/10.1016/J.ENPOL.2012.05.054>
- CCC, 2018. Reducing UK emissions – 2018 Progress Report to Parliament.
- Chesbrough, H., 2010. Business model innovation: Opportunities and barriers. *Long Range Plann.* 43, 354–363. <https://doi.org/10.1016/j.lrp.2009.07.010>
- Chesbrough, H.W., 2006. *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business Press.
- Edler, J., Fagerberg, J., 2017. Innovation policy: What, why, and how. *Oxford Rev. Econ. Policy* 33, 2–23. <https://doi.org/10.1093/oxrep/grx001>
- Energiesprong, 2018. The Netherlands – Energiesprong [WWW Document]. URL <http://energiesprong.eu/country/the-netherlands/> (accessed 5.8.18).
- Energiesprong, 2017. United Kingdom – Energiesprong [WWW Document]. URL

- <http://energiesprong.eu/country/united-kingdom/> (accessed 3.7.17).
- Energiesprong, 2014. Transition Zero 1–30.
- Engelken, M., Römer, B., Drescher, M., Welp, I.M., Picot, A., 2016. Comparing drivers, barriers, and opportunities of business models for renewable energies: A review. *Renew. Sustain. Energy Rev.* 60, 795–809. <https://doi.org/10.1016/j.rser.2015.12.163>
- Fawcett, T., 2014. Exploring the time dimension of low carbon retrofit: owner-occupied housing. *Build. Res. Inf.* 42, 477–488. <https://doi.org/10.1080/09613218.2013.804769>
- Flyvbjerg, B., 2006. Five Misunderstandings About Case-Study Research. *Qual. Inq.* 12, 219–245. <https://doi.org/10.1177/1077800405284363>
- Foxon, T.J., 2011. A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecol. Econ.* 70, 2258–2267. <https://doi.org/10.1016/j.ecolecon.2011.07.014>
- Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: Drivers, barriers and systems failures. *Energy Policy* 33, 2123–2137. <https://doi.org/10.1016/j.enpol.2004.04.011>
- Haines, V., Mitchell, V., 2014. A persona-based approach to domestic energy retrofit. *Build. Res. Inf.* 42. <https://doi.org/10.1080/09613218.2014.893161>
- Hall, S., Foxon, T.J., Bolton, R., 2016. Financing the civic energy sector: How financial institutions affect ownership models in Germany and the United Kingdom. *Energy Res. Soc. Sci.* 12, 5–15. <https://doi.org/10.1016/j.erss.2015.11.004>
- Hannon, M.J., Foxon, T.J., Gale, W.F., 2013. The co-evolutionary relationship between Energy Service Companies and the UK energy system: Implications for a low-carbon transition. *Energy Policy* 61, 1031–1045. <https://doi.org/10.1016/j.enpol.2013.06.009>
- Hellström, M., Tsvetkova, A., Gustafsson, M., Wikström, K., 2015. Collaboration mechanisms for business models in distributed energy ecosystems. *J. Clean. Prod.* 102, 226–236. <https://doi.org/10.1016/j.jclepro.2015.04.128>
- Hoetker, G., 2006. Do modular products lead to modular organizations? *Strateg. Manag. J. Strat. Mgmt. J.* 27, 501–518. <https://doi.org/10.1002/smj.528>
- Howells, J., 2006. Intermediation and the role of intermediaries in innovation. *Res. Policy.* <https://doi.org/10.1016/j.respol.2006.03.005>
- Hyysalo, S., Juntunen, J.K., Martiskainen, M., 2018. Energy Internet forums as acceleration phase transition intermediaries. *Res. Policy* 47, 872–885. <https://doi.org/10.1016/j.respol.2018.02.012>
- IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Summary for Policymakers and Technical Summary, Climate Change 2014: Mitigation of Climate Change. Part of the Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. <https://doi.org/10.1017/CBO9781107415416.005>
- Jaffe, A.B., Newell, R.G., Stavins, R.N., 2005. A tale of two market failures: Technology and environmental policy. *Ecol. Econ.* 54, 164–174. <https://doi.org/10.1016/j.ecolecon.2004.12.027>
- Kivimaa, P., 2014. Government-affiliated intermediary organisations as actors in system-level transitions. *Res. Policy* 43, 1370–1380. <https://doi.org/10.1016/j.respol.2014.02.007>
- Kivimaa, P., Boon, W., Hyysalo, S., Klerkx, L., Group, I., 2018. Towards a typology of intermediaries in sustainability transitions : a systematic review and a research agenda. *Res. Policy* 1–31. <https://doi.org/10.1016/j.respol.2018.10.006>
- Kivimaa, P., Martiskainen, M., 2018a. Dynamics of policy change and intermediation: The arduous transition towards low-energy homes in the United Kingdom. *Energy Res. Soc.*

- Sci. 44, 83–99. <https://doi.org/10.1016/J.ERSS.2018.04.032>
- Kivimaa, P., Martiskainen, M., 2018b. Innovation, low energy buildings and intermediaries in Europe: systematic case study review. *Energy Effic.* 11, 31–51. <https://doi.org/10.1007/s12053-017-9547-y>
- Kivimaa, P., Martiskainen, M., 2016. Innovation towards low energy buildings and the role of intermediaries in the transition-Review of Scholarly Case Studies in Europe. *Creat. built Environ. new Oppor.* 1, 103.
- Klerkx, L., Leeuwis, C., 2009. Establishment and embedding of innovation brokers at different innovation system levels: Insights from the Dutch agricultural sector. *Technol. Forecast. Soc. Change* 76, 849–860. <https://doi.org/10.1016/j.techfore.2008.10.001>
- Lente, H. van, Hekkert, M., 2003. Roles of Systemic Intermediaries in Transition. *Int. J. ...* 7, 247–279. <https://doi.org/10.1142/S1363919603000817>
- Lewis, J., Smith, L., 2013. Breaking the barriers: An industry review of the barriers to Whole House Energy Efficiency Retrofit and the creation of an industry action plan -Energy Efficiency Partnership for Buildings (EPPB).
- Mahapatra, K., Gustavsson, L., Haavik, T., Aabrekk, S., Svendsen, S., Vanhoutteghem, L., Paiho, S., Ala-Juusela, M., 2013. Business models for full service energy renovation of single-family houses in Nordic countries. *Appl. Energy* 112, 1558–1565. <https://doi.org/10.1016/j.apenergy.2013.01.010>
- Martiskainen, M., Kivimaa, P., 2017. Creating innovative zero carbon homes in the United Kingdom — Intermediaries and champions in building projects. *Environ. Innov. Soc. Transitions.* <https://doi.org/10.1016/J.EIST.2017.08.002>
- Massa, L., Tucci, C.L., 2013. Business model innovation. *Oxford Handb. Innovation Manag.* 27, 420–441. <https://doi.org/10.1093/oxfordhnb/9780199694945.013.002>
- Mcelroy, D.J., Rosenow, J., 2018. Policy implications for the performance gap of low-carbon building technologies. *Build. Res. Inf.* 1–13. <https://doi.org/10.1080/09613218.2018.1469285>
- McMahon, D., Thorsteinsdóttir, H., 2013. Pursuing endogenous high-tech innovation in developing countries: A look at regenerative medicine innovation in Brazil, China and India. *Res. Policy* 42, 965–974. <https://doi.org/10.1016/j.respol.2012.12.003>
- Midgley, G., Lindhult, E., 2015. What is Systemic Innovation?
- Mignon, I., Kanda, W., 2018. A typology of intermediary organizations and their impact on sustainability transition policies. *Environ. Innov. Soc. Transitions.* <https://doi.org/10.1016/J.EIST.2018.07.001>
- Mlecnik, E., 2013. Opportunities for supplier-led systemic innovation in highly energy-efficient housing. *J. Clean. Prod.* 56, 103–111. <https://doi.org/10.1016/j.jclepro.2012.03.009>
- Mlecnik, E., Kondratenko, I., Cré, J., Vrijders, J., Degraeve, P., Van Der Have, J.A., Haavik, T., Aabrekk, S.A., Grøn, M., Hansen, S., Svendsen, S., Stenlund, O., Paiho, S., 2012. Collaboration opportunities in advanced housing renovation. *Energy Procedia* 30, 1380–1389. <https://doi.org/10.1016/j.egypro.2012.11.152>
- Mlecnik, E., Kondratenko, I., Haavik, T., n.d. Business model development for customer-oriented housing renovation.
- Mlecnik, E., Straub, A., Haavik, T., 2018. Collaborative business model development for home energy renovations. *Energy Effic.* <https://doi.org/10.1007/s12053-018-9663-3>
- Nolden, C., Sorrell, S., Polzin, F., 2016. Catalysing the energy service market: The role of intermediaries. *Energy Policy* 98, 420–430. <https://doi.org/10.1016/j.enpol.2016.08.041>

