Accelerating the development of residential demand response in liberalised markets

A case study of Great Britain

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In memory of Alexandros, whose passion for energy inspired my own

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Abstract

Residential demand response (DR) is expected to play a critical role in enabling affordable, secure, and decarbonised electricity systems. Yet in many liberalised markets, residential DR has remained fragmented, small-scale, and inconsistently integrated into mainstream retail and system operations. Using a GB case study, this thesis investigates how policy can create the conditions for rapid and durable DR growth in liberalised markets. It analyses residential DR from three different but complementary perspectives: industry, households, and the innovation system as a whole.

From an industry perspective, the thesis investigates how GB electricity suppliers and aggregators interpret, value, and operationalise DR within commercial, regulatory, and institutional constraints. Drawing on 33 expert interviews, it shows that weak value stacks, legacy IT systems, regulatory uncertainty, and slim retail margins create strong disincentives to invest in DR capability. Innovation occurs, but it remains peripheral, fragile, and challenging to scale.

Then, it looks at households and how they engage with a national DR programme: the GB Demand Flexibility Service. Using domestication theory and 25 participant diaries, it identifies the symbolic, practical, and cognitive dimensions through which DR is integrated in everyday life. The analysis reveals uneven ‘flexibility capital’ across households and highlights how programme design, communication strategies, and automation shape long-term willingness to participate.

Finally, the thesis integrates the industry and household perspectives into a whole-system historical account of DR development in GB over the past 15 years, using a Technological Innovation Systems (TIS) approach and event history analysis. It shows that incremental reform and fragmented governance have created an environment rich in pilots but poor in stable markets, with foundational enablers developing out of sequence and DR legitimation remaining contested.

Overall, the thesis demonstrates that DR does not fail for technical or behavioural reasons but because governance, commercial incentives, and household practices are misaligned. I argue that strategic coordination, commercial viability, and DR policy and products designed for mass DR users will help scale DR at the pace required for decarbonisation. The thesis offers a policy framework for sequencing reforms, strengthening market formation, and embedding DR into everyday life.

Thesis papers

Paper 1

Will liberalised markets deliver demand response? Insights from industry experts in Great Britain

Author: Anca-Elena Mihalache

Published in *Energy Policy* in May 2026

Paper 2

Domesticating residential demand response. Learning from Great Britain's 2022-2023 Demand Flexibility Service

Authors: Anca-Elena Mihalache, Sam Hampton, Sarah Darby[1]

Published in *Energy Efficiency* in October 2024

Paper 3

Why piecemeal is not enough: a Technological Innovation Systems analysis of residential demand response in Great Britain and the case for a strategic coordinated approach

Author: Anca-Elena Mihalache

Published in *Energy Policy* in May 2026

[1] Co-authorship statement is available in annex 8

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Abbreviations

ADE – Association for Decentralised Energy

BEIS – Department for Business, Energy and Industrial Strategy

BM – Balancing mechanism

BSC – Balancing and Settlement Code

CBA – Cost-benefit analysis

CM – Capacity market

DCC – Data Communications Company

DFS – Demand Flexibility Service

DNO(s) – Distribution network operator(s)

DSO(s) – Distribution system operator(s)

DR – Demand response

DSR – Demand-side response

DUoS – Distribution use-of-system (charge)

EHA – Event history analysis

ERM – Enterprise resource management (platform)

ESA(s) – Energy smart appliance(s)

ESO – Electricity System Operator

EU – European Union

EV(s) – Electric vehicle(s)

FSO – Future System Operator

GB – Great Britain

HEM(s) – Home energy management (systems)

HHS – Half-hourly settlement

I&C – Industrial and commercial

IHD(s) – In-home display(s)

IT – Information technology

MHHS – Market-wide half-hourly settlement

MPAN – Meter point administration number

NESO – National Energy System Operator

NZIP – Net Zero Innovation Portfolio

REMA – Review of Electricity Market Arrangements

RIIO ED – Electricity distribution price control framework (Revenue = Incentives + Innovation + Outputs)

RTP – Real-time pricing

RTS – Radio-tele-switching

SCR – Significant code review

SMETS1 / SMETS2 / SMETS3 – Smart Metering Equipment Technical Specifications (first, second, third generation)

TCR – Targeted Charging Review

TIS – Technological innovation system(s)

TNUoS – Transmission network use-of-system (charges)

TOU – Time-of-use (tariff)

TVT(s) – Time-varying tariff(s)

UK – United Kingdom

UKDRA – UK Demand Response Association

UKPN – UK Power Networks

US – United States of America

V2G – Vehicle-to-grid

VLP – Virtual Lead Party

Introduction

Sir Humphrey: Minister, this is getting urgent.
Hacker: Urgent, Humphrey? What a lot of new words we're learning!

(Yes, Minister, Series 1, Episode 5: The Writing on the Wall)

This chapter outlines the urgency and importance of studying residential demand response (DR). It sets out why residential DR has become a critical component of electricity system decarbonisation and why it is important to study it in the context of liberalised electricity markets. It introduces the thesis research question and the structure and logic employed to answer it. The chapter also explains why the development of residential DR in Great Britain (GB) constitutes a compelling case study for answering the research question and outlines the three embedded papers that make up this thesis, explaining how, together, they help answer the overarching research question. The chapter also provides a positionality statement and key terminology used throughout the thesis.

RATIONALE FOR STUDYING RESIDENTIAL DR IN LIBERALISED MARKETS

Electricity systems worldwide are under pressure to decarbonise. As variable renewable energy expands and electrification of heat and transport accelerates, the ability to shape and shift electricity demand – that is, making demand more flexible – is becoming fundamental to system reliability, affordability, and progress towards net-zero objectives (Torriti, 2016). DR – defined as *'the change in electricity consumption patterns in response to a signal'* (Element Energy, 2012, p.9) – can deliver flexibility at speed and scale if policy, markets, and households can adapt accordingly.

Electricity systems have traditionally adjusted supply to match relatively predictable demand patterns. With the increasing variability of supply and the expected rise in demand, this paradigm is no longer sufficient (Heptonstall and Gross, 2020). DR, as a solution to this challenge, is widely recognised for its potential to reduce system investment needs (Pourramezan and Samadi, 2023), maintain reliability (Wang et al., 2017), and benefit users (Uddin et al., 2018). To clarify the size of the challenge: the International Energy Agency (2023) anticipates that 500 GW of DR will be needed worldwide by 2030, which represents roughly a tenfold increase over 2020 DR deployment levels, to support decarbonisation.

Residential DR is especially important. The residential sector already accounts for about a third of global energy use (Mata et al., 2020; Quintana and Cansino, 2023). As heat and transport electrify, they will require significant investment in new infrastructure (Barrett et al, 2021), which residential DR could help reduce. In the residential sector, participation in DR does not hinge only on technology or price signals. Instead, working patterns, household composition, life stage, wealth, and access to flexible assets shape what has been termed 'flexibility capital' or *'the capacity to responsively change patterns of interaction with a* *system to support the operation of that system.'* (Powells and Fell, 2019, p. 57). Scaling up residential DR hinges on understanding and accommodating the user experience of DR. Studying residential DR in liberalised markets is especially important: unlike regulated or vertically integrated systems, where a single utility could coordinate DR efforts (Eid et al., 2016), liberalised markets rely on dispersed decision-making and competitive incentives (Joskow, 2008). Understanding how DR develops in such conditions helps design policies and market structures that expose DR's full role in decarbonisation, looking at the ways in which markets signal DR value, commercial actors mobilise participation in DR, and households interpret and act on DR signals.

In this context, scaling up residential DR in liberalised markets is integral to decarbonisation, so this thesis seeks to understand how it can be deployed fast enough to align with the urgency of climate change.

RESIDENTIAL DR IN GREAT BRITAIN

As will be shown in the research papers comprised in this thesis, GB has a tradition of liberalised markets and retail energy competition, which many countries have followed (Joskow, 2008) and which creates a distinctive environment for DR to develop in.

At the same time, GB is considered one of the most advanced countries globally in its readiness for large-scale residential DR (Blunomy, 2025) thanks to the rollout of smart meters accompanied by user feedback devices, time-variable tariffs (TVTs), and energy smart appliances (ESAs) (Carmichael et al., 2021; Davarzani et al., 2021; Nubbe et al., 2020). The Demand Flexibility Service (DFS), a national DR programme, saw participation from over 2.4 million households across winters 2022–24 (HM Government, 2025a); and 1.5% of GB residential peak demand responds to TVTs (National Energy System Operator, 2024a).

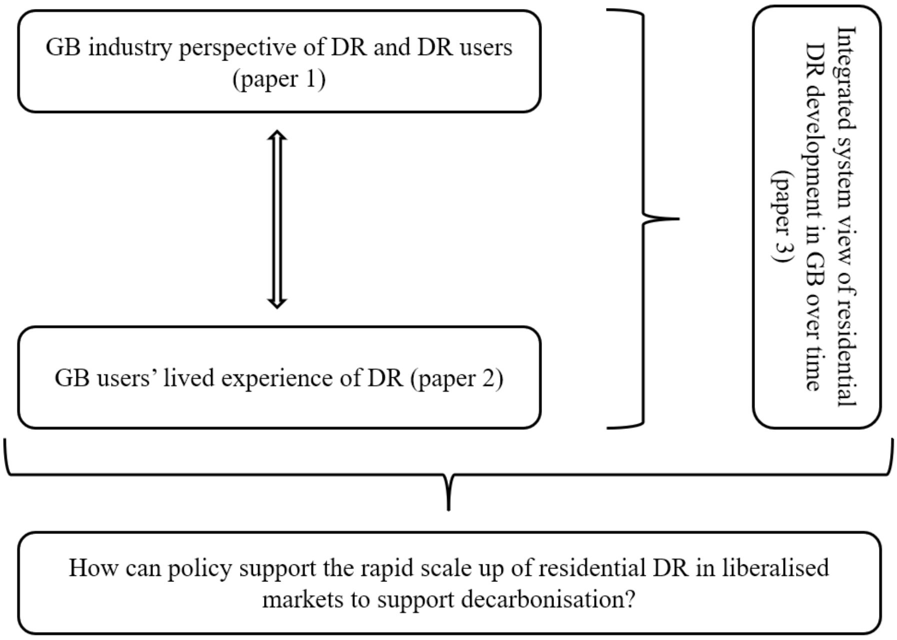
Building on this progress, the Government set an ambition for 10–12 GW of DR by 2030 (HM Government, 2024a), a four- to five-fold increase from 2024 levels, highlighting the pace at which DR must progress to support decarbonisation and electrification goals.
GB thus provides an analytically rich case for examining how residential DR develops in a liberalised market which can be used to critically examine the opportunities and limitations of scaling residential DR.

THESIS OVERVIEW AND STRUCTURE

In line with the rationale above, this thesis uses a GB case study to answer the following research question: *How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation?*

The thesis is made up of three research papers analysing DR from different but complementary perspectives, as shown in Figure 1 below. Given the centrality of commercial actors in offering innovative DR products in liberalised electricity markets, paper 1 looks at industry experts' perspectives on residential DR and DR users. Because householders' willingness and ability to engage with DR ultimately determine its success, paper 2 presents users' lived experience of DR, enabling a comparison between industry and user perspectives in the discussion chapter of this thesis. Paper 3 provides an overview of the DR innovation system as a whole, integrating industry and user perspectives in a historical account of how DR has developed in GB and what is missing to accelerate its development in liberalised markets.

Figure 1: Contribution of research papers in answering the overarching research questions



Paper 1: Will liberalised markets deliver residential demand response? Insights from industry experts in Great Britain

Research questions: *What is the industry perspective on DR in GB, and what implications does that have for the development of DR in a liberalised market? How can policy make use of these findings to further support the development of DR in liberalised electricity markets?*

The first paper investigates how *industry experts* understand, value, and operationalise DR in GB. Drawing on 33 semi-structured expert interviews in 2022-2023 across electricity suppliers, aggregators, technology companies, distribution network operators (DNOs), and consultancies, the paper examines how commercial actors perceive the opportunities and barriers to residential DR, and how these perceptions, alongside organisational capabilities, incentives, and regulatory frameworks, shape DR product design. The analysis considers the role of settlement arrangements, billing structures, market rules and IT capabilities in shaping suppliers' and aggregators' ability and appetite to offer DR, and reflects on the implications for participation, equity, and progress of DR ambitions in liberalised markets.

Paper 2: Domesticating electricity demand response. Learning from Great Britain's 2022-2023 Demand Flexibility Service

Research questions: *How, and with what success, did participant households domesticate the DFS over winter 2022-2023? What can future DR initiatives learn from the experience of these households?*

The second paper turns to *households* and analyses how participants integrated DR into their daily routines during the 2022-2023 DFS programme. Using domestication theory and empirical data from 25 participant diaries recorded across 13 DR sessions over a five-month winter period, the paper explores how households understand, interpret, and create routines around DR, and what motivations, artefacts, and experiences support or hinder sustained participation. The analysis identifies five distinct pathways of domestication, showing that successful DR engagement depends both on financial incentives and technology, and on symbolic, practical, and cognitive dimensions of everyday life. The paper offers recommendations for designing commercial DR programmes that better align with real household practices and motivations.

Paper 3: Why piecemeal is not enough: a technological innovation systems analysis of residential demand response in Great Britain and the case for a strategic coordinated approach

Research questions: *What factors have contributed to the development of residential DR in GB? How can policy accelerate the development of residential DR to support decarbonisation?*

The third paper takes a *system* view, using a technological innovation systems (TIS) approach to analyse the evolution of residential DR in GB between 2009 and 2024. Drawing on over 300 documented developments and 12 expert interviews, I examine how policies, markets, technologies, and user practices co-evolved during this period, and what impact they have had on DR's pace of development. Based on the GB experience, the paper illuminates the type of strategically coordinated approach that governments could take from the start to scale up DR faster.

Table 1 below brings together the research questions asked across the thesis.

Table 1: Research questions

Overarching research question	**How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation?**		
Papers	**Industry perspective (paper 1)**	**User perspective (paper 2)**	**DR innovation system view (paper 3)**
Research questions	What is the industry perspective on DR in GB, and what implications does that have for the development of DR in a liberalised market? How can policy make use of these findings to further support development of DR in liberalised electricity markets?	How, and with what success, did participant households domesticate the DFS over winter 2022-2023? What can future DR initiatives learn from the experience of these households?	What factors have contributed to the development of residential DR in GB? How can policy accelerate the development of residential DR to support decarbonisation?

As the research design and methodology chapter will show, the thesis amounts to an exploratory-explanatory single-case study design with three embedded units of analysis (industry, users, system), each explored through a dedicated research paper. Triangulating between the three perspectives helped build a comprehensive answer to the overarching research question, as will be shown in the discussion chapter of this thesis. To improve readability, all references, including those of the three papers, are presented at the end of the thesis, rather than after each chapter.

POSITIONALITY STATEMENT: MY JOURNEY WITH RESIDENTIAL DR IN GB

I stumbled upon residential DR in 2018, when I was still trying to find my way to what I imagined was the heart of the energy sector, in a bid to support decarbonisation efforts. One year earlier, I had completed a Masters degree in energy economics, law and policy at the University of Aberdeen, convinced that this would naturally lead me into the world of energy decarbonisation that had inspired me to move to GB.

Instead, I found myself working as a civil servant in the Smart Metering Implementation Programme (SMIP) at the Department for Business, Energy and Industrial Strategy (BEIS) – adjacent to, but not quite at the heart of GB energy policymaking. I volunteered to gather evidence on the benefits of and potential for smart meter enabled DR to support the programme's cost-benefit analysis. I found, however, divergent views on both DR's potential and how to support DR growth through policy. The experience convinced me that DR was underdeveloped, although fundamental to decarbonisation – and it sparked the questions that would become central to this research.

I continued working in BEIS, later the Department for Energy Security and Net Zero (DESNZ), throughout the six years of my DPhil, growing increasingly close to the heart of the energy sector I had once imagined from afar.

Between 2019 and 2022, I led SMIP's engagement with the energy suppliers responsible for rolling out smart meters in GB. I came to understand the retail market in which they operate and the regulatory constraints they face. I worked alongside my colleagues to support energy suppliers through the Covid-19 pandemic and the 2021 market exits prompted by the high gas prices resulting from Russia's war on Ukraine. It was one of the most intense professional experiences I had had, but it helped me forge the government and industry relationships that later influenced my research. During this time, I collected, transcribed, and analysed most of the expert interviews for papers 1 and 3.

In 2023, I moved to lead DESNZ's Energy Governance Reform team, responsible for rebalancing regulatory powers over energy codes – the detailed rules and regulations that underpin the energy sector – between Ofgem, the energy regulator, and industry participants; and supporting the creation of the National Energy System Operator (NESO). I gained detailed insight into the institutional architecture of the GB energy sector and the relationships across institutions involved in policy, regulation, and system operation. My role coincided with the first DFS winter, during which I collected and analysed the household diaries for paper 2.

I finally secured the DESNZ role most relevant to DR – Head of Smart Energy Policy – in 2024. Overseeing DR, storage, and digitalisation brought me as close to the core of GB energy policymaking as I had hoped. Drafting papers 1 and 3 during this period helped me make sense of the system around me and identify the opportunities to improve it. The 2024 general election could not have been timelier. The Clean Power Action Plan (2024a), published shortly after the election, prompted a shift in government priorities by bringing forward GB's clean power target by five years, to 2030, which inevitably focused minds on flexibility. From my research, I was aware that flexibility requires much more coordination and direction to help deliver clean power in only five years. With this in mind, I led the development of the Clean Flexibility Roadmap (HM Government, 2025a), working with Ofgem and NESO to establish a vision, a plan, and an implementation framework to maximise flexibility's contribution to clean power. A dedicated DR chapter in the Roadmap spells out how 10-12 GW of DR can be delivered by 2030 – an ambition which had been set in the Clean Power Action Plan.

I left the civil service a few months after publishing the Clean Flexibility Roadmap to finalise my DPhil thesis and continue my contribution to DR development and decarbonisation from the private sector.

I have been aware throughout my journey that my dual role as a researcher and a civil servant creates advantages and challenges. My professional position gave me privileged access to interviewees, insider knowledge of technical issues, and a shared professional language that facilitated candid discussions. At the same time, it introduced risks of bias: colleagues and friends may have provided cautious or socially desirable responses; perceptions of government interest may have influenced some interviews; and I have had to remain vigilant to avoid conflating professional views with academic conclusions. I was also conscious of reputational implications, particularly because my DPhil was partially government-funded. I explain in the research design and methodology chapter how I addressed these challenges and how I ensured that the conclusions of this thesis are grounded in the research, and not in DESNZ policy.