- Nykvist, B., Whitmarsh, L., 2008. A multi-level analysis of sustainable mobility transitions: Niche development in the UK and Sweden. *Technol. Forecast. Soc. Change* 75, 1373–1387. <https://doi.org/10.1016/j.techfore.2008.05.006>
- OECD, 2015. *System Innovation: Synthesis Report* 101.
- Osterwalder, A., 2004. *Business model ontology* - PhD Thesis. l'Université de Lausanne.
- Osterwalder, A., Pigneur, Y., 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*, A handbook for visionaries, game changers, and challengers. <https://doi.org/10.1523/JNEUROSCI.0307-10.2010>
- Osterwalder, A., Pigneur, Y., Tucci, C.L., 2005. Clarifying Business Models: Origins, Present, and Future of the Concept. *Commun. Assoc. Inf. Syst.* 16, 1–25. <https://doi.org/10.1.1.83.7452>
- Richter, M., 2013. Business model innovation for sustainable energy: German utilities and renewable energy. *Energy Policy* 62, 1226–1237. <https://doi.org/10.1016/j.enpol.2013.05.038>
- Roelich, K., Knoeri, C., Steinberger, J.K., Varga, L., Blythe, P.T., Butler, D., Gupta, R., Harrison, G.P., Martin, C., Purnell, P., 2015. Towards resource-efficient and service-oriented integrated infrastructure operation. *Technol. Forecast. Soc. Change* 92, 40–52. <https://doi.org/10.1016/j.techfore.2014.11.008>
- Roome, N., Louche, C., 2016. Journeying toward business models for sustainability: A conceptual model found inside the black box of organisational transformation. *Organ. Environ.* 29, 11–35. <https://doi.org/10.1177/1086026615595084>
- Rosenow, J., Eyre, N., 2014. Re-energising the UK 's approach to domestic energy efficiency 281–289.
- Rosenow, J., Kern, F., Rogge, K., 2017. The need for comprehensive and well targeted instrument mixes to stimulate energy transitions: The case of energy efficiency policy. *Energy Res. Soc. Sci.* 33, 95–104. <https://doi.org/10.1016/j.erss.2017.09.013>
- Rosenow, J.A.N., Leguijt, C.O.R., Pato, Z., Eyre, N., Fawcett, T., 2016. An ex-ante evaluation of the EU Energy Efficiency Directive — Article 7 5, 1–20.
- Sanchez, R., Mahoney, J.T., 1996. Modularity, flexibility, and knowledge management in product and organization design. *Strateg. Manag. J.* 17, 63–76. <https://doi.org/10.1002/smj.4250171107>
- Sarasini, S., Linder, M., 2018. Integrating a business model perspective into transition theory: The example of new mobility services. *Environ. Innov. Soc. Transitions* 27, 16–31. <https://doi.org/10.1016/J.EIST.2017.09.004>
- Schaltegger, S., Hansen, E.G., Lüdeke-Freund, F., 2016. *Business Models for Sustainability: Origins, Present Research, and Future Avenues*. *Organ. Environ.* 29, 3–10. <https://doi.org/10.1177/1086026615599806>
- Smits, R., Kuhlmann, S., 2004. The rise of systemic instruments in innovation policy. *Int. J. Foresight Innov. Policy* 1, 4. <https://doi.org/10.1504/IJFIP.2004.004621>
- Stewart, J., Hyysalo, S., 2008. Intermediaries, Users And Social Learning In Technological Innovation. *Int. J. Innov. Manag.* 12, 295–325. <https://doi.org/10.1142/S1363919608002035>
- Stubbs, W., Cocklin, C., 2008. Conceptualizing a “Sustainability Business Model.” *Organ. Environ.* 21, 103–127. <https://doi.org/10.1177/1086026608318042>
- Teece, D.J., 2018. Business models and dynamic capabilities. *Long Range Plann.* 51, 40–49. <https://doi.org/10.1016/J.LRP.2017.06.007>
- Teece, D.J., 2010. Business models, business strategy and innovation. *Long Range Plann.* 43,

- 172–194. <https://doi.org/10.1016/j.lrp.2009.07.003>
- Teece, D.J., 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Res. Policy* 15, 285–305. [https://doi.org/10.1016/0048-7333\(86\)90027-2](https://doi.org/10.1016/0048-7333(86)90027-2)
- Treib, O., Bähr, H., Falkner, G., 2007. Modes of governance: towards a conceptual clarification. *J. Eur. Public Policy* 14, 1–20. <https://doi.org/10.1080/135017606061071406>
- Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. *Sci. Public Policy* 39, 74–87. <https://doi.org/10.1093/scipol/scr008>
- Wilson, C., Crane, L., Chryssochoidis, G., 2015. Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Res. Soc. Sci.* 7, 12–22. <https://doi.org/10.1016/j.erss.2015.03.002>
- Winther, T., Gurigard, K., 2017. Energy performance contracting (EPC): a suitable mechanism for achieving energy savings in housing cooperatives? Results from a Norwegian pilot project. *Energy Effic.* 10, 577–596. <https://doi.org/10.1007/s12053-016-9477-0>
- Yin, R.K., 1994. *Case Study Research—Design and Methods*, Sage Publications.
- Zott, C., Amit, R., 2010. Business model design: An activity system perspective. *Long Range Plann.* 43, 216–226. <https://doi.org/10.1016/j.lrp.2009.07.004>

Appendix A

Table A1 Business Model interviews

Business model archetype	Organisation	Actor
Expert Scoping		
All	University of Oxford	Senior Research Fellow - energy efficiency policy
	United Kingdom Green Building Council (UKGBC)	Policy Advisor
	Energy Saving Trust (EST)	Senior Insight Manager
	Building Research Establishment (BRE)	Director (Wales)
	Energy Programs Consortium	Counsel and Director of Finance Programs (USA)
	Buildings Performance Institute Europe (BPIE)/Reshape innovation	Innovation Strategist - Founder (Reshape Innovation)
	Georgia Institute of Technology (USA)	Professor of Energy Policy
	Association for Environmental Studies and Sciences (AESS)	Principal and Independent Consultant
Practitioner		
Atomized market model	Building Research Establishment (BRE)	Director (Wales)
	Sustainable Design Collective	Architect – Managing Director
Market intermediary model	Greater London Authority (RE:NEW)	Program Manager -Energy
	Nottingham Energy Partnership	Contracts Manager
	Birmingham Energy Savers (BES) (Consultant)	Sustainability Consultant
One stop shop	Retrofit works / Parity projects	Director
	Segel AS - Norway	Business Development Consultant
	Brighton and Hove Energy Services Company (BHESCo)	CEO

Energy Service Agreement	Energies POSIT'IF - Paris France	Innovation Strategist - Founder (Reshape innovation)
	ICF Habitat- Paris France	Head of Energy & Water
	RENESCO – Riga, Latvia	Managing Director
Managed Energy Service Agreement	Energiesprong – UK, Netherlands	Project manager /Rainmaker

Table A2 Finance Mechanism Interviews

Finance Mechanism	Organisation
Expert Scoping	
All	Climate Strategy and Partners
	United Kingdom Green Building Council (UKGBC)
	Building Research Establishment (BRE)
	Energy Programmes Consortium (USA)
	Climate Bonds Initiative
	Marksman Consulting LLP
	Energy Pro Ltd
Practitioner	
Public/credit enhancement	Energy Saving Trust Home Energy Efficiency Programme Scotland (EST-HEEPS)
	Amber Infrastructure (LEEF/MEEF)
On Bill Finance and Repayment	National Conference of State Legislatures (NCSL)
	Business Energy and Industrial Strategy (BEIS)
Energy Service Agreement	Servizi Energia Ambiente (SEA)
	Joule Assets Europe
	RENESCO – Riga, Latvia
PACE	RENEW Financial
	PACE Nation
Energy Efficiency Mortgage	European Mortgage Federation (EeMAP)
Community Finance	Brighton and Hove Energy Services Company (BHESCo)

Appendix B

Table B1 Low energy housing intermediaries: Sequence of interviews, interviewee types and focus.

Interview round	No. of interviews	Type of interviewees	Focus	Timing of interviews
1st	10	I1 NGO, I2 charity, I3 charity, I4 research organisation, I5 charity, I6 campaign, I7 NGO, I8 membership organisation, I9 network organisation, I10 ex-government	UK building energy efficiency policy development	July–September 2014
2nd	12	I11 social enterprise, I12 community organisation, I13 anonymous, I14 social housing fund, I15 charity, I16 research organisation, I17 social enterprise, I18 local administration, I19 social enterprise, I20 local administration, I21 social enterprise, I22 membership organisation	Developments in UK low-energy homes; activities of specific organisations	May 2015–March 2016
3rd	7	I23 membership organisation, I24 network organisation, I25 ex-government, I26 academic-practitioner, I27 network organisation, I28 academic-practitioner, I29 consultancy	Activities and influence of intermediary organisations on policy development	May 2017, February–March 2018

Appendix C

Table C1 Energiesprong case study interviews

Actor Type	Organisation	Role
Intermediary	Energiesprong Market Development Team X3	Project Manager
		Head of International Market Development
		Founding Partner
Client	Nottingham City Homes	Head of Energy and Sustainability
Contractor	Melius Homes	Director
Policymaker (Netherlands)	Ministry of the Interior and Kingdom Relations	Director Building & Energy
Policymaker (UK)	Nottingham City Council	Head of Energy and Sustainability

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7 Overcoming the systemic challenges of retrofitting residential buildings in the United Kingdom

A Herculean task?

*Donal Brown, Paula Kivimaa,
Jan Rosenow and Mari Martiskainen*

Introduction

In Greek mythology, the Hydra was a giant serpent with many heads. The second of the 12 labours of Hercules was to kill the Hydra. However, when one of the Hydra's heads was cut off, two more grew in its place. In many ways, overcoming the 'multi-headed-challenges' of achieving widespread energy efficiency (EE) retrofit is an equally Herculean task. Policy initiatives in the UK, such as the Energy Companies Obligation (ECO) and the Green Deal, have sought and failed to achieve the mass uptake of residential retrofit. This chapter will argue that such policies have failed to address four systemic challenges that constrain uptake for whole house retrofits, and that a more comprehensive and wide-reaching policy approach will be needed to overcome each of these challenges. The chapter is therefore focused on some of the solutions to these challenges from the perspective of three key elements of a retrofit: the business model, financing and intermediaries. It also discusses the ways in which policy could support these outcomes.