In hindsight, my professional choices influenced my DPhil journey, and vice versa. I do not think I grasped, back in 2018 when I first encountered DR, exactly how much it would change my life, or its potential to change everyone's. Nor did I understand the size of the challenge of delivering DR. It gradually became evident as I discovered the mindset within which industry operates (paper 1), the complexities of integrating DR in everyday life (paper 2), and the systemic change that needs to happen to align both (paper 3).

A final note concerns the quotes at the beginning of each thesis chapter. These are lines from two famous British political satires: *Yes, Minister,* and *Yes, Prime Minister*. When I first joined the British civil service, I struggled to make sense of the government's unwritten rules, rhythm, and – alas – its acronyms. The series became an unexpected guide. Over my eight years in the civil service, I found the 1980s satire entertainingly accurate, so I include these quotes to capture truths that academic analysis never could.

A NOTE ON TERMINOLOGY AND DEFINITIONS

I have encountered a rich and, at times, confusing terminology related to DR. Having found no evidence of a commonly agreed-upon terminology across industry, government, and academia, I have noted below the meanings of the terms I have used in this thesis and the rationale for their choice. This is meant to improve the readability of the thesis, not to promote a commonly accepted terminology. A list of abbreviations is available at the beginning of this thesis.

The definition I use for *DR* – '*the change in electricity consumption patterns in response to a signal' (Element Energy, 2012)* – is the simplest and most encompassing definition I could find. It allowed me to integrate concepts like implicit and explicit DR, automated and manual DR, ESAs, and home energy management (HEM) systems into my research without creating too many questions of scope. Although the term demand-side response (DSR) was traditionally preferred in GB, I preferred the more international term DR in my thesis – but kept references to DSR when quoting interview respondents in my papers. Increasingly, GB experts refer to DR/DSR as 'consumer-led flexibility' (CLF) – a term coined in the Clean Power Action Plan – but CLF has yet to gain international traction at the time of writing.

To the extent possible, I avoid equating DR with demand-side flexibility, which I view – in line with the Clean Flexibility Roadmap – as *encompassing* DR, grid-scale storage, and other technologies.

In terms of categories of DR, I use:

- Implicit and explicit DR in line with the definition provided by the International Energy Agency (2023), whereby 'implicit DR uses price signals and tariffs to incentivise consumers to shift consumption; and explicit DR makes direct payments to consumers who shift demand as part of a DR programme.' I found this distinction particularly helpful when looking at DR from the perspective of government or commercial actors, and although not always clear-cut, the distinction is widely used in academia (El Gohary, 2024; Lamprinos et al., 2016; Vallés et al., 2016) and in GB industry and government circles.
- *Manual* and *automated* DR when expressing how users engage in DR, regardless of whether it is implicit or explicit DR. *Manual DR* refers to users switching appliances on and off manually in response to a signal, whilst *automated DR* implies the use of smart appliance controls to respond to the signal e.g. Direct Load Control. As long as the user does not have to physically be at home to turn something on and off in real time, I consider it automated DR.

Automated DR is enabled by *ESAs* and *HEMs*. ESAs, in this thesis, refers to any smart-enabled electric devices like electric vehicles (EVs) and EV charge points, home batteries, heat pumps with smart controls, storage heaters with thermostats, etc. The smart controls allow the user to control the device remotely or to delegate that control to a third party. This is also true for HEMs, but HEMs are broader in scope as they are digital/home-level systems that monitor, control, and optimise a household's energy generation, storage, and consumption. The two definitions align with the jargon used by the interview respondents.

I use *TVTs* as an all-encompassing term for tariffs that account for the time when electricity is used, so any tariff that would qualify as implicit DR, regardless of whether users respond to it manually or via some form of automation. To the extent possible, I avoid terms like smart tariffs, time-of-use (TOU) tariffs, or static and dynamic TOU tariffs because their scope is unclear and they are often used interchangeably. I have, however, kept such references in interview quotes to preserve their integrity. When I focus on a specific type of TVT, I clarify its features in advance.

I use the term '*DR products'* as an overarching term to encompass any DR commercial offer, explicit or implicit. When the distinction is important, it should be evident from the text whether it refers to implicit or explicit DR products. Explicit DR products are also sometimes referred to as *events* or *sessions*, especially in paper 2, in line with government and industry jargon.

To maintain clarity, I avoid equating *energy* with *electricity* where possible. I also distinguish between *GB* (made up of England, Wales, and Scotland) and the *United Kingdom* (UK) of which GB is part, alongside Northern Ireland. This distinction is important because the UK government's energy policy only applies to GB, and Northern Ireland's energy policy is a devolved matter. However, some broader policies – like net zero – apply across the UK. These distinctions are less clear in the interview quotes, but I prioritised preserving the integrity of the original quotes.

I use the terms *industry, industry experts,* and *commercial actors* interchangeably. So, when I talk about *industry perspectives***,** I refer to the perspectives of commercial actors involved in the development of *residential* DR, unrelated to *industrial and commercial* (I&C) DR, which is out of the scope of this thesis.

To avoid confusion, I refer to the sub-units of this thesis as *chapters* – so each research paper is a chapter – and the sub-units of each paper/chapter as *sections*. So, whilst the thesis has a discussion and a conclusions chapter, each of the papers has a discussion and conclusions section.

Finally, I talk about *DR customers* or *DR users* rather than *electricity consumers*. This reflects the active (rather than passive) role that households play in DR. Paper 1 – focused on industry – predominantly talks about *DR customers* to reflect the contractual arrangements between industry actors (electricity suppliers and demand aggregators) and households. Paper 2 conceptualises households and their members as DR users who should be treated as central stakeholders in DR product development. Treating households as active actors in energy systems aligns with how they are conceptualised in the *DR user experience* body of literature, which will be discussed in the next chapter.

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To summarise, this thesis aims to develop policy recommendations to accelerate residential DR scale-up in liberalised markets to support urgent decarbonisation goals. Using a GB case study, it investigates the challenge through three complementary perspectives – industry, households, and the wider DR innovation system – while situating the analysis in my dual position as a researcher and (former) civil servant.

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The rest of this thesis unfolds as follows: the next chapter provides an overview of the DR literature and the two theoretical frameworks – domestication theory and TIS – that underpin the research. The following chapter explains the research design and methodology employed across the thesis, and its limitations and mitigation strategies. The next three chapters present the industry, user, and system perspectives of DR, which the discussion chapter then brings together to answer the thesis' overarching research question. The discussion chapter also maps out the empirical and conceptual contributions of the work, its international relevance, and areas of future research. The final chapter concludes.

Literature review and theoretical frameworks

Hacker: You're a cynic, Humphrey!
Sir Humphrey: A cynic is what an idealist calls a realist.

(Yes, Minister, Series 3, Episode 4: The Moral Dimension)

This chapter reviews DR literature and sets out the two theoretical frameworks that underpin the thesis. It first provides a selective, structured overview of residential DR research, organised around three bodies of work most relevant to the thesis research question. The chapter highlights where empirical findings converge or diverge and shows the literature gaps this thesis aims to fill. It then introduces domestication theory and the TIS framework as complementary approaches for addressing these gaps. The chapter reveals the tension between idealised assumptions and the practical reality of DR, which is further explored in the thesis' three papers.

DR LITERATURE REVIEW

Residential DR literature is extensive, spanning over two decades and multiple geographies. I do not aim to provide a systematic or exhaustive review. Instead, I draw selectively on the literature that best supports the research questions and underpins the three papers and the thesis discussion. I organise this literature into three main bodies: (1) barriers to DR scale-up, (2) DR business models, and (3) user experience with DR. I identify here the key tensions and gaps across these bodies of literature, and I return to them in the discussion of the thesis.

Barriers to DR scale-up

This body of literature maps the systemic barriers that constrain DR development in liberalised markets. Some studies identify general barriers (Bogdanova et al., 2023; Davarzani et al., 2021; Langevin et al., 2024; Parrish et al., 2020; Sousa and Soares, 2023; Uddin et al., 2018; Weck et al., 2017), while others focus on specific types of obstacles. Collectively, they provide a near-exhaustive catalogue of barriers. I focus here on the barriers most relevant to my research questions: misaligned incentives and other barriers to value stack accumulation; technical barriers to scaling DR product offers; and governance and coordination barriers.

Misaligned incentives and other barriers to value stack accumulation

A substantial sub-body of literature shows that DR suffers from weak, missing, or misaligned incentives in liberalised markets. Torriti et al. (2010) and Nolan and O'Malley (2015) discuss how the inability to quantify the value of DR deters investment. Good et al. (2017) demonstrate how limited access to capital, incomplete markets, imperfect competition, and transaction costs further undermine the DR business case. Willems and Zhou (2020) argue that a market-based approach to mass-scale DR requires cost-reflective network tariffs, higher capacity tariffs, and optional tariff components for flexibility provision. Grünewald et al. (2012), Eid et al. (2016), and Lockwood et al. (2020) show how traditional electricity market rules favouring large generators continue to disadvantage DR in Europe.

Network-focused studies reinforce these findings. Vallés et al. (2016) identify regulatory and market barriers to scaling DNO-level DR, while Morell-Dameto et al. (2023), drawing on a Slovenian case, discuss how network tariffs redesign can actively incentivise engagement in DR. Looking at DR's position in specific energy markets, Koliou et al. (2014) show how constraints like minimum bidding volumes and bid duration undermine DR's participation in the German balancing mechanism (BM). Liu (2017), based on GB and US analyses, highlights the limited revenue opportunities from capacity markets (CM) and the importance of addressing the risk of unstable funding. Capper et al. (2024) show that aligning technical and bidding requirements across markets and making energy prices reflective of carbon content, location, and time-of-use could support DR scale-up. Forouli et al. (2021) identify DR barriers in the UK, Belgium, Italy, and Greece and recommend streamlining market access and settlement reform to incentivise residential DR. Weck et al. (2017) and Torriti (2024) further emphasise the importance of settlement reform in incentivising DR. Taxation regimes also shape DR incentives. Katz et al. (2018) and Voulis et al. (2019) provide evidence that *ad-valorem* energy taxation[2] improves the DR business case, while Rosenow et al. (2025) prove that shifting levies to general taxation or gas bills would improve the appeal of heat pumps and deliver significant bill savings through TVTs.

Together, these studies show the difficulty of creating price differentials that are strong enough to change customer behaviour, as highlighted by Choi et al. (2020), and help explain the dearth of attractive DR products for households identified by D'Ettorre et al. (2022).

[2] A percentage of the generation price paid by the customer instead of a fixed amount of tax per kWh

Technical barriers to scaling DR product offers

A smaller, predominantly engineering-focused literature examines the technical barriers to offering DR products. Ma et al. (2021) describe optimal control strategies of HEMs to support DR. Parejo et al. (2021) analyse the technical architecture of automated DR solutions. Chen and Ge (2024) show the design requirements for modern information systems to be efficient, secure, and user-friendly. Interoperability between different smart technologies and legacy IT systems is also reported as a barrier to offering DR products by McKenna et al. (2012), Weck et al. (2017), Sovacool and Furszyfer Del Rio (2020) and Davarzani et al. (2021).

Governance and coordination barriers

Another strand of literature focuses on governance and coordination failures between system actors. Eid et al. (2016) show how the lack of coordination between electricity markets and network operation hinders DR scale-up. Earl and Fell (2019) highlight that EV manufacturers see improved coordination among suppliers, aggregators, DNOs, and customers as fundamental to their business case. Carmichael et al. (2021) argue for coordinated policy and awareness-raising to accelerate storage and EV uptake. D’Ettorre et al. (2022) show that fragmented regulatory frameworks leave roles and responsibilities unclear between traditional and new market actors in Denmark, France, Italy, and Spain. Torriti (2024) sets out governance principles for supporting DR development in the UK. El Gohary (2024) critiques the European Union (EU) price-signal paradigm for shifting responsibility for system balancing from policymakers and operators onto users and outlines alternative governance approaches.

DR business models

The business model literature explores how incumbents and new entrants like demand aggregators – i.e. electricity suppliers or other commercial entities who act as intermediary agents that pool flexibility from different customers and act as a single entity when engaging in electricity markets and selling services to system operators (Burger et al., 2017; Granado et al., 2023) – commercialise DR and how emerging models reshape user engagement. It examines, for instance, the conditions under which community energy (Hargreaves et al., 2013), peer-to-peer trading (Brown et al., 2019; Watson et al., 2024) prosumerism and vehicle-to-grid (V2G) models (Brown et al., 2019; Furszyfer Del Rio et al., 2020) can support DR development.

Research examines how commercial actors shape DR provision in liberalised markets and reveals the structural and strategic constraints that frame what DR can look like in reality. Burger et al. (2017) provide a regulatory template for enabling efficient aggregation while avoiding opportunistic behaviour. Božičević Vrhovčak and Malbašić (2023) analyse how aggregators can maximise profits and minimise risks in European energy markets. Langevin et al. (2024) show that load aggregators can significantly increase customer uptake of and engagement with DR.

A comparative perspective on incumbents and new entrants shows that regulation shapes business model evolution. Schittekatte et al. (2021) examine how EU regulation can improve contractual relationships between suppliers and aggregators. Kattirtzi et al. (2021) demonstrate that digitalisation has progressed least amongst energy incumbents compared to decentralisation and decentralisation efforts. Ruggiero et al. (2021) discuss how regulation and competition shape business model innovation amongst incumbents and new entrants. Sonsaard et al. (2023) find that state utilities acting as aggregators constitute the most effective DR business model under current Thai power market structures. Annala et al. (2022)

examine whether DR business models developed in advanced markets can travel successfully to other countries.

DR user experience

While user-related barriers sometimes appear in the general barriers literature, I treat user experience as a distinct body of scholarship that goes well beyond a simple barriers framing. This literature spans six main sub-bodies, , each looking at the DR user experience from a different angle: behavioural studies; social practice theory; user-technology interaction; data sharing, privacy, control, and automation; user characteristics, motivations, and preferences; and justice, equity, and capabilities. As will be discussed later in this chapter, whilst some of these bodies of literature are complementary and support a comprehensive understanding of the DR user experience, they leave a gap in terms of providing an integrated framework that could support DR policy development.

Behavioural studies

Economic research conceptualises DR primarily as price responsiveness. TVT trials consistently find peak reductions (Aigner and Lillard, 1984; Faruqui and Sergici, 2010; Herter et al., 2007), but also substantial heterogeneity and persistent non-response. Behavioural explanations for this discrepancy focus on bounded rationality, cognitive bias, and temporal discounting (Baddeley and M., 2011). Bradley et al. (2016) and Ito et al. (2018) show that environmental and social motivations can rival financial incentives, while Nicolson et al. (2017a) demonstrate the effect of loss aversion on TVT uptake. Buryk et al. (2015) discuss the importance of environmental framing and ease of demand shifting. Nicolson et al. (2017b) demonstrate that EV owners are more likely to switch to TVTs shortly after vehicle purchase. Nicolson et al. (2018) show that opt-out designs would raise DR uptake close to 100% whereas opt-in designs reduce it dramatically.

Social practice theory (SPT) and hybrids

SPT reframes electricity use as embedded in routines rather than discrete choices. Powells et al. (2014) discuss how cooking, dining, washing, and media use constrain flexibility. Nicholls and Strengers (2015) show how family dynamics and gendered roles shape unequal capacities for flexibility. Strengers (2014) critiques the 'Resource Man' ideal embedded in smart energy design. Friis and Haunstrup Christensen (2016) reveal the temporal complexity of laundry, dishwashing, and EV charging. Blue et al. (2020) argue that promoting flexibility requires attending to social rhythms. Goulden et al. (2018) show how industry imaginaries of users constrain DR development. Öhrlund et al. (2019) prove that households prioritise avoiding disruption over financial reward.

User-technology interaction

With the rise of ESAs, automation, and digital feedback, DR research increasingly focuses on user-technology relations to explain the level of DR response. Pallonetto et al. (2016) demonstrate that automation improves reliability. Weck et al. (2017) show how technology increases the attractiveness of DR propositions. Trial evidence confirms the centrality of communication and feedback (Öhrlund et al., 2019; Parrish et al., 2020; Wang et al., 2020). On the other hand, Verbong et al. (2013) provide evidence that excessive focus on technology and price constrain smart home development and Osunmuyiwa et al. (2021) show that the contrast between industry's 'technological saviourism' and the value that households place on 'agency' prevents DR scale-up. To resolve this, Schot et al. (2016) argue for treating users as stakeholders in innovation to increase its appeal. Lopes et al. (2016) recommend embedding DR in existing routines and ensuring override options. Shekari et al. (2021) find that social, cultural, and behavioural variables play a significant role in DR implementation alongside technical and economic concerns. Christensen et al. (2020) show how visibility, ownership, trust, and simplicity shape the response to TVTs.

More generally, Hargreaves and Wilson (2017) provide a framework for analysing user-technology interaction and Darby (2018) and Gram-Hanssen and Darby (2018) explore what smart homes mean to users. Sovacool and Furszyfer Del Rio (2020) propose 13 categories of smart home technologies from basic to automated and sentient homes.

Data sharing, privacy, control, and automation

A cross-cutting subset of DR user literature focuses on how data sharing, data privacy expectations, control, and automation shape DR user acceptance and the user experience. Lee and Hess (2021) identify the impact of prevailing privacy practices in Europe and North America, including customer opt-out policies and independent data storage. Buchanan et al. (2016) show how autonomy, privacy, and trust affect DR uptake and how users respond positively to automation. Gupta and Morey (2022) find general acceptability of automated DR in social housing if accompanied by thermal comfort limits and manual override. On the other hand, Grünewald and Reisch (2020) provide evidence of widespread reluctance to share location data due to mistrust in utilities. Sousa and Soares (2023) identify privacy and cybersecurity as some of the biggest barriers to DR scale-up. Vindegg and Julsrud (2025) show that digital housekeeping complexities make DR technologies difficult to operate and reinforce gendered divisions of labour.

User characteristics, motivations, and preferences

Another set of cross-cutting studies shows the diversity of user characteristics and preferences which shape DR scale-up potential. Grünewald et al. (2015) surface tensions between TVT complexity and customer preference for simplicity. Bradley et al. (2016) provide evidence that rewards, motivations, and practice disruption shape DR response. White and Sintov (2018) show that perceived rather than realised savings drive tariff switching. Wang et al. (2020) demonstrate that younger, wealthier households with multiple appliances are more likely to engage in DR. Sridhar et al. (2023) demonstrate that customers prefer financial over environmental incentives and expect up to €200/year for enrolling heating appliances in DR. Finally, Parrish et al. (2020) argue that familiarity and trust, complexity and effort, and consumer characteristics and routines must be considered in DR product design.