Retrofit of buildings involves the 'construction approach involving the action of introducing [retrofitting] new materials, products and equipment into an existing building with the aim of reducing the use of energy of the building' (Baeli, 2013, p. 17). This is different from renovating or refurbishing – which refers to work undertaken to repair homes or make them more aesthetically pleasing (Baeli, 2013). Retrofits of residential buildings have significant potential to reduce carbon dioxide emissions (CCC, 2016), fuel poverty (Sovacool, 2015), and improve occupant health and wellbeing (Willand *et al.*, 2015). However, in the UK, much of this potential is yet to be realised. Residential buildings account for almost a quarter of the UK's carbon emissions (CCC, 2016), and for every £1 spent on retrofitting fuel poor homes an estimated £0.42 is saved in National Health Service spending (UKGBC, 2017). The Committee on Climate Change (CCC, 2015b) estimates that there is cost-effective¹ potential to reduce direct emissions² from all buildings by a third by 2030, with the need to achieve near-zero emissions from the sector by 2050 (CCC, 2016). It is estimated that this level of retrofit

activity would create a Gross Domestic Product (GDP) effect of approximately £25.3 billion in gross value added (Guertler and Rosenow, 2016). The UK government has therefore announced a target for all UK homes to achieve an Energy Performance Certificate (EPC) rating of C or above by 2035 (HM Government, 2017).

To achieve these targets, an increasingly comprehensive whole house approach to residential retrofit will be needed (Hansford, 2015). Such an approach involves multiple measures with strategies for insulation, draught proofing, ventilation, heating systems and low-carbon microgeneration (*ibid.*). However, the traditional policy approach to residential retrofit has tended to incentivise single measures and piecemeal interventions, which may cause damaging unintended consequences;³ such as mould growth, poor air quality and in some cases structural damage (Davies and Oreszczyn, 2012). Thus, a comprehensive whole house retrofit; where the entire building is treated as a system rather than as individual elements or measures, can mitigate such issues and achieve greater reductions in emissions (Hansford, 2015). Much literature in this area has focused on the key ‘barriers’ to uptake (Fylan *et al.*, 2016; Sorrell *et al.*, 2004; Kangas *et al.*, 2018). However, this focus on barriers has tended to characterise retrofit decision-making in terms of rational choices while ignoring broader social and contextual factors (Walker *et al.*, 2014). This framing also carries the assumption that there is a latent *demand* for retrofit (Wilson *et al.*, 2015).

The UK is an interesting case study – although achieving major progress in power sector decarbonisation, it still has one of the least efficient housing stocks in Europe. This is despite recent policy initiatives for residential EE. This chapter starts with a brief overview of recent UK policy on residential retrofit. It then moves onto characterising four challenges that constrain demand for retrofits, then proposes solutions centred around three key elements of successful whole house retrofits: business models (Brown, 2018); financing (Borgeson *et al.*, 2013) and intermediaries (Kivimaa and Martiskainen, 2018). Drawing on recent empirical work at the CIED, we then argue that achieving these ambitions will require a comprehensive mix of policies (Kern *et al.*, 2017; Kivimaa *et al.*, 2018).

UK policy on residential retrofit

Improved EE has played a pivotal role in reducing the UK’s energy use and carbon emissions. On a temperature corrected basis, total UK household energy use decreased by 19 per cent between 2002 and 2016, despite a 12 per cent increase in the number of households and a 10 per cent increase in population (BEIS, 2016). Per-household energy consumption fell by 37 per cent between 1970 and 2015, with most of this decrease (29 per cent) occurring since 2004 (*ibid.*). EE improvements in individual households have offset the 46 per cent increase in the number of households, the 5.6°C increase in average internal temperatures and the rapid growth in appliance ownership over this period, with the result that total household energy consumption has increased by only 7 per cent in 45 years.

Although rising energy prices and the 2008 recession contributed to recent trends, the bulk of the reduction in per-household energy consumption can be attributed to public policies to improve EE (CCC, 2017; CEBR, 2011; DECC, 2015; Odyssee, 2017). Of particular importance have been the major home insulation programmes funded by successive ‘supplier obligations’ (SOs) such as the Carbon Emissions Reduction Target (CERT – 2008 to 2012) (Rosenow, 2012) and ECO – 2013 onwards. Since 1994, energy and carbon-saving targets imposed on electricity and gas suppliers have allowed them to recover the costs through a levy on household energy bills. Also important were the requirement for condensing boilers within the UK Building Regulations and the progressive tightening of EU standards on the EE of electrical appliances (CEBR, 2011). Evaluations of these policies have shown them to be highly cost-effective, both in terms of the cost savings to participating households and in terms of broader societal welfare (Lees, 2006, 2008; Rosenow and Galvin, 2013). This experience supports the argument that market forces alone cannot deliver all cost-effective investments in residential buildings, owing to multiple and overlapping market failures. Instead, policy intervention can be used to increase the uptake of residential retrofit through a mix of regulation, public engagement and incentives.

Despite dozens of instruments in the broader EE policy mix targeting residential buildings (Kern *et al.*, 2017) and the apparent success in reducing energy demand through policy, in more recent years there has been a marked shift in the policy landscape. Previously, SOs supported relatively low-cost EE measures, and dedicated grant programmes funded through general taxation provided support for low-income households to invest in EE measures. The last version of such grant programmes – Warm Front, was terminated in 2011 and the government decided to radically change the way EE was delivered in the UK. Through the introduction of the Green Deal in 2013, an on-bill-repayment loan scheme, the government intended to trigger substantial investment in EE retrofits while the SO would fund only the costlier EE measures. It is now widely recognised that this approach failed – the Green Deal was effectively terminated in 2015 and funding provided through SOs has been significantly reduced (Rosenow and Eyre, 2016). As a result, the uptake rate of EE improvements has stalled since 2012.

There are, however, signs of a change to the approach taken. The Clean Growth Strategy, launched by the UK government on 12 October 2017, sets out ambitious long-term targets for EE – especially for buildings and would require a significant increase of the current EE improvement delivery rate. The targets specify that all homes as far as possible should reach EPC band C by 2035 and all fuel poor homes by 2030. This requires both adjusting the ambition levels of existing policies and the implementation of new instruments. At the time of writing, government is consulting on several new policy measures, and has recently introduced minimum energy efficiency standards (MEES) for the private rented sector.

Key challenges for residential retrofit

The limited uptake of cost-effective EE measures, characterised as the ‘energy efficiency gap’ (Jaffe and Stavins, 1994), remains the focus of much academic and policy research. This is especially the case with residential buildings, where the benefits of retrofitting go beyond emissions reductions, including improvements to health and wellbeing, social welfare and economic development (UKGBC, 2017).

Previous literature on retrofit has adopted key ‘barriers’ to uptake as the theoretical basis for understanding this gap (Fylan *et al.*, 2016; Sorrell *et al.*, 2004). Yet the original focus of much of this barriers literature, such as Sorrell *et al.* (2004), was on firm level decision-making, rather than on households. As such, the focus on barriers has tended to characterise retrofit decision-making in terms of rational economic choices, while downplaying social and contextual factors (Walker *et al.*, 2014). This framing also carries the inherent assumption of latent demand for retrofit once these barriers are removed (Wilson *et al.*, 2015). This framing has come to dominate the design of recent policy initiatives such as the Green Deal and ECO, which were predicated on households saving money on their energy bills (Rosenow and Eyre, 2016).

We argue that this framing is problematic, primarily because it misrepresents how and why home renovation decisions are made, and by whom. This chapter instead frames the problem in terms of four interrelated challenges that continue to contribute to low household uptake of residential retrofits.

Information, engagement and trust

A lack of knowledge of the specific options and benefits of retrofit remains widespread among households in the UK (Marchand *et al.*, 2015). While many of the technologies and tools exist to retrofit existing buildings, their uptake is not widespread, largely due to a lack of household interest (Bonfield, 2016). Public engagement and marketing schemes have tried to generate demand but tended to be top-down (Rosenow and Eyre, 2016), short term and focus on specific subsidy schemes (UKGBC, 2017). This has also created a supply chain largely reliant on short-term policy incentives (CCC, 2015a). Complicated government programmes such as the Green Deal have often been difficult for households to grasp (Marchand *et al.*, 2015). Households who do decide to retrofit often have to interact with multiple tradesmen and installers, who influence decisions on technology choices and subsequent use (Maby and Owen, 2015). These challenges of gaining appropriate advice, concerns over post-retrofit performance, combined with poor-quality workmanship, has undermined trust with the wider public (Pettifor *et al.*, 2015).

Uncertain benefits and quality

Predicted energy and cost savings from retrofits are based on modelled energy performance. There is consistently a ‘performance gap’ between these models

and actual energy performance outcomes (Fylan *et al.*, 2016). This is characteristic of an industry with a reputation for low quality, with few contractual penalties for under-performance (Bonfield, 2016). Equally, retrofit interventions may alter a building's existing features, affecting a household's routines and practices in ways that may make them reticent to change (Wilson *et al.*, 2015). By only focusing on financial savings, policies have also failed to recognise that retrofits could be framed and promoted in terms of aesthetics, comfort and wellbeing (Rosenow and Eyre, 2016). Much evidence now suggests that those who undertake energy retrofits do so because of these non-economic *sources of value*, such as environmental concerns, desire for improved comfort and living standards, property longevity and aesthetics (Fawcett and Killip, 2017; Kivimaa and Martiskainen, 2018).