Justice, equity, and capabilities

Justice, equity, and distributional impacts of DR have been explored for over a decade across all three main bodies of literature. Most recently, DR user literature has started to converge on the concepts that shape the flexibility justice debate. Powells and Fell (2019) introduced the concept of flexibility capital to explain unequal abilities to provide flexibility. Crawley et al. (2021) applied the flexibility capital framework to two UK trials. Fjellså et al. (2021a) warned of 'flexibility poverty' if vulnerable households lack access to enabling technologies. More practically, Torriti and Yunusov (2020) discuss who gains and loses from TVTs. Burger et al. (2020) analyse distributional impacts of TVTs. Reis et al. (2021) link energy literacy with TVT uptake. Winther and Sundet (2023) and Phelps and Lanza (2025) show that DR programmes often overlook equity, disadvantaging tenants and low-income households. Calver and Simcock (2021) evaluate the normative implications of DR for energy justice and offer recommendations for customer protection.

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The research papers draw on all three bodies of literature, and their introduction and discussion sections provide detailed explanations of the specific studies most relevant to each paper. To give an overview:

- In paper 1, I draw on DR business models and DR barriers literature to establish the conceptual framework for the interview data analysis. In particular, I explore the impact of technical barriers, barriers to value stack accumulation, and data-related barriers on industry's appetite for and ability to offer DR products.

- In paper 2, I contextualise my findings against research on user-technology interactions and social-practice hybrid studies and draw on user motivations literature to explain why some households were more successful than others in domesticating DR.
- In paper 3, I map out how DR literature has evolved over the past 15 years in GB to understand how it contributed to DR development.
- I draw on justice, equity, and capabilities research across the three papers when discussing risks to DR scale-up.

Although the three bodies of literature were instrumental in contextualising and conceptualising the research papers, when considered alongside the thesis research questions, a few gaps emerge. I show the thesis' contribution to filling these gaps in the discussion chapter.

First, it was difficult to identify studies that cover both the breadth and depth of barriers to DR in a liberalised market. Moreover, the literature only partially reveals the obstacles to scaling from trial to commercial product because it pays insufficient attention to the evolution of DR innovation and to the evaluation of policy outcomes over time. It lacks a conceptual framework for assessing DR's stage of development and only has a limited understanding of how liberalised market structures and policy interventions shape DR dynamics in practice. A model of coordinated policy intervention for DR scale-up in liberalised markets is absent.

Second, whilst literature explains why DR struggles to scale structurally, it pays limited attention to how commercial actors themselves interpret these constraints and translate them into product design and strategy, especially among non-incumbents such as technology firms, demand aggregators, and small electricity suppliers. Most studies treat demand aggregators as a solution to DR scale-up, but do not address who holds system responsibility for coordinating baselines, protecting customers, managing data access, or resolving conflicts between suppliers and aggregators, or how policymakers should think about these issues holistically. Studies thus remain largely diagnostic rather than prescriptive regarding rapid DR scale-up in liberalised electricity markets, and there is little specification of which policy levers should be used and in what sequence to move from niche experimentation to mass-market commercial products.

Third, across the DR user strands, DR research remains fragmented because economic and behavioural approaches downplay the socio-material dynamics of everyday life, whilst SPT gives only limited attention to how DR technologies are actively appropriated and made workable in the home. Smart-home studies often treat the home as a stable site rather than a negotiated space, and trial evidence reveals patterns but rarely explains how DR becomes woven into daily routines. Literature also remains largely silent on how such insights can be translated into a coherent policy strategy for rapid, system-wide DR scale-up in liberalised electricity markets. The focus is predominantly on explaining individual behaviour, everyday routines, meanings of home, and ethical risks, rather than on specifying how market rules, institutional responsibilities, and regulatory instruments should be redesigned to embed these insights into mass-market DR delivery.

BRINGING ESTABLISHED THEORY TO NEW TERRAIN: TWO FRAMEWORKS FOR DR

Below is an overview of the two theoretical frameworks I used in papers 2 and 3 and their contributions to answering the thesis research question. The papers explain the theoretical frameworks in more detail.

Domestication theory

Originating in media and technology studies, domestication theory explains how technologies become embedded in everyday life through users' active negotiation of their meanings, roles, and values. Early work by Hirsch and Silverstone (1992) showed that technologies do not enter the home as neutral devices but are interpreted and re-purposed within the household. According to domestication theory, domesticating an artefact or a process – in this case, DR – means to negotiate its meaning and use in a dynamic and interactive manner, and it implies that both the technology or process, and the user are transformed in the interaction (Sørensen et al., 2012).

When socio-technical learning literature adopted the domestication theory framework, it emphasised three levels (or dimensions) at which domestication takes place: symbolic, practical, and cognitive (Sørensen et al., 2012).

- *Symbolic* domestication captures the meanings and identities attached to technologies. Adoption is shaped both utility and alignment with household narratives. Technologies that are at odds with the household's identity often provoke ambivalence or resistance. Studies show that symbolic interpretations frequently diverge from designers' intentions, illustrating user agency in meaning-making (Bakardjieva and Smith, 2001).
- *Practical* domestication concerns the routines, skills, and material arrangements to accommodate a technology or process in the home. It includes learning to operate devices, coordinating household tasks, adapting routines and troubleshooting. Practical domestication emphasises that technologies require continual effort, and that sustained use hinges on constructing stable, workable routines (Hargreaves et al., 2018).
- *Cognitive* domestication involves building the mental models and interpretive frameworks needed to understand a technology's functions, risks and benefits. It

encompasses learning-by-using, trial-and-error and situating information within existing beliefs. This dimension helps explain why trust, comprehension, and prior experience shape engagement (Parrish et al., 2021).

Although not previously applied directly to DR, domestication theory offered a strong lens for analysing residential DR scale-up. It helped examine how user participation in DR is continuously negotiated rather than triggered by price signals or incentives, showing that DR scale-up depends on coordinating and aligning DR products and devices with household routines, competencies, and identities. Additionally, it captured dynamic participation, demonstrating how engagement with DR changes over time as households learn, adapt, routinise, or resist DR practices. Finally, it helped map out the heterogeneity of DR domestication pathways, which can support DR product and policy design.[3]

Technological Innovation Systems

TIS is a framework for analysing how technologies emerge, mature and diffuse (Markard and Truffer, 2008). Developed within innovation studies (Carlsson and Stankiewicz, 1991), TIS analyses the key conditions or 'functions' that support or hinder the growth of innovative technologies (Hekkert et al., 2007).

TIS analyses the way in which structural elements (actors, networks, institutions) interact to support the fulfilment of a TIS' seven functions (Bergek et al., 2008). Actors (firms, policymakers, etc), networks (trade bodies, customer groups, etc), and institutions (rules, policies, cultures, routines, etc) shape the setting in which a technology develops, but on their

[3] A lot of user-focused DR literature uses social-practice theory, which I have also considered for this thesis. Whilst social-practice theory is strong on explaining routines, I found it less suitable to understanding the *adoption* of new technologies or practices which is what paper 2 is looking to understand.

own they say little about whether the system is actually functioning well. TIS analysis thus focuses on the fulfilment of functions as an indicator of a TIS' performance.

Hekkert et al. (2007) and Bergek et al. (2008) identify seven TIS functions described in Table 2 below and analysed in paper 3. The functions capture what the system *does* rather than what it *is*. They are also actionable – they can be improved through targeted policy or industry intervention.

Table 2: Overview of TIS functions based on Hekkert et al. (2007) and Bergek et al. (2008)

TIS functions	Overview
Knowledge development and diffusion	This function concerns the production and spread of scientific, technical, and market knowledge through research, trials, learning-by-doing, and inter-organisational exchange. Strong knowledge networks accelerate problem-solving and reduce uncertainty, whereas fragmented or weak networks hinder diffusion.
Influence on the direction of search	Technological expectations, visions, policy targets, and socio-political narratives shape which opportunities actors pursue. Signals such as climate targets or electrification strategies guide investment patterns and influence whether new entrants join the TIS.
Entrepreneurial experimentation	Entrepreneurial experimentation involves probing new applications, business models, and technical configurations. Experimentation reduces uncertainty and generates variety. High experimentation is especially important in formative phases.
Market formation	New technologies rarely compete on equal terms with incumbents. Early market formation often relies on temporary niches, subsidies, standards, or preferential procurement. Without dedicated or accessible markets, firms lack incentives to invest and scale.
Legitimation	A technology must be perceived as desirable and credible among policymakers, industry actors, financial institutions, and the public. Advocacy coalitions, policy debates, societal narratives, and the perceived fairness or safety of the technology influence legitimation. Opposition from incumbents frequently delays legitimacy.
Resource mobilisation	Firms and networks require financial capital, human competencies, infrastructures, and complementary assets. Mobilising these resources is determined by investors' confidence, supportive institutions, and the perceived maturity of the technology.

Development of positive externalities	As a TIS develops, spillovers arise: complementary services develop, specialised labour markets form, shared infrastructures grow, and learning in one function strengthens others. These reinforcing feedback loops underpin the transition from a formative to a growth phase.

Analysing how the TIS' seven functions are being fulfilled helps draw implications about the TIS' phase of development. Building on cyclical models of industry evolution (Tushman and Anderson, 2004; Utterback and Abernathy, 1975), TIS scholars distinguish between two phases of a TIS' development (Bergek and Jacobsson, 2003).

- A TIS' *formative* phase is characterised by high uncertainty and scepticism, many entrants and competing designs, a strong need for entrepreneurial experimentation – for instance, through innovation trials, and emerging institutional change.
- When a TIS enters a *growth* phase, uncertainty reduces, there are fewer new entrants, and dominant technology design starts to crystalise, markets are increasingly self-sustaining, and innovation is incremental rather than radical.

TIS scholars assess the maturity of a TIS not by the presence of structural elements (actors, networks, institutions) (Bergek et al., 2008), but by how effectively system functions are fulfilled relative to the two phases above.

Paper 3 used the TIS framework to diagnose the maturity of residential DR development in GB (based on how TIS functions have been fulfilled over time) and to extract policy recommendations to accelerate its scale-up in similar liberalised markets. The TIS focus on activities that can be improved – rather than on structures that are slow to change and unique to each country context – helped explain why DR has evolved as it has in GB and where interventions can most effectively support its future development across liberalised markets.[4]

[4] For the purposes of this paper, TIS offered a better fit than policy-process frameworks such as Multiple Streams, Advocacy Coalition Framework, Punctuated Equilibrium Theory, or Historical Institutionalism

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To summarise, this chapter identified three literature gaps that are particularly salient for scaling up residential DR: the limited attention paid to how DR evolves over time beyond trials; the lack of insight into how commercial actors themselves interpret regulatory and market constraints when designing DR products; and the difficulty of translating rich accounts of household practices and user experience into system-level policy and market design. Domestication theory helps analyse how DR is integrated in everyday life, while the TIS approach offers a structured way to assess DR's ability to scale up. Together, these frameworks support a theoretically grounded assessment of what scaling residential DR entails in practice.

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because the object of explanation was not a discrete policy change, agenda shift, coalition struggle, or path-dependent institutional outcome, but the long-term development of residential DR as a socio-technical innovation system. Over a 15-year period, the central analytical task was to trace how policies, markets, infrastructures, business models, user practices, and expectations co-evolved to shape DR's capacity to diffuse and scale. TIS is particularly well suited to this because it provides a common analytical language for assessing not only politics and institutions, but also experimentation, market formation, legitimation, resource mobilisation, knowledge diffusion, and the feedback between them. By contrast, the alternative frameworks would have illuminated important but narrower dimensions of the story: Multiple Streams moments of agenda coupling, Advocacy Coalition Framework conflicts over beliefs and alliances, Punctuated Equilibrium episodes of abrupt change, and Historical Institutionalism the path-dependent effects of earlier institutional choices. None, however, offers as direct a basis for judging whether the system as a whole was moving from a formative to a growth phase, or for explaining why substantial policy activity and experimentation did not translate into durable market expansion. TIS therefore enabled the paper to connect dispersed developments across the full 2009–2024 period into a single diagnosis of system performance and maturity, which was essential to answering the paper's question about how policy can accelerate residential DR at scale.a

Research design and methodology

Sir Humphrey: If local authorities don't send us statistics, Government figures will be a nonsense.
Hacker: Why?
Sir Humphrey: They'll be incomplete.
Hacker: Government figures are a nonsense, anyway.
Bernard: I think Sir Humphrey wants to ensure they're a complete nonsense.

(Yes, Minister, Series 3, Episode 3: The Skeleton in the Cupboard)

This chapter explains how the choice of research design helps make sense of a complex, policy-relevant phenomenon using evidence that is necessarily incomplete, uneven, and produced from different vantage points. It sets out how an exploratory-explanatory single-case study research design with embedded units of analysis – industry, users, system – helps answer the research question. The chapter details the epistemological and ontological positioning of the research, the mixed-methods approach adopted across the three empirical papers, and the research's limitations.

THESIS RESEARCH DESIGN

Following the typology proposed by Yin (2018), this thesis employs an *exploratory-explanatory single-case study design with embedded units of analysis.* The single case is the *development of residential DR in GB,* and the three units of analysis are: *DR industry*, *DR users*, and the *DR innovation system*. Each unit is explored through a corresponding empirical paper. Collectively, the three papers help answer the case study research question: *How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation?*

Why case study design

Yin (2018) suggests that a case study design is preferable to others when the main research question is a 'how' or 'why' question, the researcher has little or no control over the events analysed, and the focus of the study is a contemporary phenomenon (as opposed to an entirely historical one). This study meets all three criteria.

Why single-case study design

According to Yin (2018), a few conditions justify the use of single-case study design. Table 3 below shows how *the development of residential DR in GB* as a single-case study meets these conditions to help illuminate *how policy can scale residential DR for decarbonisation.*

Table 3: Rationale for single-case study design based on DR in GB in line with Yin (2018)

Condition	Definition (in line with Yin (2018)	Application in this thesis
Critical case	The case represents a significant contribution to knowledge and theory-building by confirming, challenging, or extending the theory	The development of residential DR in GB is a critical test of theories about the role of competition and market-led initiatives in supporting decarbonisation through innovative propositions like residential DR

Unusual / extreme case	The case deviates from theoretical norms. The findings may reveal insights into normal processes	GB offers a unique case of residential DR development because it combines full retail energy market liberalisation, a near-universal smart meter rollout ambition, half-hourly settlement (HHS) reform, generous DR innovation funding, and significant focus on electrification and decarbonisation – the UK was the first country to set legally binding decarbonisation targets
Revelatory case	The researcher has an opportunity to observe and analyse a phenomenon previously inaccessible to social science inquiry	The thesis joins domains rarely studied together: internal industry reasoning, longitudinal household engagement with DR, and longitudinal analysis of DR evolution. This provides a rare opportunity to observe interactions across the multiple dimensions that make up the development of residential DR to support decarbonisation. Additionally, the single-case study is revelatory by virtue of my role in energy policymaking during the DPhil
Longitudinal case	Studying the same case over time and following its trends of evolution	Temporality is embedded throughout the research: paper 1 captures industry perspectives on DR during and after the gas price crisis of 2022-2023; paper 2 follows household engagement with DR over a 6-month period in winter 2022-2023; paper 3 traces DR development over the 15 years since the start of the smart meter rollout in GB. Together, the papers reveal the trends in DR evolution over time.

Why embedded single-case study design

According to De Vaus (2001), a well-designed case study avoids examining just some constituent elements and not others. Instead, it takes into account information gained from several levels to build up a picture of the case. The final case study says more than any of the constituent levels would say on its own. This explains the choice of an embedded (rather than holistic) case-study design tracking industry, users, and the DR innovation system as a whole.

Why exploratory explanatory case study design

In line with the classification offered by De Vaus (2001), this thesis adopts an exploratory-explanatory case study design. To answer the research question, the thesis explores the emerging and under-theorised aspects of residential DR in a fast-changing liberalised market (exploratory approach) and identifies the mechanisms through which industry perceptions, household practices, and system-level institutions shape DR development over time (explanatory approach).

Together, these rationales justify the use of a *single-case study with embedded units* to produce a rich, layered explanation of residential DR development in GB.

EPISTEMOLOGICAL AND ONTOLOGICAL POSITIONING

The thesis adopts a critical realist ontology. It assumes that institutional structures, market arrangements, and technologies are real and have causal effects, yet the interpretations, practices, and meanings of industry actors and households mediate their influence. Residential DR is therefore understood as emerging through the interaction of material infrastructures, organisational systems, and socially constructed user practices.

Epistemologically, the thesis also draws on an interpretivist understanding of how actors perceive, enact, and negotiate DR, combined with a pragmatic commitment to generating explanations that can inform policy and system design. Knowledge is produced through meaning-making (interviews, diaries) and through systematic analysis of institutional and technological developments (event-history analysis). The thesis, therefore, embraces methodological pluralism, recognising the socially constructed nature of DR while analysing its development within real structural constraints.

METHODOLOGY AND DATA

The ontological and epistemological stance supports the mixed-method approach taken in this research. The approach allowed me to unpack the complexity of the overarching research question and collect a richer and stronger array of evidence than with a single method. Empirical papers (or embedded units of analysis) use methods suited to their analytical focus, producing complementary insights. Table 4 below presents an overview of the methods and data used throughout the thesis and how they help answer the overarching research question.

Table 4: How the methods and data support the research question

Overarching research question: How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation?			
	Paper 1	**Paper 2**	**Paper 3**
Units embedded in the case study	DR industry: electricity suppliers, demand aggregators, technology firms, and intermediaries	DR users: households engaging with DR through the 2022-2023 DFS	DR innovation system: actors, networks, and institutions shaping DR development
Methods	Thematic coding of semi-structured expert interviews	Longitudinal diary study covering 13 DR sessions	Event history analysis (EHA) of approx. 300 events relevant to DR that took place over 15 years of DR development Thematic coding of semi-structured expert interviews
Data	Approx 260 pages of transcripts of 33 semi-structured expert interviews held between May 2022 and December 2023 with 11 energy suppliers, three technology companies, three consultancies, three demand aggregators, and one DNO. Purposive and snowball sampling approach	Diaries held by 25 participants between September 2022 and March 2023, covering the 13 DR sessions that comprised the first winter of the DFS. Snowball sampling approach	Over 200 expert reports, policy documents, websites, and specialised energy-sector news platforms. Snowball sampling approach Approx 85 pages of transcripts of 12 semi-structured expert interviews held between May 2022 and December 2023 with seven DR policymakers, three experts from two large electricity suppliers and one independent expert. Purposive sampling approach.