Complexity, disruption and timing

Whole house retrofits involve multiple activities carried out by multiple contractors and consultants. Management of this process is complex and time consuming for the household (Pettifor *et al.*, 2015). Alongside the significant disruption of extensive works, this can be a major deterrent to uptake (Snape *et al.*, 2015). Thus, households may prefer to retrofit gradually, when it is less disruptive to do so, despite the higher costs and longer duration (Fawcett, 2014). Consequently, energy retrofit may only be considered during wider renovations (Wilson *et al.*, 2015). Identifying such 'trigger points' could therefore promote retrofit in certain circumstances, such as moving into a new home (Maby and Owen, 2015).

Capital cost and split incentives

While retrofits result in long-term energy savings, whole house retrofits typically require long periods before the capital cost can be recovered in energy savings (Gouldson *et al.*, 2015). Thus, many households lack access to up-front capital, with the benefits of the investment not being realised when moving house or in a landlord-tenant situation – termed 'split incentives' (Sorrell *et al.*, 2004). While the up-front cost barrier has largely been the focus of recent policy initiatives in the UK, the economics of long-term financing is extremely sensitive to interest rates (Gouldson *et al.*, 2015), particularly if energy bill neutrality⁴ is required (Rosenow and Eyre, 2016). Further, while households may value funding for wider non-energy measures, such as general repairs, the majority of policies fund EE measures alone (Borgeson *et al.*, 2013). These four related challenges are shown in Figure 7.1.

Typically, policy interventions in this area have targeted one or at most two of these issues. However, to overcome these 'multi-headed challenges' and deliver on the promise of residential retrofit, a systemic approach across multiple sectors and involving multiple government departments will be necessary (see the Conclusions and Policy Recommendations section). This chapter draws on

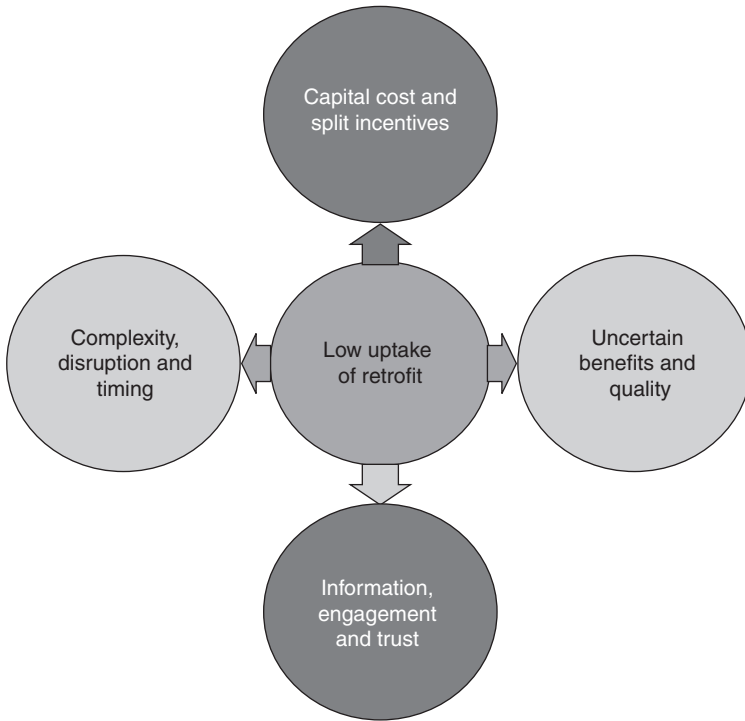


Figure 7.1 Key systemic challenges for driving retrofit uptake.

Source: the authors.

three emerging research themes: business models, financing and intermediaries. Building on these insights we then propose policy solutions to overcome the challenges for the widespread diffusion of whole house residential retrofit.

Overcoming the challenges for residential retrofit

In the following section we explore how best practice approaches to retrofit – business models, financing and intermediaries – can overcome many of the challenges that constrain uptake identified in the previous section.

Retrofit business models

A business model is defined as the nature of the products or services delivered to customers, the activities involved in delivering these and the means of capturing revenue from these activities (Boons *et al.*, 2013). Many radical innovations only became widespread once a complementary business model enabled their diffusion (Teece, 2010). Examples such as the MP3 player, low-cost air travel and smartphones owe their success to the effective pairing of the technology

with an appropriate business model and in many cases financing package. Emerging ‘service-based’ business models provide the useful end service rather than the technology or commodities themselves, shifting incentives for resource efficiency onto suppliers (Bocken *et al.*, 2014). Consequently, energy service business models are promoted as a means of reducing energy demand (Labanca *et al.*, 2014). Innovations such as distributed energy⁵ and whole house retrofit may therefore require novel, complementary business models before they are viable on a large scale (Hall and Roelich, 2016). Drawing on recent research at the CIED (Brown, 2018), we argue that despite significant policy action in this area, a major reason for the lack of uptake of whole house retrofit is the limitations of the traditional business model.

The dominant business model for residential retrofit (Figure 7.2) is characterised by a piecemeal offering; with a fragmented supply chain, a focus on single (rather than multiple, complementary) measures, and no guarantees on performance. This is typically marketed on estimated energy cost and carbon savings and involves measures and technologies installed by separate contractors. Customers procure the individual measures, energy audits and finance separately, with the result that multiple interfaces are required for a comprehensive residential retrofit. The offer of energy savings is based on modelled impacts of measures, and no performance guarantees are provided. Therefore, any finance package is based on estimated rather than guaranteed savings. Such an approach has typified the delivery of the EE through UK policies such as ECO and the Green Deal.

This approach introduces significant *complexity* for customers in managing multiple interfaces with sub-contractors, energy auditors and finance providers, also tending to result in major *disruption* for a whole house retrofit. Equally, the narrow emphasis on estimated cost savings, without performance or ongoing

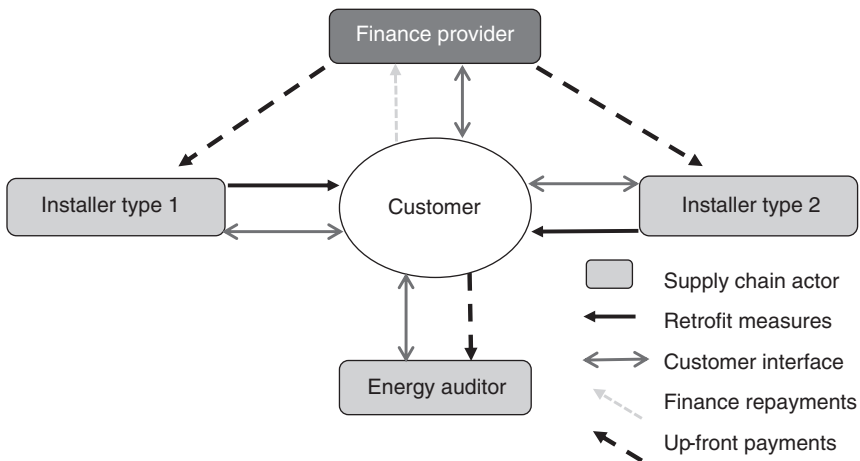


Figure 7.2 The incumbent ‘atomised market model’ for residential retrofit.

Source: Brown (2018), with permission (and without changes).

maintenance guarantees, means *uncertain benefits* for the customer and provides limited trust on installation *quality*. Unsurprisingly, this approach has resulted in low demand for comprehensive residential retrofits.

Recently, novel, integrated business models for residential retrofit have begun to emerge. These approaches emphasise a broader source of value for a whole house retrofit; focused upon aesthetics, increased property value, comfort, health and wellbeing alongside energy and carbon savings. Such approaches involve integrated and increasingly industrialised supply chains providing comprehensive whole house retrofits, through a single contractor or well-integrated network of sub-contractors. These approaches are characterised by a simplified customer interface with a single expert point of contact to coordinate the entire project. Some examples also offer integrated financing packages, and in some cases energy performance guarantees.

The Energiesprong initiative originated in the Netherlands and has expanded into the UK (Energiesprong, 2017). Customers are offered a comprehensive residential retrofit, based upon net-zero energy consumption. Typically, an Energiesprong retrofit involves the rapid delivery and installation of off-site manufactured, insulated wall facades, integrated with renewable heat systems and photovoltaic panels as well as ventilation and controls. The provider offers a 30-year energy performance guarantee (based on set internal temperature) for annual net-zero energy consumption, with specified energy usage limits, alongside an upstream financing package. An energy service contractor (ESCO) also takes on responsibility for the payment of the energy bill of the customer to provide ‘total energy management’. This represents a holistic energy services offering to the household, commonly termed a Managed Energy Services Agreement (MESA) (Kim *et al.*, 2012; Figure 7.3). This approach is currently being trialled in multi-family buildings and across large social housing estates.

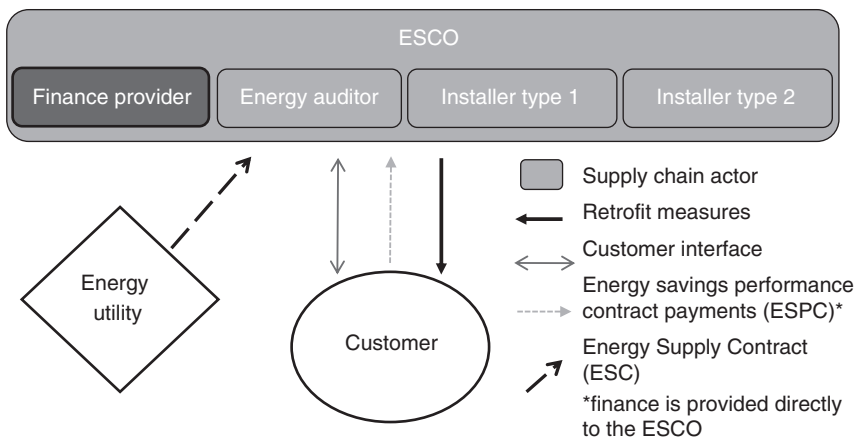


Figure 7.3 The Energiesprong Managed Energy Services Agreement (MESA).

Source: Brown (2018), with permission (and without changes).

Integrated business models such as the MESA have significant potential to drive demand for residential retrofit. By emphasising broader sources of value and including additional renovation measures as part of the offering, suppliers can attract customers by appealing to the *wider benefits* of improved aesthetics, increased property value, comfort, health and wellbeing alongside energy and carbon savings. Creating a simplified customer journey through an integrated supply chain, project co-ordination and a financing offer reduces *complexity* and minimises *disruption* for households. Further, the offer of energy performance guarantees provides *certainty* surrounding the ongoing performance benefits of the retrofit and the *quality* of the installation. While this may be the optimal solution, it is worth noting that integrated business models also face barriers and their uptake has been slow in the residential sector (Kangas *et al.*, 2018).

Business model innovation involves novel approaches and relationships for the delivery of products and services (Chesbrough, 2010). However, incumbent business models may be heavily embedded with existing industry practices, technological artefacts and regulatory regimes (Hannon, 2012). Therefore, adopting integrated energy service business models remains a challenge for an industry dominated by small-scale small and medium-sized enterprises (SMEs).

Retrofit finance

The up-front *capital cost* of retrofit measures and the *split incentives* faced by tenants and landlords remain a key challenge for the scaling up of comprehensive residential retrofits. Many UK households are also still in fuel poverty – defined as the necessity to spend more than 10 per cent of household income on energy bills (Sovacool, 2015).

As noted above, the UK's market-based SOs have funded significant loft and cavity wall insulation, low-energy lightbulbs and other low-cost measures (Rosenow and Eyre, 2014). ECO, the latest evolution of the SO policies, was initially designed to fund more expensive retrofit measures, such as solid wall insulation. It has since been criticised for its focus on single measures (Brown, 2018), dis-incentivising comprehensive installations, with no funding for complementary work such as ventilation and damp prevention (Hansford, 2015). SO policies require a levy on all households' energy bills, and thus increase the energy bills of households that do not benefit from programmes such as ECO (Rosenow *et al.*, 2013). The ECO has now been redesigned to focus on the 'fuel poor'. Although, having added approximately £50 a year to average household bills – a total of £1.3 billion annually (DECC, 2013), policies like ECO are arguably a poor tool for addressing fuel poverty (Rosenow *et al.*, 2013).

Meeting the UK's retrofit targets will require an estimated £85.2 billion of net investment to 2035 (Rosenow *et al.*, 2017). Achieving this level of investment through an SO like ECO could introduce politically unacceptable bill rises (Kern *et al.*, 2017) and be particularly regressive for the fuel poor who do not adopt retrofit measures (Rosenow *et al.*, 2013). Previous fuel poverty policies such as Warm Front did not raise wider energy bills as they were funded by

general taxation (Sovacool, 2015). A fuel poverty policy funded by general taxation is also more consistent with targeting the co-benefits of social welfare (Rosenow *et al.*, 2013) and improved health and wellbeing (UKGBC, 2017).

Alongside fuel poverty grants, there is a likely need for repayable retrofit financing for the 'able-to-pay' segment (Freehling and Stickles, 2016). The UK's Green Deal policy involved a novel *finance mechanism*, intended to deliver approximately 2 million retrofit installations per year and leverage billions of pounds of private sector investment. The scheme was based on private sector lending to households, paid back through energy bills – known as on-bill-repayment. However, the scheme achieved a fraction of its targets, and resulted in a significant loss to the UK taxpayer before its premature scrappage in 2015 (Rosenow and Eyre, 2016).

A range of other retrofit finance mechanisms have been developed in the UK, wider EU and USA, including several that have been markedly more successful than the Green Deal (EEFIG, 2015). Examples include: property assessed clean energy finance (PACE) in the USA, repaid through property taxes (Kim *et al.*, 2012); low-cost public loans (such as the German KfW scheme) (Schröder *et al.*, 2011); utility funded on-bill-financing (State and Local Energy Efficiency Action Network, 2014); retrofit mortgages (EEFIG, 2015); state-backed guarantee funds (Borgeson *et al.*, 2013); and energy service agreements (ESA) – where finance for measures is procured upstream by an ESCO as part of an energy performance contract (Kim *et al.*, 2012).

Examples of successful retrofit financing programmes, including Germany's KfW programme and California's PACE scheme, share some common features. These schemes typically include: a *cost of capital* that is low enough not to deter households and enable deeper retrofit measures to remain cost-effective (Rosenow and Eyre, 2016); a simplified *customer journey* – with finance often arranged by the contractor or project manager (Brown, 2018), use of an existing repayment channel (such as property taxes), attaching the debt to the property not the householder (resolving the spilt incentive issue); and funding for *broader sources of value*, such as wider renovation work or essential home improvements, that are often more highly valued by households (Fawcett and Killip, 2017).

By contrast the Green Deal involved a complex vetting and application process, that required a separate interface with a third-party provider, with no funding available for wider improvements. Introducing significant complexity that was likely to be offputting for most households. The Green Deal also had relatively high interest rates of 7–11 per cent (Marchand *et al.*, 2015). Indeed, the total cost of capital amounted to at least 49 per cent of total Green Deal Plan costs over 15 years (UKGBC, 2014). Programmes such as the KfW scheme offer finance at extremely low or zero interest rates (>2 per cent) (Schröder *et al.*, 2011). Such offers are likely to be more appealing to households (Marchand *et al.*, 2015) and drastically improve the economics of whole house retrofits with longer payback periods (UKGBC, 2014).

Several approaches exist to reduce the cost of capital for retrofit finance. Privately funded schemes such as PACE and retrofit mortgages are *secured*

against the property and can be securitised and sold to secondary markets – reducing risk and transaction costs for investors (Borgeson *et al.*, 2013). State actors may also assist in reducing the cost of capital, particularly where customers face difficulties or high costs in accessing finance. Policy options include interest subsidies (Gouldson *et al.*, 2015), state provision of subordinated (high risk) capital (State and Local Energy Efficiency Action Network, 2014), investor guarantee funds (Borgeson *et al.*, 2013) or the direct provision of low-cost loans, as has been the case in Germany's KfW programme (Schröder *et al.*, 2011).

However, there are limits to what financing alone can achieve. In most cases financing is likely to be an *enabler* of retrofit projects rather than a *driver* of demand (Borgeson *et al.*, 2014). Consequently, policymakers can introduce a range of incentives to promote demand for retrofit. These include fiscal or energy supplier incentives, such as variable property taxes (i.e. stamp duty or council tax), income tax rebates, VAT reductions or EE feed-in tariffs (Rosenow and Cowart, 2017; UKGBC, 2013). Some can be made fiscally neutral through penalising properties that do not meet a certain performance level (UKGBC, 2013). Incentives are likely to be particularly effective when they are available at key junctures when broader renovation decisions are being made. Thus, approaches that target key *trigger points* such as when properties change hands, during extensive renovations or heating replacements, are likely to be most successful (Maby and Owen, 2015).

Retrofit intermediaries

Intermediaries – that can be individuals, organisations or platforms – facilitate innovation processes (and broader transition processes) by educating, collecting and allocating financial and human resources, assessing new technologies and practices, creating partnerships, and influencing changes in regulations and rules (Stewart and Hyysalo, 2008). They may also shape how innovation occurs when it faces the user and negotiate on behalf of other actors (*ibid.*). Intermediaries may act as a single point of contact between households and retrofit contractors. In this section, we focus on how intermediaries can (1) stimulate, guide and manage different whole house retrofit projects, and (2) aid the creation of a market for new retrofit business models and financing solutions, supporting a transition towards a low-energy housing stock.

To address the challenges of *information, engagement and trust* as well as the complexity of whole house retrofits, intermediary actors are needed both at project level (e.g. specific retrofits) and the broader market level. In the former, intermediaries interconnect different technological, human and financial solutions. In the latter, they can have a crucial role in building trust and aggregating and disseminating clear and reliable information on retrofit techniques, suppliers and contractors.

A review of European case studies (Kivimaa and Martiskainen, 2018) shows that two types of intermediaries are specifically important in driving the market for retrofit. First, *innovation funders* such as Innovate UK are important in

supporting successful piloting of complex architectural or systemic innovation (i.e. interconnecting innovative and standard solutions to deliver whole house retrofits). Second, *social housing providers and local community actors* are crucial in market creation and advancing retrofits in practice. Yet, the role of social housing providers has lately diminished through policies introducing rent caps and ‘right to buy’ schemes, as well as local authority budget cuts – leaving less resources for housing providers to carry out retrofits in their building stock. In addition, *business networks*, such as the Passive House Platform in Belgium (Mlecnik, 2013) are important in pooling together different types of companies and solutions to create new business models and promote retrofitting. In the UK, the Green Deal Pioneering Places also stimulated cooperatives to deliver retrofits. What still seems to be largely lacking in the UK are intermediaries that can effectively stimulate the market for whole house retrofitting by owner-occupiers and private landlords, at the community level.