Theoretical foundations	Empirical research with data analysed against five themes derived from academic DR literature	Domestication theory	TIS
How the methods and data support answering the overarching research questions	Expert interviews revealed how commercial actors make decisions that shape the future of DR in liberalised markets, especially in how they design DR products. Positioning the findings in the wider DR literature helped clarify the areas of improvement needed for speeding up DR development	Diaries designed around the three dimensions of domestication showed how and how successfully households integrate DR within everyday lives, which informed recommendations about designing mass-market DR products	EHA helped trace and explain the evolution of residential DR in a liberalised market, whilst expert interviews validated the conclusions. TIS helped assess how well DR developed in GB and identify the areas of improvement that could speed up its development

JUDGING THE QUALITY OF THE RESEARCH

Four logical tests are commonly used to establish the quality of most social science research: construct, internal and external validity, and reliability (De Vaus, 2001; Kidder et al., 1986; Yin, 2018). Table 5 below explains how this thesis meets the criteria.

Table 5: Research tactics employed to develop quality research

Tests	Research tactic
Construct validity tests whether the methods accurately capture the concepts they are intended to study	**Using constructs conceptually central to the research questions:** The research papers making up this thesis explore three constructs: DR industry, DR users, and the DR innovation system. The papers show how and why each construct is conceptually central to understanding and accelerating DR development in liberalised markets and explain how the concepts have been operationalised for this purpose **Use of complementary established theoretical frameworks:** The three constructs explored in this thesis were grounded in DR scholarship and further developed through the application of domestication theory and TIS to residential DR. The approach helped link household practices to system-wide innovation dynamics and commercial practices, providing holistic explanations of residential DR development

	Triangulation of concepts and uses: One of the strengths of the research design is its capacity to reveal the interdependencies between industry, users, and system perspectives on DR. Few studies integrate all three perspectives within a coherent analytical frame. The thesis offers a holistic account of how DR develops, how it is practised, and why its scale remains limited **Explanatory depth of concepts:** Together, the grounding in DR literature, the use of theoretical frameworks, and the triangulation between the three concepts explored in this thesis provide explanatory depth to the concepts used in this research **Uniform and nuanced use of complex terminology**: As shown in the introduction chapter, the terminology in this thesis is used intentionally and uniformly, with clear rationales for how and why terms are used. The use of terminology is grounded in both academic research and commercial/government expertise: the former through academic supervision of the thesis and the academic publication peer-review process; the latter through expert interviews that underpin the analysis. This allows the thesis to provide accurate explanations for complex concepts and processes (e.g. implicit and explicit DR, HHS)
Internal validity tests whether the research identifies causal relationships convincingly	**Methodological triangulation**: The integration of expert interviews, participant diaries, and EHA strengthens the credibility of the findings because each method compensates for blind spots in the others: interviews expose organisational logics and commercial incentives to offer DR, but only make assumptions about the lived experience of DR; diaries tests these assumptions by capturing households' experience of DR; EHA reveals structural and temporal patterns which impact commercial decision-making and users' experience of DR. Together, they create a triangulated understanding that would not be possible through a single method **Convergence of themes:** Themes converge across the three papers, strengthening the conclusions, e.g. the centrality of automation, distributional consequences, and misaligned incentives **Triangulation facilitated by dataset richness:** Interviews were collected from a large number of respondents with diverse expertise and divergent agendas (electricity suppliers, demand aggregators, DR policymakers, technology companies) over a relatively lengthy period of time (one and a half years); diaries captured real-time household engagement with DR over five months; and the EHA was based on over 300 events that took place over 15 years of residential DR development. This allowed triangulation both between different perspectives and across different periods of time **Iterative analysis:** Coding frameworks were iteratively updated and grounded in theoretical frameworks, ensuring that explanations emerge from data rather than assumptions
External validity tests whether and	**Strategic case selection**: As discussed in the introduction chapter, GB is recognised as one of the most advanced DR markets in the world with high smart meter penetration, a competitive retail market, and ongoing

how the results of a case study can be generalised beyond the study context	implementation of market-wide HHS (MHHS). The findings are therefore transferable to other liberalised markets moving towards similar structures, as will be evidenced in the discussion chapter **Diversity of organisational perspectives**: Papers 1 and 3 incorporate perspectives from incumbents (large electricity suppliers), challengers (small electricity suppliers and demand aggregators), policymakers, technology firms, and consultants with an interest in DR. This diversity strengthens transferability by capturing a range of business models and institutional logics relevant to accelerating DR development **Contribution to a field with high policy relevance:** The design positions the thesis to contribute meaningfully to debates on energy system decarbonisation, flexibility markets, and household participation in DR. The research offers insights that are theoretically grounded yet practically relevant **Positioning in wider literature:** All three papers and the thesis as a whole are positioned in wider DR literature to test the validity of the findings
Reliability tests whether the research process is replicable and consistent	**Clear documentation of research procedures**: I explain in each paper how I collected the data and what steps I took to analyse them. I provide extensive participant quotes either in the main body of the paper (paper 2) or in the annexes (papers land 3). For paper 3, I provide evidence that supports the EHA undertaken in annexes 10-12. This transparency allows future researchers to replicate or extend the work

As with any qualitative, multi-method case study, this research is shaped by several limitations. These are grouped below into three categories: limitations arising from the research design (Table 6), from the researcher's role (Table 7), and from the chosen methods and data collection (Table 8). The limitations are discussed in the tables, along with the mitigations employed to address them. Across the thesis, the combination of methods and theoretical frameworks further mitigates these limitations through triangulation.

Table 6: Limitations arising from research design and mitigation strategies

Limitations	**Mitigation strategies**
Qualitative inference rather than controlled causal identification. This limits the ability to attribute changes in DR uptake to specific market or policy interventions	The internal validity of the research is strengthened by coherent explanation-building and systematic triangulation, as shown above
Focus on embedded units rather than on whole-system map. In examining the three embedded	This reflects both the pragmatic limits of the research project and the reality that such a

units – DR industry, DR users, and the DR innovation system – the thesis captures the key components of the relevant DR landscape but does not attempt to produce a complete system map of all elements relevant to residential DR in GB	map is not well defined in practice. Further elaboration would not have strengthened the answer to the research question, as it would simply reproduce GB-specific institutional arrangements that are not generalisable. Where GB-specific elements are introduced, the thesis clarifies their relevance to other contexts; the papers also provide the necessary contextual explanations of the GB setting
Limited generalisability of a single-case approach. Although justified through Yin's four rationales, the focus on a single national context limits the external generalisability of the findings. GB represents a distinctive combination of market liberalisation, smart metering, and policy frameworks; therefore, the dynamics identified here may not transfer directly to countries with vertically integrated utilities or strongly centralised flexibility governance	The thesis addresses this by placing DR in wider DR scholarship and, where possible, providing a comparison of results with results from other countries

With regards to the transferability of the findings, these are likely most transferable to electricity systems that share the main scope conditions of the GB case: liberalised or liberalising market structures, supplier- and/or aggregator-led engagement with households, sufficient metering, settlement, billing, and data infrastructure to support TVTs or DR programmes, and decarbonisation pressures that make DR systemically valuable. In such contexts, the mechanisms identified in this thesis — fragmented value streams, weak incentives for commercial actors, legacy IT constraints, uneven household flexibility capital, and the need for strategic coordination — are likely to travel beyond GB. Transferability is weaker in vertically integrated or strongly centralised systems, or where the basic enabling infrastructures for residential DR are not yet in place, because the causal dynamics of DR development are different. The thesis therefore claims analytical transferability to markets moving toward similar arrangements, rather than universal generalisability.

Table 7: Limitations arising from the researcher's role and mitigation strategies

Limitations	Mitigation strategies
Researcher positionality. My insider status may have shaped data collection and interpretation of ambiguous statements or policy dynamics	As discussed in the positionality statement, I have been aware throughout my research that my insider status could pose challenges to both data collection and interpretation. I have thus taken the following steps to minimise bias: • Immediate transcription of interviews to reflect on my interaction with the participants and avoid bias in subsequent interviews • Re-analysing data at different points in time, as I transitioned from insider to outsider. For instance, I collected and analysed interview data from energy suppliers for papers 1 and 3 whilst I was working in SMIP, but re-analysed these data and wrote the papers two years later, when I both had a better understanding of DR, and I had detached myself from the bias I held with regards to energy suppliers by virtue of my day-to-day engagement with them • Challenging myself to find evidence against things I knew automatically, without being able to identify how I came to know them in the first place. This was especially important for paper 3, which offers a historical perspective of DR development, and much of that history had been my lived experience over the last six years. This lessened the risk that I would bring assumptions or factually wrong interpretations into my research. Cross-verification with public documentation and independent interviews reduced interpretive bias • Prioritising readily observable facts and numerical evidence when adopting critical perspectives • Seeking challenge from supervisors and peers across disciplines. • Iteratively analysing data alone and with co-authors (paper 2) to avoid projecting my own interpretations • Using theoretical frameworks and literature reviews to anchor findings in wider scholarship. The process allowed me to find interpretations and nuances that I had not grasped in my professional capacity • Using my disagreement with participants' views as an opportunity to surface underlying assumptions Nonetheless, interpretations cannot be entirely detached from the lived experience that informed them
Researcher's interpretive role. As with all qualitative and interpretive research, the researcher plays	Coding choices, thematic framings, and the application of theoretical frameworks involve judgment and reflexive positioning. Throughout the thesis, I have prioritised transparency, but readers should remain aware of the constructive nature of socio-technical analysis

an active role in shaping data interpretation	

Table 8: Limitations arising from methods and data collection, and mitigation strategies

Limitations	Mitigation strategies
Expert interviews *Potential respondent bias due to professional identity* Some interviewees, particularly in paper 1, may have emphasised smart metering or settlement constraints because of my prior affiliation with SMIP *Potential recall bias in interviews* Industry experts and policymakers may have recollected events selectively or through organisational narratives	I used the University's research ethics procedures to reassure participants that my research was independent of government. I also triangulated the data across organisations to reduce the influence of individual narratives. The paper 3 EHA cross-checked interview claims against published documents and regulatory records. Where memory biases were likely, events were only included if corroborated by at least one documentary source
Diaries *Diary self-reporting bias* Participants may have over- or understated the extent of load shifting *The household diary sample is non-representative* Diaries collected for paper 2 were geographically concentrated and over-indexed on early adopters of DFS	Diaries required concrete descriptions, which reduced the ambiguity common in attitudinal survey responses. Participants were asked to complete them within hours or days of each DR session to reduce retrospective distortion. Paper 2 does not claim representativeness; instead, it aims for analytical generalisation (Yin, 2018). The findings are explicitly framed as illustrating pathways to domestication, not population-level prevalence and the data limitations are disclosed in the paper
EHA *EHA subjectivity* EHA synthesises extensive documentary evidence but depends on the visibility and archival availability of system events; some informal or internal developments inevitably remain opaque	Events were included only if linked to a specific TIS function, reducing arbitrariness. Paper 3 annexes provide the evidence that underpins the analysis, allowing external scrutiny

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To summarise, adopting an exploratory-explanatory single-case study of residential DR in GB with embedded units of analysis allows the research to capture industry behaviour, household experience, and system-level dynamics in an integrated and longitudinal way. The mixed-method approach and use of complementary theoretical frameworks allow triangulation across perspectives and time, strengthening explanatory depth while remaining attentive to the limits of inference. Together, these choices provide a transparent foundation for the empirical chapters that follow and for answering the thesis research question.

Will liberalised markets deliver demand response? Insights from industry experts in Great Britain (paper 1)

Sir Arnold: It is the law of Inverse Relevance: the less you intend to do about something, the more you have to keep talking about it.

(Yes, Minister, Series 1, Episode 1: Open Government)

This chapter examines the role of industry actors in developing residential DR in liberalised electricity markets. Drawing on 33 semi-structured interviews with electricity suppliers, demand aggregators, technology firms, and other market participants, it analyses how commercial actors understand the potential of DR, how they prioritise it relative to different business and regulatory pressures, and how these perceptions shape the types of DR products that are brought to market. While interviewees consistently emphasise the importance of DR for decarbonisation, the chapter shows that commensurate levels of commercial commitment or organisational investment do not match this rhetorical prominence. Instead, DR remains widely discussed but narrowly implemented, constrained to small customer segments, and treated as contingent on future reforms rather than as an immediate strategic priority.

HIGHLIGHTS

- Energy suppliers in liberalised markets need strong policy incentives to deliver DR
- DR products will likely target only early-adopters, widening inequalities
- Legacy IT systems constrain electricity suppliers' ability to offer DR
- Demand aggregators need stronger policy support to compete with suppliers

ABSTRACT

As electricity systems decarbonise and integrate more variable renewable generation, DR is key to maintaining energy security and affordability. GB provides a valuable case study for understanding DR development in a fully liberalised retail market where electricity suppliers, rather than system operators or vertically integrated utilities, are the primary interface with residential customers. Drawing on 33 semi-structured expert interviews from all major GB electricity suppliers, and several demand aggregators, technology firms, DNOs, and consultancies, this study examines how industry actors perceive opportunities and barriers to residential DR. The analysis identifies five themes shaping DR development: customer interest and equity considerations; market value extraction and commercial incentives; policy and regulatory frameworks; technological readiness, including smart metering and IT system capabilities; and organisational capacity within suppliers and aggregators. The findings show that electricity suppliers predominantly design DR products for early adopters of EVs, assuming low engagement among the wider customer base. Structural barriers – such as split incentives under elective HHS, non–time-reflective bill components, legacy IT systems, and inconsistent market rules – limit the commercial case for offering DR at scale. These dynamics risk constraining DR to a narrow segment of households and embedding distributional inequalities. The paper concludes that achieving GB's projected 10–12 GW of

DR by 2030 will require stronger and more coherent policy incentives, improved market access for demand aggregators, and regulatory frameworks that broaden participation beyond early adopters and ensure equitable distribution of benefits.

INTRODUCTION

Energy systems worldwide are transitioning from a model in which system operators could constantly match supply and demand by controlling the amount of electricity generated, to one in which supply variability is gradually becoming the norm as systems incorporate more renewable electricity (Heptonstall and Gross, 2020). In such systems, DR or '*the change in electricity consumption patterns in response to a signal'* (Element Energy, 2012, p. 9) is one of the tools available to deliver clean power whilst maintaining system security and making electricity affordable (Jalilzadeh Hamidi and Asadinejad, 2024). Residential DR, the subject of this study, is expected to contribute 500 GW capacity worldwide by 2050 (International Energy Agency, 2024a).

DR supports clean power objectives by facilitating the introduction of increased amounts of renewable electricity (Bogdanova et al., 2023) and by reducing the impact that electrification of transport and heat will have on electricity grids (Matevosyan et al., 2019). Customers benefit from the reduction in system costs either directly, if they can participate in DR, or indirectly because lower overall system costs are reflected in price (HM Government, 2025a).

Experts distinguish between various types of DR which mainly fit into one of two broad categories: implicit, or price-based DR, when customers are exposed to a TVT that broadly reflects the cost of supplying and/or transporting electricity at different times; and explicit or incentive-based DR, which rewards customers for reducing or increasing electricity demand upon request, usually with a few hours' notice (Lamprinos et al., 2016; Vallés et al., 2016).

An expansive body of literature discusses various aspects of DR.

DR user studies focus on perceptions and acceptance of DR and examine how users understand and evaluate DR offers, including issues of trust, privacy, and perceived loss of control (D'Ettorre et al., 2022; Lee and Hess, 2021; Parrish et al., 2020). Work on flexibility of routines explores how everyday practices and lifestyle constraints shape households' ability to engage with shifting demand (Friis and Haunstrup Christensen, 2016; Mihalache et al., 2024; Reis et al., 2021). Research on automation and user response investigates the role of automated technologies in enabling participation and improving reliability of response (Nilsson and Bartusch, 2024). With the development of smart technologies, Strengers (2014) introduces the notion of Resource Man to shine a light on a prevalent industry vision of electricity customers as rational and tech-savvy. Finally, conceptual contributions on equity introduce the idea of flexibility capital to explain how structural and material conditions shape households' ability to act flexibly (Powells and Fell, 2019).

Policy-oriented research examines DR through several lenses. Studies on regulatory structures and market liberalisation analyse how competitive frameworks and institutional arrangements shape opportunities for DR to develop (Bergaentzlé et al., 2014; Torriti, 2024; Vallés et al., 2016). Work on incentive design and settlement mechanisms investigates how pricing signals and market rules support or hinder DR participation (Eid et al., 2016; Forouli et al., 2021; Sousa and Soares, 2023).

Studies on household financial benefits quantify the savings achievable through DR participation in different national contexts (Gnann et al., 2025; Katz et al., 2018; Sundt et al., 2020; Vesterberg and Krishnamurthy, 2016). Work on tariff structures and cost-reflectivity examines how pricing design can better align customer incentives with system needs (Burger et al., 2020; Morell-Dameto et al., 2023; Willems and Zhou, 2020).

Technical aspects of DR research focus on device and system performance and analyse the reliability of smart meters and smart technologies (Chen and Ge, 2024; D'hulst et al., 2015; Gupta and Morey, 2022; Kepplinger et al., 2024; Ma et al., 2021; Parejo et al., 2021). Research on organisational and integration challenges explores how utilities' IT platforms, migration processes, and user-facing technologies shape their ability to deliver innovation and interoperable DR solutions (Kattirtzi et al., 2021; Vindegg and Julsrud, 2025; Weck et al., 2017).

Some studies focus on demand aggregators. i.e. electricity suppliers or other commercial entities who act as intermediary agents that pool flexibility from different customers and act as a single entity when engaging in electricity markets and selling services to system operators (Burger et al., 2017; Granado et al., 2023). Studies analyse how organisational structures and resource constrains influence demand aggregators' ability to innovate (Brown et al., 2019; Capper et al., 2024; Schittekatte et al., 2021).

Despite extensive research on DR users, technologies, market design, and policy frameworks, the literature lacks an integrated, up-to-date analysis of how industry actors perceive, design, and operationalise DR in liberalised markets, and how these perspectives shape DR development. This research fills that gap through a qualitative case study of residential DR in GB – a country with a tradition of liberalised markets and energy retail competition – as seen from the perspective of industry experts, with a particular focus on electricity suppliers who are the main conduit through which GB customers can access DR. It seeks to answer the following research questions: *What is the industry perspective on DR in GB and what implications does that have for the development of DR in a liberalised market? How can policy make use of these findings to further support development of DR in liberalised electricity markets?*

The study makes three key contributions to the literature on DR in liberalised electricity markets. First, it provides the most complete qualitative assessment to date of DR perceptions across the GB energy industry, drawing on interviews with 33 experts from all major residential electricity suppliers and a wide range of demand aggregators, technology providers, and consultancies. Given GB's advanced smart metering infrastructure, competitive retail market, and the upcoming implementation of MHHS in 2027, these findings offer insight into how commercial actors think about DR in a context that other markets may soon resemble. It complements and updates findings from Goulden et al. (2018), Earl and Fell (2019) and Capper et al. (2024) who also sought views from GB industry experts to draw implications for DR development. Together, the papers reflect the evolution of expert perceptions over DR in GB over the last decade. Second, the study advances conceptual understanding of how electricity suppliers design DR products around imagined user types and how this design shapes customer reach and distributional consequences. Third, the study identifies structural misalignments between regulatory incentives, organisational capabilities, and market design that hinder supplier and aggregator participation in DR. The findings illuminate how policy and regulation can better align commercial incentives with system needs.

The rest of the paper unfolds as follows: the next sub-section provides an overview of the GB retail market aspects relevant to the development of DR. The methodology section then describes the data collection and analysis process, and the limitations of the research. The results section presents the findings from interviews which are then contextualised and interpreted against previous research in the discussion section. The discussion section also draws out the policy implications of the findings and sets out future areas of research. The final section concludes.

CHARACTERISTICS AND EVOLUTION OF THE GB RETAIL MARKET

The liberalisation of the GB energy sector in the 1990s established one of the most market-oriented governance models in Europe, built on the assumption that competition would decrease prices, stimulate innovation, and improve customer service compared with vertically integrated monopoly regimes (Joskow, 2008).

The GB retail energy market is designed around a supplier hub model whereby each customer has a single, licenced energy supplier, which is the primary point of contact for and intermediary between the customer and the energy system (Watson et al., 2024). Beyond managing transactions between customers and the energy system (like billing customers for all energy costs), energy suppliers in GB are also responsible for rolling out smart meters across their customer portfolios, accompanied by in-home displays (IHDs) and energy efficiency advice to support customers better understand their energy usage (Darby, 2010). Suppliers' direct relationship with customers puts them at an advantage over demand aggregators when offering DR products by virtue of their ability to control customer billing, settlement, and data flows (Watson et al., 2020). All this makes electricity suppliers key players in delivering GB's ambition of 10-12GW of DR capacity by 2030, a four-fold increase from 2025 levels (HM Government, 2024a).

The GB retail energy market has changed significantly over the last decade. A competitive boom up until around 2020 gradually weakened the dominance of the 'Big Six' energy suppliers[5] – British Gas, EDF, SSE (whose supply business is now part of Ovo Energy), Scottish Power, E.On, and Npower (now part of E.On) – who had traditionally served nearly

[5] Most GB suppliers offer both gas and electricity supply. When referring to both their gas and electricity business, the article talks about *energy* supply. Otherwise, the article refers to *electricity* supply only

all GB households (Kattirtzi et al., 2021). Challenger firms like Ovo, Bulb and Octopus Energy grew quickly, offering cheaper deals and innovative tariffs.

Octopus Energy stands out for having become GB's largest electricity supplier in less than ten years after its creation (Derrick, 2024). Its proprietary DR-enabling enterprise resource management (ERM) platform, Kraken, now also serves customers in Texas (Latief, 2023), Japan (Octopus Energy, 2023a), and Germany (Latief, 2025). ERM platforms are critical for modern energy supply businesses because they are the IT platforms serving as the backbone for handling customer portfolios by integrating complex operational flows like supplier switching, customer billing, and tariff changes. By capturing and analysing detailed customer data, a supplier can tailor pricing and service offerings, improve responsiveness, and streamline cost structures. Some ERM platforms, like Kraken also support the integration of DR by linking real-time data flows, customer segmentation, and dynamic tariffs (Trahan and Hess, 2021).

The 2021 gas price crisis triggered a wave of supplier collapses, with 29 energy suppliers exiting the market by April 2022 (National Audit Office, 2022). The retail market domination of the Big Six broadly resumed by 2025, albeit with slightly different players: Octopus Energy, British Gas, EDF, E.On, Ovo, and Scottish Power. Some small energy suppliers still operate in the market, mostly specialised in various niches like green tariffs (Ecotricity, 100 Green, Good Energy), prepayment customers (Utilita, E Energy), or multi-utility bundles (Utility Warehouse).

The 2021 market exits highlighted the vulnerabilities of a low-margin retail market which since 2019 has been operating under a price cap. The price cap was introduced to protect customers on standard variable tariffs – the tariffs onto which customers default after their fixed-term contracts expired – if they do not switch supplier or tariff (Ofgem, 2018). The price cap also applies to the approx. 4 million customers on a prepayment meter (Ofgem, 2023a) – customers who pay for their electricity in advance of using it, a type of payment introduced to prevent debt accumulation amongst the less affluent energy users (Fawcett et al., 2024).

Even with these protections, GB electricity bills are some of the highest in Europe (Bolton, 2025), prompting a political pledge from the ruling Labour party to reduce energy bills by up to £300 by 2030 (The Labour Party, 2024). The main components of the GB electricity bill, or the bill stack, are wholesale costs (~30%), policy costs (~25%), network costs (~21%) and supplier costs and margin (~14%) (James, 2025). Of these, only wholesale costs and a small proportion of the network and policy costs are time-reflective which, as shown in the discussion section, is key to DR development. Electricity suppliers' wholesale costs depend both on market prices and on how effectively they manage risk through hedging (i.e. buying electricity in advance at agreed prices). After customers actually use electricity, the settlement process checks whether the supplier bought the right amount. If they bought too little, they must pay extra; if they bought too much, they may get money back. Settlement has traditionally been based on standardised consumption profiles rather than customers' actual half-hourly usage. Profile-based settlement blunts the time dependence of the price signals that would otherwise flow through to suppliers and, in turn, to consumers, limiting the incentives for DR and reducing the value of flexible loads.

In 2016, electricity suppliers were given the option to settle their customers on a half-hourly basis through *elective* HHS, an arrangement that suppliers could opt into if they thought it beneficial for their business. In 2021, a decision was made to move to *market-wide* HHS from 2025 onwards, removing for suppliers the optionality that elective HHS had offered. The target date for MHHS completion later moved to 2027 due to implementation delays. HHS – as opposed to settling on standard average profiles – is expected to incentivise electricity suppliers to offer DR products by exposing them to the true cost of serving each customer.

Most recently, NESO has been running the DFS since winter 2022. The DFS is an explicit DR national programme, in which both electricity suppliers and demand aggregators can enter their customers. The DFS represents a turning point for DR in GB because it is the first DR-dedicated market, with over 2 million participants in 2024-2025 (HM Government, 2025a)

METHODOLOGY

Data collection

This study is based on interviews with all the large GB residential electricity suppliers (i.e. those with more than 5% market share) and all but one of the small residential electricity suppliers with a market share equal to or above 1%. Altogether, these suppliers served c. 95% of GB electricity customers in 2025. Table 9 shows the 2025 market share of each electricity supplier interviewed for this research. Additional interviews with industry experts across specialised consultancies, network companies, technology companies, and demand aggregators helped complete the picture of how industry experts regard DR in GB.

Table 9: Market share of interviewed electricity suppliers

Electricity supplier	Market share (electricity, residential) in Q2 2025*
Octopus	24.6%
British Gas	20.9%
E.On	15.7%
Ovo	12.2%
EDF	10.2%

Scottish Power	8%
Utility Warehouse	3%
So Energy	1%
E Energy	~1%
Good Energy	~1%
Ecotricity	~1%

*https://www.ofgem.gov.uk/energy-data-and-research/data-portal/retail-market-indicators

Altogether, 33 expert interviews were held between May 2022 and December 2023 with 11 energy suppliers, three technology companies, three consultancies, three demand aggregators, and one DNO. Interviews were held over MS Teams and recorded with the consent of the participants, then pseudonymised and manually transcribed. Table 10 shows the number of participants and interviews held, alongside details about the organisations with which they were affiliated, to the largest possible extent without the risk of compromising participants' anonymity.

Table 10: Interview participants and organisations

Type of organisation	**Number of organisations**	**Number of interview participants**	**Participating organisations**
Electricity suppliers	11	17	Octopus Energy, British Gas, E.On, Ovo, EDF, Scottish Power, Utility Warehouse, So Energy, E Energy, Good Energy, Ecotricity
Technology companies	3	3	A multinational corporation active in the search engine technology and cloud computing space; an independent data transfer service for the energy market; a smart appliance manufacturer
Demand aggregators	3	3	A cloud-based platform that automatically optimises EV charging; an app that helps manage household demand; a not-for-profit company that establishes and manages local energy markets
Consultancies	3	8	LCP Delta, Baringa, confidential
DNOs	1	2	Confidential
Total	21	33	

A purposive sampling approach was employed to identify the organisations in scope of the research. This method allows respondent selection based on the researcher's judgement of which respondents add most value to the research (Babbie, 2021). The aim of the research was to derive both a comprehensive understanding of perception of DR across GB energy experts, and an in-depth understanding of DR perceptions across the organisations closest to the customer. The interviews with small energy suppliers particularly provide novelty as these smaller organisations are seldom reflected in DR academic research. Interviews with both small and large suppliers, and with demand aggregators made possible the comparison of DR perceptions across the GB retail market, as will be explored in the discussion section.

A snowball sampling approach was then used to identify experts within each organisation. This allowed data to be collected in some cases from two or more respondents from each organisation which helped with corroboration and drawing conclusions around an organisations' ethos with regards to DR. To strike a balance between knowledge and authority of respondents (Kvale and Brinkmann, 2008), interviews were sought from a set of respondents diverse both in terms of area of expertise, and seniority in the organisation. Emphasis was placed on identifying participants who had worked directly on customer propositions in their respective organisations (e.g. product/commercial/pricing leads). Table 11 provides an overview of participants' roles in their respective organisations.

Table 11: Overview of interview participants' roles within their organisations

Type of role within the organisation	**Number of participants**
Commercial and/or product and/or pricing lead / expert	14
Analyst/consultant	8
Research and development and/or data lead / expert	4
Policy and regulations lead/expert	3
CEO / CTO	2
Trade specialist	2

Total	**33**

The interviews were semi-structured, and participants were asked at the start what they see as the potential and barriers to DR development in GB. Where applicable, the questions then probed further on the impact of DR on their organisation e.g. how internal processes or IT systems of the organisation would need to evolve to accommodate DR, what benefits the organisation in question would gain from DR, what partnerships the organisation had developed or planned to develop to support DR. External factors like policy and regulation, technological development, and economic and political context were also explored when relevant to DR development. The flexible interview style provided detailed insight into respondents' perspective, allowing their priorities to come to light.

Most interviews were conducted in the aftermath of the pandemic and gas price crises, so some respondents, especially small energy suppliers, focused on DR in that specific context. This gives valuable insight on perceptions of DR during times of market volatility but also prevents some conclusions from being generalisable. To mitigate this, data were collected over almost two years (between May 2022 and December 2023) and interviews from the more tumultuous period (mid-2022) were triangulated with those from the following year. Most interviews were held before the start of the DFS – which, as mentioned above, represented a significant turning point for DR in GB, – but where available, the changes in perceptions post-DFS were reflected in the results.

Although the study includes all major suppliers and a wide range of aggregators and consultancies, the sample is weighted toward suppliers. This reflects the central role suppliers play in GB's supplier hub model but also means that aggregator perspectives are less prominent. This limitation is acknowledged in the discussion section.

The researcher's network of contacts by virtue of her professional role at the time of interviews – government official working on GB's smart metering programme – made it possible to access the large and diverse sample of participants. However, it may have also shaped some of the respondents' answers. For instance, respondents may have overemphasised smart metering challenges in developing DR. To reduce this risk, participants were explicitly assured that the research was independent, and data would not be shared with government. Additionally, findings were triangulated across respondents to reduce bias.

Data analysis

The data were analysed deductively and inductively to solidify the conclusions. The process is explained below.

Step 1: A review of DR literature on industry perceptions of DR (Capper et al., 2024; Earl and Fell, 2019; Goulden et al., 2018), DR barriers, drivers, and potential (Bogdanova et al., 2023; Eid et al., 2016; Parrish et al., 2020; Sousa and Soares, 2023; Weck et al., 2017) identified five themes relevant to the research questions. Some preliminary sub-themes across each theme were also identified from the literature. Both themes and sub-themes were originally framed around barriers to DR, as derived from literature e.g. not allowed by regulation, lack of customer interest, no access to data.

Step 2: Electricity supplier interviews were coded in Nvivo using this preliminary framework. New sub-themes emerged from the data. All themes and sub-themes were then re-framed in neutral terms to accommodate the emerging variety of views from respondents e.g. what some respondents saw as a barrier, others saw as an opportunity.

Step 3: A supplementary review of wider literature was used to stabilise the emergent themes of the framework, following which the rest of the data were coded, and the results were written up.

The results section presents the themes and sub-themes identified from the interviews. When a sub-theme could fit under more than one theme, a decision on where it belongs was made based upon the prevalent framing given to it by respondents. For instance, the sub-theme ‘automation of loads and tariffs’ could fit both under the customer and the technology themes. Almost unanimously, respondents referred to automation as a key aspect of customer acceptance of DR, rather than referring to the technical aspects of automation – such as the interoperability of ESAs like EV charge points, batteries or heat pumps with smart controls – so the sub-theme was added to the customer theme.

Where possible and relevant to the research questions, the study presents the number and type of respondents who shared certain views but, in line with Maxwell (2010) avoids misleading and acontextual counting. Verbal counting is used to avoid overcounting and maintain the aesthetic presentation of the findings: ‘some’ / ‘a few’ and ‘many’ / most’ are used to denote less than half and more than half of the respondents in a certain category, respectively.

RESULTS

The research identified five themes shaping DR development in liberalised electricity markets. Ranked by the frequency of reference, these were: customers, markets, policy and regulation, technology, and organisational capability. Across these, extracting value from DR, incentives for firms to offer DR, and customer interest in DR were the most prominent sub-themes. Table 12 presents an overview of the themes and sub-themes alongside the number of references for each. Annexes 1-5 present a non-exhaustive list of supporting quotes for each theme and sub-theme chosen for illustrative purpose.[6]

Table 12: Overview of themes and sub-themes

Themes	Sub-themes	Number of references	Total references	Summary
Customers	Customer interest in DR	65	134	Respondents see simplicity, trust, fairness, and automation as critical for the adoption of DR products. The interviews reflect optimism about technological solutions such as tariff and load automation but highlight significant behavioural and demographic barriers that need addressing to achieve broader participation.
	Equity and fairness	36		
	Automation of loads and tariffs	33		
Markets	Extracting value from DR (for the system, customer, and business)	84	127	Whilst respondents recognise DR's significance to system decarbonisation, they also raise concerns about how these benefits translate to individual customers participating in DR and the businesses expected to offer DR products. Most suppliers view 'lifestyle tariffs' (explained later in this section) as a primary method to increase customer retention and satisfaction, passively aligning tariffs with existing consumption patterns, though some respondents acknowledge the potential of demand-shaping strategies that actively modify demand profiles to support renewable integration and system flexibility. The responses stress the complexities faced by commercial actors offering DR products, including concerns over profitability, market power imbalances, and regulatory support. Market barriers such as administrative hurdles, unclear methodologies, and limited access for smaller players hinder the growth of DR share in various markets.
	Coordination and alignment between commercial actors	25		
	Market barriers	18		

[6] Many quotes which were used in the analysis were excluded from the annexes to preserve the anonymity of the respondents

Policy and regulation	Incentives for firms to offer DR	83	121	The complexity of the regulatory environment in which electricity suppliers operate is hindering DR innovation. MHHS is fundamental to incentivising firms to offer DR products, but lighter touch early alternatives like elective HHS are insufficient for swaying the balance of costs and benefits of system change in favour of DR.
	Policy and regulatory context	38		
Technology	Types of loads suitable for DR	37	115	The business case for offering DR products is dependent on the rollout of flexible loads like EVs and heat pumps. Electricity suppliers' legacy IT systems pose a challenge to integrating these flexible loads with DR products, so the ongoing migration to modern IT platforms is key to DR development. Smart metering is identified as both a technological enabler and a barrier, with issues related to communication reliability and customer acceptance. Whilst many respondents emphasise the importance of customer privacy and trust when it comes to data sharing, access to data is viewed as a barrier by non-supplier respondents, but not by suppliers.
	Business systems	33		
	Smart metering	23		
	Data access	22		
Organisational capability	Perspectives on innovation	12	56	Most electricity suppliers, especially small ones, have limited resources for DR innovation. Although large suppliers experimented with DR and are investing in upgrading their IT systems, Octopus Energy was the only supplier whose business model revolved around innovative DR products at the time of interviews.
	Resources and expertise	44		

The themes and sub-themes are detailed below.

Customer theme

Customer interest in DR

All respondents identified customer interest as a critical factor shaping the viability of DR. A recurring perception throughout all interviews is that most customers prefer simplicity and are reluctant to engage with complex pricing models. The challenge of customer understanding of and buy-in to DR is emphasised as a significant barrier by most respondents.

All but one electricity suppliers assumed limited customer interest in DR beyond early adopters and attributed this to the socio-demographic characteristics of their customer portfolios (e.g. age, socio-economic position, and technical proficiency). While small suppliers *assumed* (rather than tested) low interest, large suppliers cited evidence from own trials and commercial products to provide a view of DR interest across their customer portfolios, broadly concluding that some segments of their customers, especially those with EVs, could be interested in and benefit from DR. Six electricity suppliers spoke of their customer portfolios in contrast to that of Octopus Energy and believed that customers interested in DR had already switched to Octopus. As such, they did not regard Octopus Energy's DR products as genuine competition for their remaining customer base.

Other respondents, especially demand aggregators, were generally more optimistic than electricity suppliers with regards to potential customer interest in DR and saw awareness raising and education as variables that can increase customer pull for DR.

All suppliers had a strong focus on customer journeys. Suppliers with more advanced DR customer propositions or plans to offer DR soon highlighted life events, such as EV purchase or moving home, as critical engagement opportunities. A holistic view of customer journeys emerged across these suppliers, encompassing data access, incentives, and recognition of heterogeneous needs and capabilities across customer portfolios.

Equity and fairness

Concerns about fairness, especially regarding the impact of TVTs on different customer groups, are prominent across interviews, with extensive discussion about the challenge of balancing incentives for shifting demand without penalising those unable to shift. The risk of high peak-time prices disproportionately affecting vulnerable groups was mentioned by most suppliers, and respondents consistently agreed that participation in DR would not suit all households and that higher-load customers (i.e. with EVs and heat pumps) in favourable socio-economic circumstances would benefit most, at least initially. One supplier and one consultant suggested that Government subsidies for EVs and heat pumps can widen those benefits. One supplier had capped the exposure under its TVT but did not regard this solution as scalable in the high price environment in 2022-2023.