At the project level, intermediaries are needed to stimulate interest in whole house retrofits, share experiences among home owners, and provide necessary expertise during planning and implementation. Platforms, such as Eco Open Houses in the City of Brighton and Hove, organised in 2008 and between 2010–2015, enabled people to see and visit sustainable homes. These cases demonstrate that such events have been extremely useful in providing information, stimulating engagement and sharing knowledge on whole house retrofits, as well as providing details of trusted local tradespeople and installers. When planning and executing whole house retrofits, individual actors taking up intermediary roles – for example, *architects*, *building cooperatives* or *local authority officers* taking actions beyond their usual roles – are valuable in helping households make choices over technologies and materials. Previous research has shown the importance of local authority energy managers, planners (Lovell, 2008) and sustainability officers (Martiskainen and Kivimaa, 2018) as important intermediaries in project planning and implementation.

Recent CIED research involved a case study of a three-bedroom terraced home built in 1860 in Southampton Street, Brighton. The house was part of a local project obtaining funding from the ‘Green Deal Pioneer Places’ Programme (a national government-funded programme that sought to demonstrate the benefits of EE). The house has undergone an extensive retrofit, motivated by the owners’ interest in climate change and sustainable living, though the owners had no specific knowledge or interest to carry out a retrofit themselves. This was coordinated by the Green Building Partnership, which was formed initially to take part in the programme. The owners therefore did not have to acquire knowledge on the technical or policy aspects of the retrofit. The retrofit measures included external solid wall insulation, loft insulation, improved windows, new boiler and heating controls – involving multiple partners. While the Green Building Partnership led the process, from the perspective of the owner, there was no one key intermediary communicating between the broader scheme and the owners, leading to some confusion. Southampton Street later became part of local Eco Open Houses event, acting as an example to others.

Without these intermediary roles, projects may become much more complicated. Intermediaries provide information on the retrofit options available for the building projects and help to create a plan that meets regulations. More support is, however, needed from dedicated intermediaries, to facilitate ‘one-stop-shops’ for retrofitting (Brown, 2018), through which households can access trustworthy advice on technological and financing options, as well as tradesmen, contractors and installers. In this way intermediaries are often the key actors in providing *information* for households on the options and benefits of undertaking comprehensive retrofits; *engaging* communities and supply chains to promote retrofit at a local level; and are also likely to be more *trusted* than actors with a financial stake in promoting certain services or products.

Overall, some factors for successful intermediaries can be depicted. On a broader scale, most impact occurs over a longer timeframe. For example, the Centre on Alternative Technology established in the 1970s still influences the expectation and visions behind home retrofits. While the Eco Open Houses events have been popular in Brighton, they were not organised in 2016–2017, creating uncertainty about future knowledge exchange and example setting locally. Another important determinant in market formation is the positioning between ambitious sustainability aims and connections to business and supply chains.

Innovative business models, such as the Energiesprong approach, owe much of their success to dedicated intermediaries, often initiated by government policy. Energiesprong was brought into being through a €50m grant from the Dutch government, and the setting up of a *market development team* (Energiesprong, 2017). These market development teams brought together stakeholders including the construction industry, housing providers, policymakers and financiers to radically re-think the business model through which EE retrofit is delivered. While these approaches still face challenges, they could represent a template for how the UK could deliver on its ambitious retrofit targets.

Conclusions and policy recommendations

In the ancient Greek myth, the Hydra was invulnerable only if it retained at least one head. Heracles, realising that he could not defeat the Hydra alone, worked with Iolaus, and through a combination of decapitating the beasts’ multiple heads and burning the stumps with a firebrand, stopped them growing back. The Hydra’s remaining immortal head was cut off with a golden sword given to Heracles by Athena. Heracles placed the head – still alive and writhing – under a great rock and shot it with an arrow dipped in the Hydra’s poisonous blood. Thus, his second task was complete.

The previous sections outline how tackling the ‘multi-headed-challenges’ of whole house residential retrofit will require a similarly sophisticated and multifaceted approach. Promoting business model innovation, delivering a range of financing options and incentives along with the establishment of strategic intermediaries, at both local community and national levels, will require a wide-reaching and systemic policy strategy. This strategy should incorporate a mix of regulations,

Table 7.1 Policy mix for achieving widespread comprehensive residential retrofit in the UK

Policy type	Policy	Challenge addressed	Government department
Regulation (sticks)	EE as an Infrastructure Priority (Frontier Economics Ltd, 2015)	All	HMT, NIC
	Minimum EE Standards (MEES) moving to EPC C in 2035 (Sustainable Energy Association, 2017)	All	DCLG
Financial (carrots)	New retrofit quality assurance standard such as home Quality Mark (Bonfield, 2016)	Uncertain energy savings and quality	BEIS, DCLG
	Financial Incentives at trigger points, options could include: (UKGBC, 2013)	Capital cost and split incentives	BEIS, HMT, HMRC
	<ul style="list-style-type: none"> • Variable Stamp duty • Variable Council tax • 0% VAT on renovation work that includes retrofit • Income tax rebates • EE Feed-in Tariff 	Complexity, disruption and timing	
	Government backed low-interest financing mechanism secured to property and available at point of sale of retrofit (Borgeson <i>et al.</i> , 2013)	Capital cost and split incentives	BEIS, HMT, NIC
New institutions and intermediaries (tambourines)	Fuel poverty obligation funded by general taxation (Rosenow <i>et al.</i> , 2013)	Complexity, disruption and timing	BEIS, HMT, DH, DWP
	National Retrofit Taskforce/Agency (Rosenow <i>et al.</i> , 2017) with central Information Hub and a Data Warehouse	Capital cost and split incentives	BEIS, DCLG, HMT, DfE, DH, NIC
	Area-based intermediaries based on Community Social Enterprise or Local Authority Arm's Length Management Organization (ALMO) delivery models (UKGBC, 2017). Market facing intermediaries and standardised procurement frameworks (Nolden <i>et al.</i> , 2016)	All	BEIS, DCLG, HMT, DfE, DH, NIC
		Information, engagement and trust	BEIS, DCLG, HMT, DfE, DH, NIC
		Complexity, disruption and timing	

Source: the authors.

financing and incentives along with the establishment of new institutions and the recognition of EE as a strategic infrastructure priority. Equally, different solutions will be required for socially rented, privately rented and owner–occupier sectors. This will require joined up action across multiple government departments including but not limited to: Business Energy and Industrial Strategy (BEIS), Department for Communities and Local Government (DCLG), Ministry of Housing, Communities and Local Government’s (MHCLG), the Treasury (HMT), Education (DfE) and Health (DH), the Department for Work and Pensions (DWP), Her Majesty’s Revenue and Customs (HMRC) and the National Infrastructure Commission (NIC). The following section provides an outline of the range of policies (Table 7.1) that could contribute to achieving the enormous potential for the comprehensive retrofit of residential buildings.

Standards and regulations

EE retrofits create economic benefits that are often several multiples of the initial investment (Guertler and Rosenow, 2016). Cost-effective investments in residential EE to 2035 have a current net present value of £7.5 billion. With wider benefits such as gross domestic product (GDP) effects and health improvements that could be up to £47 billion (Rosenow *et al.*, 2017). Thus, EE investments share the characteristics of other forms of infrastructure as identified in HM Treasury’s valuation guidance (Frontier Economics Ltd, 2015). Therefore, we argue that *EE should be re-framed as an infrastructure priority* by the UK government and given the level of strategic support and status as other forms of infrastructure; such as road, rail and supply side energy infrastructure and be included within the remit of the NIC (Rosenow and Cowart, 2017).

The UK Clean Growth Plan set an aspirational goal for all domestic buildings to achieve and EPC level C or higher by 2035. We support these aims, but argue the government could go further, mandating MEES for the owner–occupier sector in the 2020s. This could take the form of a gradual step change through to a *minimum EPC level of C by 2035* at the point of sale, with potential for ever-tightening standards moving into the 2040s and beyond (Sustainable Energy Association, 2017).

There remain concerns surrounding the standard and quality of many installations currently funded under ECO, particularly solid wall insulation, which is to be a key part of the UK’s targets (Hansford, 2015). Therefore, we support the findings of the recent Each Home Counts – ‘The Bonfield Review’, that the government should establish a *new quality assurance standard* such as a home Quality Mark (Bonfield, 2016). Such a policy should be designed not to introduce a further regulatory and cost burden on SMEs and could build on existing standards of good practice along the lines of the Investor Confidence Project in the commercial sector (Investor Confidence Project, 2015).

Taken together these three high-level regulatory policies would set the strategic direction for UK residential retrofit policy and would send market signals

for the development of integrated business models, novel financing solutions and market intermediaries. However, on their own, top-down regulations are unlikely to build a sufficient market for whole house retrofit.

Financial measures

Overcoming the up-front capital cost of EE retrofit remains a challenge for many households. Current fuel poverty schemes such as ECO are limited in size and have inherent design flaws (Rosenow *et al.*, 2013). For those in fuel poverty we instead propose that these costs should largely be met through government grants in the form of a *fuel poverty obligation paid for by general taxation*. This would allow the government to better spread the costs of such a scheme, and if properly designed could reduce spending in areas such as health, social care and welfare (Rosenow *et al.*, 2017).