Some DNO, aggregator and consultant respondents warned of a ‘postcode lottery’ effect of explicit DR products offered by DNOs, whereby households with low flexibility capital could face higher costs, while those with greater flexibility might not be able to capture the full benefits of DR due to their geographical location[7].

When prompted, most respondents saw the potential of prepayment meter customers benefiting from tailored DR products, but no supplier had plans or an appetite to do so.

Automation of DR loads and tariffs

Automation of DR loads and tariffs was viewed by all respondents as fundamental to the success of DR products, particularly for large loads like EVs and heat pumps. Manual DR was deemed unviable except for customers motivated by environmental values, with low tariff-switching rates cited as evidence of behavioural inertia. Respondents argued automation both increased customer rewards and reduced disruption. One DNO and one aggregator respondent interviewed post-DFS showed some optimism about manual DR, but it was at best considered a short-term top-up to automated DR in energy security crises. No

[7] Section *Postcode lottery* in annex 1 provides more insight into how respondent define this industry jargon term

respondents mentioned habit formation as a pathway to sustainable manual DR. A few respondents suggested strategies like real-time feedback, gamification, and notifications could improve engagement, alongside the need for education and reassurance around DR products.

Most respondents assumed that customers would accept automation alongside an override option. One supplier raised concerns around acceptance of automation in the context of talking about a non-DR product they had offered; by contrast, one supplier and one aggregator reported their customers were very receptive to automation and very rarely overrode the automation in spite of having the possibility.

Markets theme

Extracting value from DR

Respondents recognised DR's system-level benefits, such as integrating renewables and reducing reinforcement costs, but saw limited value for individual customers or suppliers.

Value of DR for the system

A few respondents proactively spoke about DR's importance to building flexible systems and streamlining infrastructure planning to enhance renewable energy integration and system efficiency while addressing societal fairness issues. One large supplier expected the need for DR to grow as the system integrates more intermittent renewable energy. One consultant and the two DNO respondents highlighted the challenge of reconciling network build with affordability and fairness as insufficient network capacity leads to the underutilisation of renewable generation, which could incur higher costs than expanding infrastructure. One DNO respondent saw investment in network reinforcement as a societal decision, especially when such investments may remain unused for decades, raising questions about fairness and cost distribution. All three respondents saw DR as an opportunity to bridge these tensions.

Value of DR for the customer

The discussions revealed a consensus that while customers are interested in energy savings, their participation in DR is heavily influenced by the perceived financial benefits versus the upfront costs of participation.

All but one large electricity supplier highlighted that trials or commercial products they had offered failed to secure sufficient savings for the customer to make their participation in DR worthwhile. Large suppliers cited customer savings ranging from £20 to £60 per year but expect savings of around £100 are needed to motivate participation. It was not clear from the interviews what load or customer types had been targeted for these trials or commercial products. By contrast, one supplier claimed significant benefits across their customer portfolio (without providing a number), especially from automated EV TVTs. Whilst some suppliers acknowledged, when prompted, the opportunity of getting higher customer savings from DR in the high-price environment of the interview period, no supplier planned to act on this.

One consultant noted that the main customer barrier to DR is the upfront cost of installing new systems, which customers are often unwilling or unable to pay, especially when these costs are in the hundreds of pounds. One supplier and one demand aggregator called for subsidies to encourage customer participation in DR.

Some respondents thought that customers often struggle to relate unit rate reductions to actual daily or hourly savings, indicating a need for better communication and framing of benefits. One DNO respondent emphasised the potential of negative pricing (or demand turn-up) to motivate customer participation in DR, suggesting that this could be an effective gateway for increasing customer engagement in DR programs.

Most suppliers tended to view TVTs as ‘lifestyle tariffs’ which they described as tariffs that match a customer’s already un-peaky lifestyle, suitable for instance to shift workers who tend to not be home during the evening peak. Some of the customer savings quoted above had been derived from lifestyle tariffs. Electricity suppliers saw lifestyle tariffs as a way of increasing customer retention and satisfaction by aligning tariffs with existing consumption patterns. Suppliers discussed the possibility of offering lifestyle tariffs tailored to specific customer segments, such as EV owners or remote workers. One large supplier talked at length about the complexity of offering a lifestyle tariff which they believed complicates hedging and customer quoting, whilst at the same time creating unpredictability for the supplier if the customer behaves unexpectedly. Regardless of the downsides, the respondent still saw lifestyle tariffs as the only option for TVTs. Another supplier acknowledged the potential of behavioural economics and nudging techniques to influence customer behaviour rather than offering a tariff that fits their existing lifestyle. However, they emphasised that their goal was to help customers save money and as a result foster positive brand perception rather than supporting behaviour change.

Alongside consultants and demand aggregators, only Octopus Energy understood DR as going beyond lifestyle tariffs, arguing that lifestyle tariffs do not address the core opportunity of DR. They emphasised that the real opportunity lies in engaging customers to modify their demand profiles actively, which would support renewable energy integration and system flexibility. They suggested that offering lifestyle tariffs is less innovative than demand-shaping strategies.

Value of DR to commercial actors offering DR products

Overall, the interviews reflect a consensus that while there are benefits and potential profitability from offering DR products, significant operational, market, and behavioural challenges remain, with profitability being dependent on market conditions, customer asset ownership, and regulatory support.

Return on investment in DR was a persistent concern across electricity suppliers, with five large and two small suppliers leaning towards investment in DR not being worthwhile, versus three large and one small supplier focusing more on the benefits of DR than its costs in their responses. Six respondents speculated that Octopus was not making a profit from its Agile tariff and potentially subsidising it, with one supplier and a demand aggregator reporting rumours that Octopus Energy is using the subsidy to promote Kraken, the flexibility arm of its ERP platform.

In terms of benefits of DR for their business, one supplier reported potential market power redistribution from generation to demand. Another supplier described the potential to make profit from less peaky prepayment meter profiles by offering attractive DR products. On the flipside, another supplier emphasised that profitability hinges on wholesale market exposure and that wholesale market prices before the Covid-19 pandemic had not been compelling for offering DR products.

One demand aggregator confirmed the lack of appetite from suppliers and private investors to support DR due to perceived risks and customer engagement concerns, with government support deemed necessary. One supplier also raised scalability and efficiency in deploying TVTs as significant hurdles, especially regarding smart meter capabilities and customer engagement. They also highlighted that until customers possess large electricity-consuming assets like EVs, the risks for suppliers remain high, limiting the attractiveness of offering TVTs.

Suppliers were prompted to consider how DR products weigh into their customer attraction and retention strategies. Most suppliers saw the potential of DR as a customer retention tool, especially for EV customers, though few acted on this at the time. Some anticipated that TVTs would become a standard customer expectation as transport electrification progressed.

Coordination and alignment between commercial actors

Some respondents proactively identified the complexity of commercial and operational arrangements in the GB electricity sector and siloed working as barriers to DR, emphasising the need for standardisation, better integration, and clearer roles among stakeholders to facilitate the transition to more flexible and efficient energy systems. The barriers ranged from data management and system integration challenges making it difficult to create innovative DR products like HEM systems[8] (six respondents); lack of coordination and standardisation between various national and local markets making it difficult for DR providers to engage in these markets, and unclear roles between suppliers, aggregators and networks in engaging customers for providing DR (five respondents); inability of price comparison websites to present TVTs in a way that would help suppliers attract customers (one respondent); and a lack of coordination between energy and non-energy actors involved in setting up smart technology (one respondent).

One consultant spoke at length about the complex ecosystem of commercial actors that underpins HEM systems, viewed as a staple of smart homes, noting that relationships still need to evolve to guarantee customer protection across the value chain e.g. clarify who is responsible for fixing a smart device on a TVT in case it breaks.

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[8] This article uses the term home energy management (HEM) system to refer to a digital/home-level system that monitors, controls, and optimises a household's energy generation, storage, and consumption. This reflects the respondents' definition of the term

Market barriers

Some respondents proactively spoke about market barriers to explicit DR in markets such as the wholesale market, the BM, ancillary services, and local markets (i.e. markets operated by DNOs). One large supplier highlighted that, at the time of interviews, the system operator was still increasing and decreasing generation as the primary tool for flexibility and was just starting to trial demand reduction techniques to assess their reliability and scalability. Another large supplier spoke about the imbalance in market power between generators and suppliers, with generators possessing more market power than retailers due to higher capitalisation and decision-making autonomy regarding when to sell energy. By contrast, retailers operate on low margins and face risks if they do not hedge their energy, making their market behaviour more constrained.

One demand aggregator, one consultant and one DNO respondent spoke about administrative barriers preventing smaller players from accessing markets in which they can sell DR, unclear baselining methodologies for DR products, and the inability to stack revenues between markets jeopardising the business case for DR.

Policy and regulation theme

Incentives for firms to offer DR

All participants discussed whether and how firms in GB, particularly electricity suppliers, are incentivised to offer DR products. Respondents referenced three aspects related to incentivisation: elective HHS, MHHS and the time reflectivity of the components which make up customers’ electricity bills.

A few electricity suppliers recognised a potentially positive financial case for *elective HHS*. All large suppliers had modelled elective HHS across their portfolios[9], but only two deployed it in practice. None of the small suppliers had modelled elective HHS across their portfolios. Most suppliers considered that the cost and effort of implementing elective HHS outweigh its benefits to the business due to IT system limitations, data quality issues, and the risk of higher balancing costs. Whilst recognising that elective HHS can lower overall system costs, they did not want to be the ones driving this benefit without their competitors pitching in. Instead, they preferred to wait until MHHS mandates sector-wide participation. Most suppliers found the current settlement arrangement easier and less risky.

All respondents expected MHHS to incentivise suppliers to develop DR products by exposing them to the true cost of serving each customer. At the time of interviews, MHHS completion was scheduled for October 2025, although most respondents expected delays, leading electricity suppliers to believe that preparation would be premature. All suppliers perceived MHHS as distant and outside their control, and noted MHHS would complicate core activities like hedging, and require integration with third-party data agents, many of whom lacked capability.

Most respondents also discussed the limited time-reflectivity of the electricity bill stack. Wholesale cost was the only component deemed by participants as sufficiently dynamic and time reflective. The static signal offered by network costs and some policy costs was seen as insufficient to incentivise suppliers to offer DR or to reward customers for changing

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[9] Elective HHS allows electricity suppliers to cherry-pick the customers they settle on a half-hourly basis – so they can settle only already un-peaky customers on a half-hourly basis, without necessarily offering these customers a DR product. The flatter profile automatically translates into a saving for the electricity supplier who can then distribute the saving across its entire portfolio to offer more attractive tariffs, including fixed tariffs

behaviour. One supplier and one DNO saw this as a significant barrier to negative pricing or demand turn-up i.e. paying customers to use electricity at times of high renewable output.

Regulatory context

All respondents discussed the policy landscape of 2022 and how the gas price crisis was making it difficult for commercial actors to stay afloat, let alone consider innovative offers like DR products. Suppliers also discussed the impact of the supplier hub model and the price cap on their ability to innovate long-term, regardless of the 2022 context. Small suppliers in particular reported heavy regulatory burdens arising from the supplier-hub model, which diverted attention from innovation. Most suppliers identified the price cap as being a barrier to DR by precluding supplier investment in innovation as well as limiting customer incentive to switch tariffs. Some suppliers raised questions about compatibility of TVTs with the cap but had not discussed these with Ofgem, the GB energy regulator.

A few respondents proactively shared their views on working with Ofgem and government and the relationship was generally described positively. Regulations overall were not seen as a barrier, and respondents saw initiatives such as the smart meter rollout and setting smart appliance standards as fundamental to DR development.

Technology theme

Types of loads suitable for DR

All respondents thought that DR requires large, automated loads like EVs and heat pumps to give customers sufficient savings to make DR worthwhile. Some electricity suppliers argued government support for electrification should precede wide DR adoption to create sufficient customer pull for DR products. Some small suppliers did not think it necessary to offer a TVT until ownership of EV and heat pumps extends beyond early adopters.

All respondents identified EVs as the most worthwhile load for DR, with most TVTs available at the time targeting EV owners. Heat pumps were considered promising by most respondents, but less available in customers' homes than EVs at the time of interviews. One supplier questioned their potential as limited by possible discomfort for customers, for instance if they have to pre-heat their homes at off-peak times. One technology company discussed the costs of running a heat pump versus a gas boiler and the role that DR can play in lowering heat pump-related electricity costs.

Most respondents saw smaller appliances like washing machines and dishwashers as impractical for DR due to disruption to everyday life. With one exception, none of the electricity suppliers planned to develop TVTs for customers without an EV, battery, or heat pump.

Business systems

All respondents discussed how most suppliers' legacy IT systems, particularly billing platforms, were poorly suited to HHS and DR. All but one supplier recognised the importance of modernising their IT systems to stay competitive and comply with MHHS requirements. At the time of interviews, all but two of the large suppliers were operating on outdated IT systems which proved cumbersome and inflexible when used for DR products. These systems were often custom-built and had been retrofitted over time, making them difficult and expensive to upgrade. Both large and small suppliers mentioned the high costs, long lead times, and technical difficulties associated with modifying legacy systems.

The interviews showed a clear industry shift taking place towards adopting modern, flexible platforms, driven by the need for agility, better customer experience, and the ability to offer complex tariffs. Octopus and Ovo had proprietary systems (Kraken and Kaluza) designed for DR. Two of the larger suppliers and one of the small ones were migrating to Kraken during the interviews. Another large supplier was migrating to a competitor platform which they expected would have DR capability Three small suppliers were already on or migrating to a competitor platform capable of DR but with fewer DR options compared to Kraken and Kaluza. All suppliers stressed the core role that such platforms play for their business, whilst some suppliers also emphasised that the migration process is often delayed, primarily due to the complexity of transitioning from legacy systems and the need to prioritise customer service during the migration.

Smart metering

All respondents saw smart meters as essential for DR, but suppliers and some consultants talked about technical failures, poor customer communication of smart meter benefits, and subsequent customer resistance. Five large and two small suppliers pointed out that communication issues, hardware limitations, and inconsistent signals hinder the effective deployment of smart meters. They mentioned that the hardware and network infrastructure, including the Data Communications Company (DCC) which sits at the heart of smart meter communications, are not yet fully reliable across GB, especially in geographically challenging areas.

Some respondents mentioned that the transition from first to second generation meters which was finalising during the interview period had disrupted switching and caused functionality loss. For one supplier this was compounded by shortages of less common meter types. One supplier criticised the centralised communication infrastructure of second-generation meters, preferring supplier-led models with greater control. A few suppliers expressed concerns about the reliability of data collection (including issues with IHDs) via the DCC which was impacting their ability to implement TVTs effectively and creating disruption to their settlement processes.

One large supplier mentioned the legacy of older metering systems, such as radio-tele switching (RTS) meters as limiting the possibility to offer DR products because of the incompatibility of these older systems with modern smart infrastructure and the gradual phasing out of RTS systems. They also discussed regulatory constraints such as the requirement for suppliers to bill households based on readings from accredited metering equipment only, as opposed to readings from meters incorporated into assets like EVs and heat pumps.

Some suppliers also noted customer scepticism, which they partly attributed to government framing smart meters as energy-saving tools. Only two suppliers acknowledged their responsibility to address technical and acceptance issues.

Data access

A few suppliers discussed the evolution of data collection and sharing practices. They highlighted the transition to high-frequency data collection to support MHHS, emphasising the importance of technical capabilities to support data storage and access. Whilst balancing customer protections with data access was discussed, suppliers did not see access to data as a barrier to DR and they welcomed the sector's shift from opt-in to opt-out access to half-hourly data[10] which was underway during the interviews. One supplier and one consultant suspected that in the pre-opt-out system, some suppliers were 'bundling consent' for half-hourly data into other agreements – i.e. assuming that by explicitly agreeing to sign up to a certain tariff, the customer also implicitly agrees to share half-hourly consumption data – and questioned the practice. One supplier raised concerns about third-party access to customer

[10] By virtue of Ofgem's 2019 decision on access to half-hourly data for settlement purposes (Ofgem, 2019)

data, such as price comparison websites potentially sharing data without consent and how this would erode customer trust for everyone.

By contrast, a technology company and a demand aggregator regarded the processes to enable customer data access as cumbersome for both customers and third parties. They focused on the benefits of opening meter data to users, promoting a privacy-centric model where users control their data. They stressed the need to streamline data sharing during sign-up procedures for explicit DR to increase participation and trust, noting significant drop-off rates.

Across respondents, there was a shared recognition of the importance of data privacy, customer protection, and the need for transparent, standardised data sharing protocols.

Organisational capability theme

Resources and expertise

Although explicit questions around resourcing for DR were not asked, the contrast between small and large suppliers' capabilities for DR was stark. Interviews with small suppliers revealed less specialisation of roles compared to large suppliers, and an overall inability across the business to focus on anything beyond essential services. Large suppliers had dedicated research and development teams, though sometimes reported as siloed and with limited effectiveness. One large supplier spoke about the pros and cons of having in-house capabilities whereby these could hinder their ability to partner up with more innovative organisations. Only Octopus Energy had a dedicated flexibility team at the time of interviews, others embedded the function within existing structures.

Perspectives on innovation

Most electricity suppliers, especially small ones, identified the magnitude of the change happening in the energy sector as a barrier to innovation, with regulatory burdens like the price cap putting pressure on their resources. Among large suppliers, Octopus Energy emerged as the leader in terms of innovation, embedding DR at the core of its business model and experimenting with multiple forms. Other suppliers focused DR narrowly on only EV tariffs, despite being in the process of upgrading their IT systems.

DISCUSSION

This section addresses the two research questions posed in this study. The first seeks to understand the industry perspective on DR in GB and its implications for the development of DR in a liberalised market environment. The second looks at how policy can make use of these findings to further support development of DR in liberalised electricity markets. The discussion integrates the five themes presented above into three issues detailed below: facilitating mass-access to DR products; incentivising electricity suppliers and demand aggregators to offer DR; and harnessing competition to support the development of DR in liberalised markets.

Mass-access to DR in liberalised markets

As shown in Table 4, respondents placed greatest emphasis on customers' interest in DR and the potential for both firms and customers to extract value from DR. As is discussed below, because of this focus, electricity suppliers in liberalised markets are likely to design DR products predominantly for early adopters of large electricity loads – especially EVs – who are also willing to allow automation of their loads. This has important implications for both the scalability of DR and its distributional impacts.

For whom are DR products designed?

Industry perceptions of DR potential have shifted significantly: from being considered *'unviable for the time being'* in 2016-2017 (Goulden et al., 2018) to a sense in 2022-2023 that DR is approaching viability, with many large suppliers investing in technological upgrades and customer trials. Nevertheless, DR is still not perceived as a mass-market offer. Respondents largely assume that interest in DR is limited to early adopters – particularly EV-owning households – and have no plans to stimulate broader uptake. Similar perceptions were reported by Weck et al (2017) in the Netherlands where they were identified as a barrier to DR.

Most suppliers plan to develop DR products only targeting EV drivers, battery owners, and heat pump owners, though enthusiasm for heat-pump specific DR products was lower. In contrast, EV manufacturers in Earl and Fell's (2019) study recommended targeting both early adopters and environmentally and financially motivated customers to normalise DR. Likewise, Mihalache et al. (2024) showed that environmentally motivated publics can successfully engage with DR. Although suppliers' focus on EVs, batteries and heat pumps aligns with projections that these assets will provide most residential flexibility (O'Reilly et al., 2024), it leaves open the question of how DR might also be tailored to benefit other customer groups like less affluent but financially conscious households, should they wish to participate.

Tariff and load automation is universally viewed as necessary for scaling DR, consistent with academic insights. Fell et al. (2015b) showed that automation increases acceptance of dynamic TVTs improves response duration and reliability, whilst Friis and Haunstrup Christensen (2016) found that customers struggle to engage manually with changing price signals. Respondents in this study make similar arguments. However, their views also reflect concerns raised by Goulden et al. (2018): suppliers often imagine customers either as rational, tech-savvy Resource Man (Strengers, 2014), or as disengaged and irrational 'Indifferent Consumers.' Drawing on Akrich (1992) notion of technological scripting – where imagined users are concrete enough in the eyes of product architects that they shape product design – the findings suggest that electricity suppliers in a liberalised market will design DR products primarily for Resource Man. In this study, Resource Man is understood as the early adopter EV owner willing to accept automation.

Suppliers report thinking holistically about customer journeys, aiming to offer DR products at moments of receptiveness. Yet they implicitly assume that purchasing an EV, battery or heat pump automatically increases openness to DR – an assumption that may not hold for customers beyond the early adopter group. Offering mass-market DR products could help normalise demand flexibility and avoid customer recruitment challenges as electrification of heat and transport widens beyond early adopters.

Although respondents unanimously view automation as fundamental, they say little about potential customer concerns around loss of control. This again reflects a design orientated towards Resource Man and overlooks evidence that non-negligeable percentages of DR trial participants report such concerns (D'Ettorre et al., 2022; Lee and Hess, 2021; Lopes et al., 2016; Parrish et al., 2020). The exclusive focus on automation risks neglecting customer agency and undermining trust, as Osunmuyiwa et al. (2021) warn.

The current focus on Resource Man, combined with limited attention to enabling the presumed Indifferent Consumer to benefit from DR, raises questions about whether the 10-12GW of DR can be achieved without further government intervention. Policymakers need to assess what proportion of EV, battery and heat pump adopters must participate in DR to provide adequate system flexibility, and how to incentivise electricity suppliers and demand aggregators to design DR products for customers beyond early adopters. Monitoring uptake of EVs, heat pumps, batteries, and DR progress in tandem will allow timely intervention if required.

Distributional impact of targeting early adopters

It must be acknowledged that not everyone can or will participate in DR, and that DR must remain voluntary to accommodate diverse user needs and preferences. For instance, Friis and Haunstrup Christensen (2016) find that routine-bound activities are difficult to shift. This study provides evidence that electricity suppliers and DR experts take distributional impacts seriously and strive to avoid customer detriment. Many express concern that DR could exacerbate inequalities, benefiting affluent households with flexible assets while disadvantaging those unable to shift demand. This aligns with calls to embed equity into DR programme design (Phelps and Lanza, 2025). Targeting DR products to early adopters risks worsening social inequality if electricity suppliers target only customers with high flexibility capital (Powells and Fell, 2019) i.e. those able to afford EVs, batteries, and heat pumps. Policymakers must therefore consider how to distribute system savings fairly across DR participants and non-participants and avoid creating the perception that DR benefits only the well-off. Subsidies for EV, batteries, and heat pumps, for instance, and policies to incentivise electricity suppliers to offer DR products tailored to prepayment meter customers can widen access to DR benefits. It should also be acknowledged and communicated that DR participation reduces wholesale prices and infrastructure costs for all consumers, and ESA like batteries are starting to be installed across income groups when they support lower bills.

The notion of demand turn-up presents a promising avenue for unlocking DR and for addressing affordability and equity concerns in the GB context. While much of the DR literature has emphasised load-reduction (turn-down) at peak times, turn-up enables households to absorb excess supply and thereby help lower system costs – a dynamic that potentially benefits customers who cannot easily reduce demand. For turn-up to realise its benefits, policy must make sure that commercial models support participation by a wide range of households, that settlement and baselining mechanisms are robust, and that incentives remain durable. Without these structural enablers, turn-up may simply reproduce existing inequalities.

Technology reliability, access to data and scaling up DR

Non-participation can also stem from technical barriers that industry and policymakers must address. Respondents cited non-functional smart meters as a barrier to DR, reflecting wider evidence that technical problems can lead to mistrust (Parrish et al., 2020) or disengagement (Mihalache et al., 2024). These challenges are likely to grow as ESAs scale. Previous research shows how prediction inaccuracies, and challenges with practical integration of technology can reduce DR benefits in both large- and small-scale trials (D'hulst et al., 2015; Gupta and Morey, 2023; Kepplinger et al., 2024). Vindegg and Julsrud (2025) also emphasise the time and effort involved in 'digital housekeeping' – setting up, maintaining, and scheduling smart home solutions – which will likely increase as households adopt more ESAs.

In GB, suppliers are responsible for installing smart meters and maintaining their functionality. Policymakers must therefore hold suppliers accountable for meeting regulatory obligations and make sure that enforcement mechanisms are sufficiently robust. At the same time, policymakers must contend with an increasingly complex ecosystem of ESAs that need to integrate with one another. GB policy has appropriately emphasised interoperability of ESAs as a first step[11], but as HEM systems develop, responsibility for appliance maintenance

[11] Via provisions in the Energy Act 2023 and subsequent legislation

may become unclear – risking technological glitches becoming an increasingly significant barrier to DR adoption.

The interviews also reveal a split in perceived data-access barriers: most electricity suppliers felt half-hourly data availability (in the context of MHHS) is already sufficient for DR, whereas technology firms and aggregators emphasised onboarding frictions that depress participation in explicit DR. This actor asymmetry mirrors the evidence that complexity, effort, and transaction costs are among the strongest impediments to enrolment and sustained participation in residential DR and that programmes must minimise customer hassle to unlock uptake (Langevin et al., 2024; Parrish et al., 2020).

Respondents' concerns about bundled consent and trust in third parties align with empirical work showing that trust, perceived control, and clarity about data use decisively shape acceptance of smart services (Buchanan et al., 2016; Grünewald and Reisch, 2020). The policy implication is that data availability is necessary but not sufficient: without credible governance of consent and data sharing, DR could struggle to recruit and retain households even when high-frequency data exist.

Incentivising electricity suppliers and aggregators to offer DR in liberalised markets

This research shows that GB electricity suppliers currently lack both strong regulatory obligations and convincing commercial incentives to offer DR products and increase DR uptake.

Using regulatory obligations to support DR development

Respondents acknowledged the importance of HHS in incentivising electricity suppliers to offer DR. The significance of HHS has also been emphasised in literature, both in GB (Capper et al., 2024; Forouli et al., 2021; Torriti, 2024) and internationally (Weck et al., 2017). However, only a couple of suppliers chose to settle customers half-hourly through elective HHS. Although this was viewed as beneficial for the system, it was not seen as providing sufficient return for individual electricity suppliers. This ‘split incentive’ (Eid et al., 2016) makes it difficult to create a business case for elective HHS. The move to MHHS resolves this tension, with mandatory frameworks shown to help scale DR (Sousa and Soares, 2023). Yet many GB electricity suppliers perceived MHHS as distant and were sceptical about timely delivery, making investment in systems and processes needed for MHHS seem premature.

Policy intervention in liberalised markets could therefore focus on creating a universal incentive to offer DR and ensuring it takes effect within a clear timeframe. Utilities can take advantage of delays or uncertainty in implementing ‘stick’-type incentives, so policy must avoid prevarication if it is to be effective. Enforcement against utilities that contribute to implementation delays can also play a key role. In the case of MHHS, for instance, delays were partially caused by suppliers’ slowness in putting forward meters for testing (Ofgem and Department for Energy Security and Net Zero, 2025). The clearer the policy framework, the lower the legal risk associated with enforcement. Achieving this requires coordinated action by policymakers and regulators to create a coherent and robust approach to policy implementation.

Creating appealing commercial incentives to offer DR

Respondents also noted that, under current GB market arrangements, customers can achieve only limited savings from DR, making the proposition unattractive. Most supplier trials and modelling produced savings of up to ~£60 per household per year, roughly 4% of the average 2023 electricity bill. For context, reported DR savings in academic literature range from up to 4% of daily electricity costs in Sweden (Vesterberg and Krishnamurthy, 2016), up to 10% of annual electricity costs in Denmark – c. 50 euro per year (Katz et al., 2018) – and up to 25%

of electricity costs in Germany in 2020 (Sundt et al., 2020). Most recently, Gnann et al (2025) found that German households with EVs, heat pumps, photovoltaics and smart energy management systems can save €900–€1200 per year, depending on mileage.

Extensive research highlights the link between DR and financial rewards. Vallés et al. (2016) show that customers participate only when incentive at least match the utility of consuming electricity at preferred times. Parrish et al. (2020) find that financial benefits are the primary motivator for enrolling in DR. Studies in India and Iran also show financial incentives as key determinants of DR enrolment (Osunmuyiwa et al., 2021; Shekari et al., 2021). This study shows that GB electricity suppliers do not view current DR rewards as sufficient to make DR attractive to customers, which in turn makes DR unattractive for suppliers – particularly given the organisational transformation required to offer it (discussed in the next section). This aligns with Earl and Fell (2019) conclusion that tariffs fail to develop where market signals and incentives do not support a DR proposition.

Respondents most frequently attributed the lack of appropriate signals and incentives to limited time-reflectivity in the GB bill stack and to market-access barriers, particularly for demand aggregators. The issue of time-reflectivity is well documented, especially network cost recovery. Willems and Zhou (2020) show that in systems reliant on market forces for DR development, network tariffs must be more cost-reflective to provide correct incentives. Burger et al. (2020) demonstrate how current volumetric tariffs[12] – covering most electricity, transmission, and distribution costs – could be redesigned to incentivise DR without exacerbating socioeconomic disparities. Morell-Dameto et al. (2023) show how network tariffs can encourage shifting of flexible loads to off-peak periods to align system and customer benefits.

[12] Charges per unit of energy consumed

Policymakers could review the price-reflectivity of the bill stack and explore alternatives that promote lower bills by better incentivising DR. One option would be to move some policy costs, most of which are not currently time-reflective, into general taxation, reducing the electricity/gas bill gap and promoting electrification, whilst at the same time increasing the proportion of the electricity bill which is time-reflective. Until recently, renewable energy costs (i.e. policy costs) have been disproportionately recovered through electricity bills, reducing time-reflectivity and disincentivising the shift away from gas[13]. This aligns with findings by Rosenow et al. (2025) who show that shifting levies to general taxation or gas bills improves heat pump appeal; and with Owen and Barrett's (2020) argument that funding low-carbon policy through general taxation would reduce costs for 65% of UK households. Voulis et al. (2019) also call for rethinking energy taxation – from per-unit to ad-valorem taxes – to better align taxation with decarbonisation objectives.

Respondents devoted less attention to market-based mechanisms for incentivising DR due to sampling bias: the sample over-represented electricity suppliers whose focus is primarily on implicit DR. Market-mediated incentives are central to explicit DR, which is typically delivered by demand aggregators, although some electricity suppliers operate in both roles (e.g. Octopus Energy and Ovo). Consistent with Capper et al. (2024), respondents cited two other barriers to DR: access to markets on par with generators; and inconsistency between participation requirements in different markets. Previous literature highlights similar issues: Weck et al. (2017) identified minimum portfolio sizes and metering requirements as barriers to ancillary services participation; Earl and Fell (2019) argued that GB DR markets are hard to navigate and require simplification; and Vallés et al. (2016) noted that fragmented

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[13] In GB, some policy costs will either be scrapped (the Energy Company Obligation) or moved to general taxation (75% of the Renewables Obligation) from April 2026 for at least three years, as announced in November 2025 (HM Treasury, 2025)

European market rules under-reward small-scale flexibility. Respondents in this study highlighted additional barriers around baselining and revenue stacking which complicate efforts to extract value from various assets.

Policymakers could therefore require market operators to periodically review and address technical and operational barriers – including complexity and inconsistent participation requirements – to improve the attractiveness of DR. This aligns with Capper et al.'s (2024) recommendation that system operators should coordinate and harmonise participation requirements, but places responsibility on policymakers to make sure this coordination occurs.

Harnessing competition to support DR development in liberalised markets

The current GB retail market arrangement, although designed to promote competition that lowers prices, improve customer services, and drive innovation, is not well suited to fostering DR innovation. Interview analysis shows that the current market structure acts as a barrier to electricity suppliers' ability to offer DR. Suppliers operate within a complex regulatory framework that keeps margins extremely tight, limiting capacity for innovation. At the same time, demand aggregators struggle to generate revenue in the markets they operate in and have less access to customer data than suppliers, reducing their ability to exert the competition pressure that should push suppliers toward offering DR.

Innovating under regulatory burdens

Respondents highlighted technological upgrades – particularly upgrades to ERM platforms – as one of the main prerequisites for DR product development and spoke at length about the challenges posed by legacy IT systems. The need for such upgrades is widely recognised in engineering literature (Chen and Ge, 2024; Ma et al., 2021; Parejo et al., 2021).

This study adds detail on what these technological upgrades mean from the perspective of electricity suppliers, showing the constraints under which commercial decisions to upgrade systems are made. Suppliers already operating on DR-capable platforms like Kraken or Kaluza showed greater capacity for innovation, confirming Kattirtzi et al.'s (2021) conclusion that IT agility differentiates innovators from laggards. Suppliers in the process of migrating to new platforms described the difficulty of selecting a system aligned with their business model and the complexity of migrating customers – often lengthier than planned and carrying significant reputational risk. Weck et al. (2017) found a similarly mixed picture in the Netherlands regarding transitions to DR-ready systems.

The implication for policy is that industry will not invest in costly system upgrades unless they can generate a return on investment, including through DR products.

Competition and coordination as a driver for DR

The challenge of migrating to expensive DR-capable IT systems is aggravated by the supplier hub model and the price cap, which place extensive obligations on energy suppliers whilst constraining revenues, thereby reducing scope for innovation.

Both the supplier hub model (Capper et al., 2024; Watson et al., 2024, 2020) and price caps (Littlechild, 2018) have been shown to hinder innovation, particularly in relation to DR (Bergaentzlé et al., 2014). This study further shows that current GB retail market arrangements disproportionately limit small suppliers' ability to deliver innovative DR products due to inadequate organisational resources, which are strong predictor of DR delivery according to Sousa and Soares (2023). While competition from small suppliers may pressure incumbents to improve service and reduce prices, it does not incentivise them to innovate in DR – leaving demand aggregators as the sole competitors to large electricity suppliers in the DR space, as discussed in Burger et al. (2017), Brown et al. (2019), and

Schittekatte et al. (2021). Sustaining a healthy level of competition from demand aggregators will require addressing the data access and market barriers outlined above and preventing regulatory capture – of the kind demonstrated by Lockwood et al. (2020) – by electricity suppliers in the redesign of retail market arrangements which is currently underway in GB.[14]

Finally, effective coordination between market actors will be key. Respondents touched on this implicitly when describing their reliance on third parties for HHS, but a thorough review of retail market arrangements must acknowledge the diverse value- and supply-chains involved in delivering DR. Suppliers' dependence on third parties highlights the inherent complexity of DR ecosystems. As already suggested by Torriti (2024), policy frameworks in a competitive market must support multi-actor collaboration, with clearly defined roles and responsibilities, to enable coherent and efficient DR development.

Areas of future research

Building on this study, future research could investigate how DR can be broadened beyond early adopters to avoid regressive outcomes as flexibility scales in line with electrification. Whilst findings highlight how suppliers design DR products around EV-owning, automation-ready Resource Man, further empirical work is needed to understand how diverse household groups – including low-income renters, routine-bound households, and those with limited digital literacy – experience, value, and resist DR offers. Longitudinal research could examine how customer preferences, automation acceptance, and trust evolve as heat pumps, EVs and HEM systems diffuse through the housing stock.

More work would also be welcomed on the equity implications of demand turn-up, including quantitative modelling of who is able to benefit from low-price or negative-price periods

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[14] Via the *Energy system cost allocation and recovery review* launched in July 2025: https://www.ofgem.gov.uk/call-for-input/energy-system-cost-allocation-and-recovery-review

under different tariff designs, and how these benefits interact with cost-recovery mechanisms in the bill stack.

Comparative international studies could illuminate how different retail market designs, baseline methodologies, and data-governance regimes support or inhibit supplier and aggregator participation in DR.

Finally, as this study identifies IT and organisational capabilities as determinants of DR readiness, future research could examine the organisational and technical challenges of scaling DR and assess how regulatory structures can lower coordination and compliance costs for suppliers, demand aggregators, appliance manufacturers, and system operators.

CONCLUSIONS

This study provides new empirical insight into how industry experts perceive and approach DR within a liberalised retail market. A central finding is that electricity suppliers are designing DR products primarily for early adopters of EVs, batteries, and smart heating – customers imagined as technologically capable and willing to automate their loads. While this focus reflects where short-term commercial value is easiest to realise, it has two important implications. First, it raises questions about whether the 10–12 GW of DR projected to be deployed in GB by 2030 can be achieved without broadening participation beyond the early-adopter segment. Second, it risks embedding distributional inequalities by concentrating DR benefits among higher-income households with flexible assets. Policymakers will therefore need to make sure that DR is both technically and economically viable, and that it is designed for mass-market accessibility.

The analysis also shows that electricity suppliers currently face neither strong regulatory obligations nor convincing commercial incentives to scale DR. Although MHHS and nascent markets in which demand flexibility can participate offer some directionality, suppliers perceive the associated benefits as insufficient relative to the required organisational transformation. Policymakers must therefore provide clearer and stronger incentives – through obligations, financial rewards, or both – to align commercial behaviour with system needs. Ensuring sufficient remuneration and reducing administrative and market-access barriers will be fundamental to creating a viable business case for DR.