For the ‘able-to-pay’ segment a range of market-led financing mechanisms may eventually emerge, including mortgage-based approaches and other private sector offerings. Yet, we argue that the government should learn the lessons of the failed Green Deal and promote a *new low-cost financing mechanism tied to the property*, perhaps retaining the on-bill repayment channel. Successful financing schemes such as Germany’s KfW programme have used government funds to provide a *low cost of capital*, involved a simplified *customer journey* and funded *broader sources of value* such as wider renovation works, which are likely to be perceived as higher value by households (Schröder *et al.*, 2011).

Although providing sources of lending for EE measures is key to *enabling* retrofit projects, it is unlikely that low-cost financing alone will be *drive* demand for retrofit (Borgeson *et al.*, 2014). Therefore, government can introduce a range of *fiscal incentives at key trigger points* to promote uptake. These might include: variable VAT, stamp duty land tax, council tax, income tax rebates or an EE feed-in tariff for households who have undertaken measures – with increasing benefits for deeper retrofits (UKGBC, 2013). Such approaches will be most effective when they are targeted at key trigger points such as moving home or when undertaking major renovations (Maby and Owen, 2015).

New institutions and intermediaries

A key challenge for residential retrofit remains the paucity of information, engagement and trust within communities. Recent work at the UK Green Building Council (2017) has highlighted a *new role for intermediaries* to catalyse retrofit and regeneration activity in *local areas*. These actors would engage local communities on the benefits of retrofit and regeneration and be the key point of contact for: information, marketing, financing and project delivery, through dedicated project managers/coordinators – drawing on the pre-existing networks of diffuse intermediaries already operating in many communities (Martiskainen and Kivimaa, 2018). These intermediaries could be based on Community Social Enterprise or Local Authority Arm’s Length Management Organization

(ALMO) delivery models, and funded through a combination of local authority budgets, central government grants and community shares (UKGBC, 2017).

Intermediaries also play a role in promoting business model innovation for the delivery of comprehensive residential retrofit. Examples such as the Dutch *Energiesprong* scheme (Brown, 2018) and the RE:FIT programme in London (Nolden *et al.*, 2016) demonstrate how public bodies can promote business model innovation, through the *creation of new market facing intermediaries* and standardised procurement frameworks. These initiatives help reduce transaction costs and bring together stakeholders to foster learning, new funding approaches and supply chain integration.

Achieving the promise of residential retrofit and tackling the ‘multi-headed-challenges’ that stand in the way, will require a joined up and coordinated strategy – as outlined in this chapter. To deliver this vision, we argue that the UK government should set up a *National Retrofit Taskforce*. This body would be responsible for the planning and delivery of the MEES targets through an overarching strategy, monitoring and verification process that brings together key stakeholders, including, Government, Third sector, Industry and Consumer groups (Rosenow and Cowart, 2017). This new high-level intermediary would also be responsible for the management of a central *Information Hub* (to act as a collection point for best practice advice and guidance) and a *Data Warehouse* (to act as a store for property-level data and information) (Bonfield, 2016). Advising multiple government departments, this body could monitor progress towards the UK’s targets for the sector and propose policies to keep this progress on track.

Climate change is perhaps the biggest challenge facing humanity in the twenty-first century. Buildings are perhaps the biggest single contributor to carbon emissions, with the existing residential buildings by far the largest component (CCC, 2016). Such a Herculean challenge will require an equally Herculean effort. We argue that the considerable rewards are more than worth rising to this challenge, and that the proposals presented here could go a long way towards achieving this.

Notes

- 1 The CCC define the cost-effective path as comprising measures that cost less than the projected carbon price across their lifetimes together with measures that may cost more than the projected carbon price but are necessary in order to manage costs and risks of meeting the 2050 target (CCC 2013).
- 2 Those that result from heating, ventilation and cooling systems as well as hot water. This term excludes emissions from electricity consumption.
- 3 Such as mould growth, poor air quality and interstitial condensation due to poor detailing, and insufficient consideration of building physics, airtightness and ventilation.
- 4 Energy bill neutrality may include requirements that modelled savings are ‘cash-flow positive’ meaning that finance repayments are equal to, or result in, net energy cost savings (Borgeson *et al.*, 2013).
- 5 Defined as electricity generation feeding into the local distribution network (operating from 132kV down to 230V), as opposed to the regional or national transmission grid (which operates from 400kV and 275kV).

References

- Baeli, M. (2013) *Residential Retrofit: 20 Case Studies*. RIBA Publishing, London, UK.
- BEIS (2016) Energy Consumption in the UK 2016. HM Government, London, UK. Available at: www.gov.uk/government/statistics/energy-consumption-in-the-uk.
- Bocken, N.M.P., Short, S.W. and Evans, R.S. (2014) A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production* 65: 42–56. DOI: 10.1016/j.jclepro.2013.11.039.
- Boons, F., Montalvo, C., Quist, J. and Wagner, M. (2013) Sustainable innovation, business models and economic performance: An overview. *Journal of Cleaner Production* 45: 1–8.
- Bonfield, P. (2016) Each Home Counts – An Independent Review of Consumer Advice, Protection, Standards and Enforcement for Energy Efficiency and Renewable Energy, Department for Business, Energy and Industrial Strategy (BEIS) and Department for Communities and Local Government (DCLG), London, UK.
- Borgeson, M., Todd, A. and Goldman, C. (2013) Getting the Biggest Bang for the Buck Exploring the Rationales and Design Options for Energy Efficiency Financing Programs. Available at: <https://eta.lbl.gov/sites/default/files/publications/lbnl-6524e.pdf>.
- Borgeson, M., Zimring, M. and Goldman, C. (2014) The Limits of Financing for Energy Efficiency. Available at: <https://eta.lbl.gov/sites/default/files/publications/lbnl-limits-of-financing-aceee-ss2012-final2.pdf>.
- Brown, D. (2018) Business models for residential retrofit in the United Kingdom; A critical assessment of 5 key archetypes. *Energy Efficiency* 11(6): 1497–1517.
- CCC (2013) Committee on Climate Change. Fourth Carbon Budget Review – Part 2. HM Government, London, UK. Available at: www.theccc.org.uk/wp-content/uploads/2013/12/1785b-CCC_TechRep_Singles_Book_1.pdf.
- CCC (2015a) Sectoral Scenarios for the Fifth Carbon Budget. Available at: www.theccc.org.uk/wp-content/uploads/2015/11/Sectoral-scenarios-for-the-fifth-carbon-budget-Committee-on-Climate-Change.pdf.
- CCC (2015b) The Fifth Carbon Budget – The next step towards a low-carbon economy – November 2015. Available at: www.theccc.org.uk/wp-content/uploads/2015/11/Committee-on-Climate-Change-Fifth-Carbon-Budget-Report.pdf.
- CCC (2016) Meeting Carbon Budgets – 2016 Progress Report to Parliament. Available at: www.theccc.org.uk/publications/.
- CCC (2017) Energy Prices and Bills – Impacts of Meeting Carbon Budgets. HM Government, London, UK. Available at: www.theccc.org.uk/publication/energy-prices-and-bills-report-2017/.
- CEBR (2011) British Gas Home Energy Report 2011: An Assessment of the Drivers of Domestic Natural Gas Consumption. Available at: www.centrica.com/sites/default/files/bg_home_energy_report_110202_0.pdf.
- Chesbrough, H. (2010) Business model innovation: Opportunities and barriers. *Long Range Planning* 43(2–3): 354–363. DOI: 10.1016/j.lrp.2009.07.010.
- Davies, M. and Oreszczyn, T. (2012) The unintended consequences of decarbonising the built environment: A UK case study. *Energy and Buildings* 46: 80–85.
- DECC (2013) Energy Company Obligation (ECO) Delivery Costs. Available at: www.gov.uk/decc.
- DECC (2015) Energy Consumption in the UK (2015). Chapter 3: Domestic Energy Consumption in the UK between 1970 and 2014. Available at: www.connaissancedesenergies.org/sites/default/files/pdf-actualites/ecuk_chapter_3_-_domestic_factsheet.pdf.

- EEFIG (2015) Energy Efficiency – The First Fuel for the EU Economy. Available at: www.unepti.org/fileadmin/documents/EnergyEfficiencyInvestment.pdf.
- Energiesprong (2017) United Kingdom – Energiesprong. Available at: <http://energiesprong.eu/country/united-kingdom/>.
- Fawcett, T. (2014) Exploring the time dimension of low carbon retrofit: Owner-occupied housing. *Building Research and Information* 42(4): 477–488.
- Fawcett, T. and Killip, G. (2017) Anatomy of low carbon retrofits: Evidence from owner-occupied Superhomes. *Building Research and Information* 42(4): 434–445. DOI: 10.1080/09613218.2014.893162.
- Freehling, J. and Stickles, B. (2016) Energy Efficiency Finance: A Market Reassessment. ACEE White Paper. Available at: <http://aceee.org/sites/default/files/market-reassessment-021716.pdf>.
- Frontier Economics Ltd. (2015) Energy Efficiency: An Infrastructure Priority. Available at: www.energysavingtrust.org.uk/sites/default/files/reports.
- Fylan, F., Glew, D., Smith, M., Johnston, D., Brooke-Peat, M., Miles-Shenton, D., Fletcher, M., Aloise-Young, P. and Gorse, C. (2016) Reflections on retrofits: Overcoming barriers to energy efficiency among the fuel poor in the United Kingdom. *Energy Research and Social Science* 21: 190–198. DOI: 10.1016/j.erss.2016.08.002.
- Gouldson, A., Kerr, N., Millward-Hopkins, J., Freeman, M.C., Topi, C. and Sullivan, R. (2015) Innovative financing models for low carbon transitions: Exploring the case for revolving funds for domestic energy efficiency programmes. *Energy Policy* 86: 739–748. DOI: 10.1016/j.enpol.2015.08.012.
- Guertler, P. and Rosenow, J. (2016) Buildings and the 5th Carbon Budget. ACE, London, UK. Available at: www.ukace.org/wp-content/uploads/2016/09/ACE-RAP-report-2016-10-Buildings-and-the-5th-Carbon-Budget.pdf.
- Hall, S. and Roelich, K. (2016) Business model innovation in electricity supply markets: The role of complex value in the United Kingdom. *Energy Policy* 92: 286–298.
- Hannon, M. (2012) Co-evolution of innovative business models and sustainability transitions: the case of the Energy Service Company (ESCo) model and the UK energy system. PhD Thesis, University of Leeds. October 2012, 1–348.
- Hansford, P. (2015) Solid Wall Insulations: Unlocking Demand and Driving Up Standards. A Report to the Green Construction Board and Government by the Chief Construction Adviser. HM Government, London, UK. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/476977/BIS-15-562-solid-wall-insulation-report.pdf.
- HM Government (2017) The Clean Growth Strategy: Leading the Way to a Low Carbon Future. HM Government, London, UK. Available at: www.gov.uk/government/.
- Investor Confidence Project (2015) Fueling Investment in Energy Efficiency. Available at: <http://blogs.edf.org/energyexchange/files/2015/07/ICP-Fact-Sheet-070115.pdf>.
- Jaffe, A.B. and Stavins, R.N. (1994) The energy-efficiency gap. What does it mean? *Energy Policy* 22(10): 804–810.
- Kangas, H.-L., Lazarevic, D. and Kivimaa, P. (2018) Technical skills, disinterest and non-functional regulation: Barriers to building energy efficiency in Finland viewed by energy service companies. *Energy Policy* 114: 63–76.
- Kern, F., Kivimaa, P. and Martiskainen, M. (2017) Policy packaging or policy patching? The development of complex energy efficiency policy mixes. *Energy Research and Social Science* 23: 11–25.
- Kim, C., O'Connor, R., Bodden, K., Hochman, S., Liang, W., Pauker, S. and Zimmermann S. (2012) *Innovations and Opportunities in Energy Efficiency Finance*. Wilson Sonsini Goodrich and Rosati, New York, USA.

- Kivimaa, P. and Martiskainen, M. (2018) Innovation, low energy buildings and intermediaries in Europe: Systematic case study review. *Energy Efficiency* 11(1): 31–51. DOI: 10.1007/s12053-017-9547-y.
- Kivimaa, P., Boon, W., Hyysalo, S., Klerkx, L. and Group, I., (2018) Towards a typology of intermediaries in sustainability transitions: A systematic review and a research agenda. *Research Policy*: 1–31. Available at: <https://doi.org/10.1016/j.respol.2018.10.006>.
- Labanca, N., Suerkemper, F. Bertoldi, P., Irrek, W. and Duplessis, B. (2014) Energy efficiency services for residential buildings: Market situation and existing potentials in the European Union. *Journal of Cleaner Production* 109: 284–295. DOI: 10.1016/j.jclepro.2015.02.077.
- Lees, E. (2006) Evaluation of the Energy Efficiency Commitment 2002–05. Report to Defra. Eoin Lees Energy, Wantage, UK.
- Lees, E. (2008) Evaluation of the Energy Efficiency Commitment 2005–08. Report to Defra. Eoin Lees Energy, Wantage, UK.
- Lovell, H. (2008) Discourse and innovation journeys: The case of low energy housing in the UK. *Technology Analysis and Strategic Management* 20(5): 613–632.
- Maby, C. and Owen, A. (2015) Installer Power – The Key to Unlocking Low Carbon Retrofit in Private Housing. Available at: <http://ukace.org/wp-content/uploads/2015/12/Installer-Power-report-2015.pdf>.
- Marchand, R.D., Koh, S.C.L.L. and Morris, J.C. (2015) Delivering energy efficiency and carbon reduction schemes in England: Lessons from Green Deal Pioneer Places. *Energy Policy* 84: 96–106.
- Martiskainen, M. and Kivimaa, P. (2018) Creating innovative zero carbon homes in the United Kingdom – Intermediaries and champions in building projects. *Environmental Innovation and Societal Transitions* 26: 15–31. DOI: 10.1016/j.eist.2017.08.002.
- Mlecnik, E. (2013) Opportunities for supplier-led systemic innovation in highly energy-efficient housing. *Journal of Cleaner Production* 56: 103–111.
- Nolden, C., Sorrell, S. and Polzin, F. (2016) Catalysing the energy service market: The role of intermediaries. *Energy Policy* 98: 420–430.
- Odyssee (2017) Odyssee Decomposition Facility. Available at: www.indicators.odyssee-mure.eu/decomposition.html.
- Pettifor, H., Wilson, C. and Chryssochoidis, G. (2015) The appeal of the green deal: Empirical evidence for the influence of energy efficiency policy on renovating homeowners. *Energy Policy* 79: 161–176.
- Rosenow, J. (2012) Energy savings obligations in the UK – A history of change. *Energy Policy* 49: 373–382.
- Rosenow, J. and Cowart, R. (2017) Efficiency First: Reinventing the UK's Energy System, Brussels, Regulatory Assistance Project (RAP). Available at: www.raponline.org/wp-content/uploads/2017/07/rap-efficiency-first-reinventing-UK-energy-system-2017-october.pdf.
- Rosenow, J. and Eyre, N. (2014) Re-energising the UK's Approach to Domestic Energy Efficiency. *ECEEE Summer Study Proceedings*: 281–289.
- Rosenow, J. and Eyre, N. (2016) A post mortem of the Green Deal: Austerity, energy efficiency, and failure in British energy policy. *Energy Research and Social Science* 21: 141–144.
- Rosenow, J. and Galvin, R. (2013) Evaluating the evaluations: Evidence from energy efficiency programmes in Germany and the UK. *Energy and Buildings* 62: 450–458.
- Rosenow, J., Platt, R. and Flanagan, B. (2013) Fuel poverty and energy efficiency obligations – A critical assessment of the supplier obligation in the UK. *Energy Policy* 62: 1194–1203.

- Rosenow, J., Sorrell, S., Eyre, N. and Guertler, P. (2017) Unlocking Britain's First Fuel: The Potential for Energy Savings in UK Housing. UKERC. Available at: www.ukerc.ac.uk/publications/unlocking-britains-first-fuel-energy-savings-in-uk-housing.html.
- Schröder, M., Ekins, P., Power, A., Zulauf, M. and Lowe, R. (2011) The KfW Experience in the Reduction of Energy Use in and CO₂ Emissions from Buildings: Operation, Impacts and Lessons for the UK. LSE Housing and Communities, London, UK, 1–80.
- Snape, J.R.R., Boait, P.J.J. and Rylatt, R.M.M. (2015) Will domestic consumers take up the renewable heat incentive? An analysis of the barriers to heat pump adoption using agent-based modelling. *Energy Policy* 85: 32–38.
- Sorrell, S., O'Malley, E., Schleich, J. and Scott, S. (2004) *The Economics of Energy Efficiency: Barriers to Cost-Effective Investment*. Edward Elgar, Cheltenham, UK.
- Sovacool, B.K. (2015) Fuel poverty, affordability, and energy justice in England: Policy insights from the Warm Front Program. *Energy* 93(1): 361–371.
- State and Local Energy Efficiency Action Network (2014) Financing Energy Improvements on Utility Bills : Market Updates and Key Program Design Considerations for Policymakers and Administrators. Available at: <https://emp.lbl.gov/publications/financing-energy-improvements-utility>.
- Stewart, J. and Hyysalo, S. (2008) Intermediaries, users and social learning in technological innovation. *International Journal of Innovation Management* 12(3): 295–325.
- Sustainable Energy Association (2017) Energy Efficiency – A Policy Pathway Addressing the Able to Pay Sector. Available at: www.sustainableenergyassociation.com/energy-efficiency-a-policy-pathway/articles/.
- Teece, D.J. (2010) Business models, business strategy and innovation. *Long Range Planning* 43(2–3): 172–194.
- UKGBC (2013) Retrofit Incentives. Task Group Report. UK Green Building Council. 1–76. Available at: www.ukgbc.org/sites/default/files/130705%2520Retrofit%2520Incentives%2520Task%2520Group%2520-%2520Report%2520FINAL_1.pdf.
- UKGBC (2014) Green Deal Finance: Examining the Green Deal Interest Rate as a Barrier to Take-up. Available at: www.ukgbc.org/ukgbc-work/green-deal-finance/.
- UKGBC (2017) Regeneration and Retrofit Task Group Report. Available at: www.ukgbc.org/wp-content/uploads/2017/09/08498-Regen-Retrofit-Report-WEB-Spreads.pdf.
- Walker, S.L., Lowery, D. and Theobald, K. (2014) Low-carbon retrofits in social housing: Interaction with occupant behaviour. *Energy Research and Social Science* 2: 102–114.
- Willand, N., Ridley, I. and Maller, C. (2015) Towards explaining the health impacts of residential energy efficiency interventions – A realist review. Part 1: Pathways. *Social Science and Medicine* 133: 191–201.
- Wilson, C., Crane, L. and Chrysoschoidis, G. (2015) Why do homeowners renovate energy efficiently? Contrasting perspectives and implications for policy. *Energy Research and Social Science* 7: 12–22.