Finally, the research reveals structural impediments within the current GB retail market arrangement. Designed to promote competition, reduce prices, and improve customer service, the existing framework constrains innovation in DR: suppliers face tight margins, compliance burdens, and legacy IT systems, while aggregators struggle with inconsistent market rules and limited access to customer data. These findings suggest that a review of retail market arrangements is needed to define the respective roles of suppliers and aggregators, reduce coordination challenges across value chains, and ensure that retail competition supports rather than inhibits flexibility deployment.

Domesticating residential demand response. Learning from Great Britain's 2022-2023 Demand Flexibility Service[15] (paper 2)

Sir Humphrey: Bernard, if the right people don't have power, do you know what happens? The wrong people get it: politicians, councillors, ordinary voters!
Bernard: But aren't they supposed to, in a democracy?
Sir Humphrey: This is a British democracy, Bernard!

(Yes, Prime Minister, Series 2, Episode 5: Power to the People)

This chapter shifts the focus from how residential DR is understood and prioritised by commercial actors to how it is experienced and enacted by households. Using longitudinal diary data from 25 participants in GB's 2022–2023 DFS, it examines how users interpreted the purpose of DR, adjusted their routines, and integrated it into their everyday lives over five months. The findings sit in contrast to industry's perception of users as tech-savvy Resource Man revealed in the previous paper. Moreover, the paper illustrates how electricity system operation often sits far from the people who must enact it. Households were asked to perform a service essential to system stability, yet the structures shaping that service were set by organisations with little direct interaction with users. Participants negotiated these expectations within their own routines, relationships, and constraints, often compensating for gaps or ambiguities in the programme's design. The chapter concludes with recommendations for designing DR products with end users in mind.

[15] The title with which the article was published is *Domesticating energy flexibility. Learning from Great Britain's 2022–2023 demand flexibility service.* This thesis kept the original title for consistent use of terminology

HIGHLIGHTS

- Applies domestication theory to a national electricity DR programme
- Investigates how households incorporate electricity DR into everyday lives
- Twenty-five diaries reflecting thirteen DR sessions in winter 2022-2023
- Analyses five ways in which participants 'domesticate' DR
- Discusses implications for future DR design and implementation.

ABSTRACT

DR is essential for balancing electricity grids with increasing proportions of intermittent renewable sources of generation. Harnessing the potential for DR in domestic settings could deliver widespread benefits for electricity systems and householders. This study applies domestication theory to a major national domestic electricity DR programme in GB, exploring how participants integrate DR sessions into their everyday routines. The study uses empirical data from twenty-five participants who completed diaries reflecting on their experience of taking part in thirteen DR sessions scheduled over a five-month period in winter 2022-2023. The study identifies and analyses five pathways for domesticating DR, making recommendations to support system-actors in boosting and sustaining the adoption of DR. The study concludes that designing electricity DR programmes, as a staple of secure low-carbon energy systems, will need to take full account of users' non-financial motivations, previous experiences of DR, and access to enabling technology.

INTRODUCTION (SECTION 1)

Electricity systems worldwide are in transition, adapting to new patterns of demand and sources of supply. DR is valued for reducing investment costs (Pourramezan and Samadi, 2023), maintaining system reliability (Wang et al., 2017) and benefiting customers (Uddin et al., 2018). Given the scale and diversity of household electricity demand, especially at peak times, there is a strong argument in many regions for residential DR (Cruz et al., 2021).

An electricity user's participation in DR is shaped by their flexibility capital or the ability to be flexible, *'determined by... a wide variety of factors including working patterns ...and – in the context of domestic energy use – household composition, size of electrical loads, presence or absence of energy storage, culture and religion, life stage, wealth and so on.'* (Powells and Fell, 2019, pp. 1-2).

DR brings together system operators and users in new ways. Customers are in effect helping operators and fellow customers by flexing their demand, a service for which they may reasonably expect to be rewarded. To be sustainable, some residential DR processes must become part of system design and operation, with appropriate technologies, software, and tariffs; and some must be integrated into daily routines in the home – that is, DR needs to be domesticated.

This study aims to contribute to the literature on residential electricity DR by applying domestication theory to a case study: adoption of the DFS, one of the largest DR programmes in GB, during the winter 2022-2023. Drawing on domestication theory, conventionally used to analyse the adoption of physical artefacts, we demonstrate its value as a framework to analyse the adoption of DR. Evidence from diaries kept by twenty-five participants is used to address two research questions*: 1) How, and with what success, did participant households* *domesticate the DFS over winter 2022-2023? and 2) What can future DR initiatives learn from the experience of these households?*

While the paper analyses householder responses to DR in a specific programme in GB, we believe the process of integrating DR into everyday life – domestication – is relevant to programmes in any region of the world, however much systems, relationships between system actors and household practices may vary.

Residential DR from a system perspective (section 1.1)

Electricity systems have traditionally been demand-led, flexing supply to meet people's fluctuating needs for energy services. Most of the world's electricity came from large fossil-fuel or hydro plants and these could be switched on and off with relative ease, especially if gas-fired or water-powered.

Starting in the 1950s, increasingly high and short-lived peak demand, especially in regions with growing air-conditioning and electric heating use, challenged the demand-led model (Bellarmine, 2000). To avoid investing in underutilised generating capacity, utilities began incentivising customers to shift demand away from peak times, marking the start of a shift towards more flexible demand. With the growth of wind and solar generation, transmission and distribution networks must now adapt to two-way electricity flows, with both supply and demand fluctuating based on weather and time of day, making DR increasingly urgent and valuable.

DR is broadly defined as *'the change in electricity consumption patterns in response to a signal'* (Element Energy, 2012, p.9). The signal is usually a change in price, however, non-financial factors like trust, perceived risk, and effort also influence the motivation and effectiveness of DR (Parrish et al., 2020).

In the long term and from a system standpoint, DR can reduce the need to invest in generation and infrastructure (Pourramezan and Samadi, 2023). For instance, a 2015 European analysis identified peak demand as the main driver of network costs and estimated that a 10% load shift away from the peak could reduce costs for distribution system operators (DSOs) by 5%. There can also be substantial advantages for transmission grid operators from delaying infrastructure investments (Koliou et al., 2015). A study by the Carbon Trust and Imperial College London (2016) estimated cumulative savings of £17-40bn by 2050 from flexibility in GB, depending on levels of demand and interconnection, and on the costs of storage and DR programmes.

In the short term, DR enables system operators to maintain reliable energy services at reduced economic and environmental cost (Wang et al., 2017). Peak load shaving – the DR most relevant to this paper – can offer direct benefits to those who own and operate an electricity system, as indicated above. It can also offer direct benefits to customers who participate in DR: reduced bills from cheap off-peak usage, and perhaps the chance to adopt useful new technologies; and indirect benefits to all users, including better system reliability and reductions in overall system costs (Uddin et al., 2018).

While residential loads are relatively small, there is a strong argument in many regions for DR in the residential sector, given the scale and diversity of demand from this sector, especially at peak times (Cruz et al., 2021). The earliest residential DR programmes took place in North America and northern Europe, and they now operate in many countries including China (Wang et al., 2020), India (Ravindra and Iyer, 2014), Iran (Saebi et al., 2022) and Brazil (Oliveira et al., 2023). The type of DR in each programme will vary, depending on characteristics such as climate, supply mix, and patterns of demand. It can take many forms, from load reduction or load-shifting a few times a year, when demand reaches a 'critical peak,' to switching smart-enabled devices such as freezers off and on for very short periods, to maintain system frequency. Each form of DR will be associated with tariffs, communications and enabling technologies (e.g. smart meters, IHDs, smart plugs, and thermostats) to achieve its purpose (Darby and McKenna, 2012; Parrish et al., 2020).

In summary, there is an established rationale for residential DR as a way of operating electricity grids more efficiently during an energy transition that aims to provide reliable energy services from renewables-based supply.

DR from a residential user perspective (section 1.2)

Analysts have long recognised that DR programmes must attend carefully to the needs of participants (Garcia, 1987), given the *'multidimensional role that attitudes, habits, and experience have in shaping energy consumption'* (Sovacool, 2014, p.11). Recent studies focus on relational and socio-technical interpretations of flexibility, emphasising interactions between electricity users and artefacts (Blue et al., 2020; Lo Piano and Smith, 2022; Powells et al., 2014). We continue in this direction, using a domestication theory framework (see Section 3) to map out attitudes, routines, and interactions with artefacts that shape our participants' experience with DR. Factors that influence residential DR uptake vary with context. For instance, a choice experiment study on US and EU participants found that environmental and system benefits can have an impact on willingness to participate (Buryk et al., 2015) and a study in Israel found that users value environmental and national security objectives when deciding to enrol to a TOU tariff (Parag, 2021). A Finnish study however found that households enrol their loads in Direct Load Control programmes for economic reasons over environmental benefits (Sridhar et al., 2023). The potential for energy savings was also found to be the strongest motivator in a US study (White and Sintov, 2018), but the authors found that users may have unrealistic expectations of these. A UK study found that incentives-based approaches can overcome some barriers to DR varying by the height of the barriers, electricity-using practice, and incentive approach (Bradley et al., 2016). A study in

Australia concluded that TOU tariffs are unlikely to reduce peak demand effectively in households with children, potentially exposing them to inequitable impacts (Nicholls and Strengers, 2015).

The concept of flexibility capital, introduced in Section 1, has gained widespread acceptance in recent years. It can be applied to continuing participation in DR as well as to uptake. For instance, a wealthy, high-consuming retired homeowner with solar PV and an EV or battery will be more likely to profit from a peak-reduction tariff than a single-parent shift-working tenant on a low income who must fit activities such as cooking, showering and laundry into limited periods of time.

More recently, the concept of *flexibility justice* has been developed to show how *'the costs of doing flexibility work are not evenly and fairly distributed between and within different households'* and how *'framings of end-user flexibility … would offer an important step to distribute the burden of flexibility work more evenly*' (Fjellså et al., 2021, p.107). Insight into customer household circumstances matters at the level of individual customers; at the macro-scale, so do policies beyond the electricity sector such as those for taxation, housing, and transport (Winther and Sundet, 2023).

The concept of *capability* has been used in relation to DR and energy justice, highlighting what people can *do* – their roles and abilities as social beings in societies that rely increasingly on smart technologies (Banks, 2022; Roberts et al., 2020). We will draw on some of these concepts and references in our discussion section.

The rest of this paper unfolds as follows: In the following sections, we provide the context and relevant details of the DFS (Section 2); domestication theory, the framework through which we analysed the DFS, and its application to DR (Section 3); collection and analysis of the twenty-five diaries (Section 4); and the mapping of five different pathways for domesticating the DFS (Section 5). We then discuss our findings and draw lessons for the design and implementation of future DR response policies and programmes (Section 6) and conclude with a research and policy agenda for maximising the contribution of DR to decarbonising the electricity system (Section 7).

OVERVIEW OF THE 2022/2023 DEMAND FLEXIBILITY SERVICE (SECTION 2)

Historically, in GB, household electricity peak demand reduction has been incentivised through Economy 7, a static TOU tariff designed for night storage heaters in the 1970s and still available today from most energy suppliers. A few energy suppliers have now diversified their offer of TVTs[16] to cater to large new electricity loads such as EVs, but the market was still nascent in 2022. The DFS came at the tail-end of the Covid-19 pandemic and in the context of Russia's February 2022 invasion of Ukraine which had led to a cost-of-living crisis and energy security concerns across Europe. For the first time in recent GB history, the Electricity System Operator (ESO) spoke publicly about rolling blackouts as a last-resort contingency plan (Alex Lawson, 2022). This context may have already decreased overall household energy consumption even before the DFS was brought in.

The DFS is a multi-year opt-in critical peak rebate programme. Such programmes carry no financial risk for participants, as shown by Nicolson et al. (2018). The first iteration of the DFS, which is the focus of this study, consisted of 13 DFS sessions of up to 2 hours each, spread between November 2022 and March 2023. About 1.6 million households and businesses took part, delivering 3.3GWh in electricity demand reduction across the winter (Electricity System Operator, 2023). Although both households and businesses participated in

[16] We use the notion of *time-varying tariff* throughout this study to reflect any type of tariff that accounts for the time when electricity is being used. This could be anything form static to dynamic time-of-use tariffs

DFS, this study focused solely on households to draw out and analyse the complex interactions between everyday life and the efforts to reduce electricity demand.

The ESO does not have a direct relationship with households in GB, so it relied on DFS providers, i.e. energy suppliers and third-party aggregators, to recruit, reward and communicate with households. By the end of the programme, 24 DFS providers offered the service to households, but only a few had offered it from day one. In theory, households could shop around for the best offer but given the novelty of the programme and a historic lack of engagement with the retail market amongst GB households (Ofgem, 2024a), most users relied on their electricity supplier to offer them the service (Centre for Sustainable Energy, 2023). Households also needed a functioning electricity smart meter to participate in the DFS, which roughly half of GB households had in winter 2022 (HM Government, 2024b). This meant that fewer than half of GB households could sign up for the DFS due to technical metering exclusions, whilst the gradual onboarding of DFS providers limited the possibility to shop around for DFS providers.

Most DFS sessions were announced a day in advance and tended to coincide with the national early evening peak demand. A few sessions were announced with shorter notice (e.g. 4 hours), mostly for the ESO to test how this impacts reductions.

At a time when the average yearly electricity bill in GB was c. £1,200 (HM Government, 2024c), the ESO estimated a saving of c. £100 across the winter for a typical household (Electricity System Operator, 2023), though the actual saving varied significantly across households, and could fall anywhere between £1 and £6 per kWh saved (Octopus Energy, 2023b). Users were rewarded for reducing their electricity consumption compared to a baseline. The ESO imposed the methodology for establishing the baseline but allowed DFS providers to vary the reward associated with each kWh of reduction.

The baseline was regarded as the household's normal usage pattern and, for each DR session, it was made up of the household's average consumption during the corresponding time-interval over the previous 10 weekdays (or 4 weekend days for weekend sessions), and an *in-day adjustment* based on how much electricity the household had used in the interval between 4 hours and 1 hour before the session (referred to as t-4 and t-1) (Electricity System Operator, 2023). This methodology meant that session outcomes (in terms of £ savings) were not comparable between households because the baseline value was specific to each household. Even within the same household, outcomes differed between sessions, as the baseline value changed for each session, affecting savings.

In practice, the context, characteristics, and methodology of the DFS gave rise to quirks which had an impact on the household experience with the programme. For instance, householders who typically used more electricity at peak times had greater potential to make savings. By contrast, those already deliberately reducing peak demand, or who had already decreased overall consumption, had relatively lower savings potential. Most users saved significantly less than the expected £100 across the winter which, as Section 5 will show, impacted how participants domesticated the DFS.

Further, the in-day adjustment meant that participants would make fewer savings if they had used little electricity on the day of the session. It also meant that users could increase their savings by increasing energy usage before the session. This so-called 'gaming' behaviour attracted some negative discussion across media platforms (Eve McGowan, 2023; Tom Grimwood, 2023) and debate to be reflected in Section 5.3 of this article on whether participants who gamed DFS had domesticated the process or not.

ANALYTICAL FRAMEWORK (SECTION 3)

This study uses domestication theory as a framework to analyse the process of integrating DR (i.e. the DFS programme) into everyday lives. We explain in this section how we use domestication theory and accompanying concepts.[17]

At its origins, domestication theory applies a constructivist lens to explore the relationship between technology and everyday life (Berker et al., 2005). It analyses the process of integrating a technology into the home as a negotiation in which both the technology and the social setting in which it is integrated mutually re-shape each other (Aune, 2001), a process akin to the domestication of plants and animals in an agricultural context (Lehtonen, 2003). Both the technology and the household transform in this non-linear process (Hirsch and Silverstone, 1992). This is different from Rogers' diffusion of innovation theory (Rogers, 2003) which dominated social science explanations of how technologies and ideas spread until the mid-1980s, and which saw adoption of technology as a rational and linear process (Berker et al., 2005).

Domestication theory has been widely used in social science energy research, often to explore users' reactions to the introduction of energy visualisation and energy control tools (Aune, 2001; Nyborg, 2015; Winther and Bell, 2018), and the integration of decentralised energy technologies such as air-source heat pumps, micro-wind generators, and solar-thermal collectors (Juntunen, 2014) into everyday life. By drawing attention to people's roles as users

[17] This paper treats domestication theory as an exploratory and adapted framework rather than as a perfect fit. Unlike many of the artefacts typically examined in domestication studies, the DFS was only partially material: participants engaged not only with devices, but with signals, timings, expectations, communications, and reward mechanisms. For that reason, this paper does not assume that DR is domesticated in exactly the same way as a conventional artefact. Instead, it uses domestication theory heuristically to examine whether and how repeated episodes of engagement with a DR intervention can become meaningful, workable, and intelligible within everyday life. The contribution is therefore not to claim a complete theoretical equivalence between DR and domestic technologies, but to test the value and limits of domestication theory for understanding participation in a recurring socio-technical demand response programme.

as well as consumers of technology, domestication theory has also been used to suggest opportunities to improve energy policy making (Parrish et al., 2021). We make DR policy recommendations in Section 6 based on our application of domestication theory to DR. Hargreaves and Wilson (2017) applied domestication theory to smart home technologies (including those related to energy consumption), classifying domestication pathways as successful, precarious, or rejection by building on Juntunen's views that '*domestication is seen as having been successful when technologies are not regarded as cold, lifeless and problematic, but as comfortable, useful tools…that are reliable and trustworthy'* (Juntunen, 2014). We further expand their classification by showing that the distinction between the three pathways is not clearcut when applying domestication theory to DR. We also show that smart technologies can but do not always play a leading role in domesticating DR.

Other studies have applied domestication theory beyond artefacts e.g. to analyse the public understanding of science and technology (Ryghaug et al., 2011; Sørensen et al., 2012); or analyse the symbolic aspects of household energy consumption and energy efficiency practices (Aune et al., 2016). We show in section 5 that domesticating DR entails re-domesticating artefacts, as well as adopting new practices or behaviours.[18]

Like Hargreaves and Wilson (2017), we employ Knut Sørensen's (1996) symbolic, practical, and cognitive dimensions of domestication theory. The symbolic dimension relates to the meanings and identities constructed in the dynamic process of use and re-use. The practical

[18] Although the published article does not dwell on this, it should be clarified that while domestication theory is conventionally used to study physical artefacts, it is also well suited to analysing DR. DFS entered the home through concrete socio-technical arrangements: notifications, peak-reduction requests, reward structures, smart appliances, apps, and household routines that had to be interpreted, negotiated, and made workable in everyday life. What required explanation in this study was therefore not simply whether households responded to a price, or incentive, or to a new artefact, but how they gave meaning to DR, fitted it around domestic routines, and developed the understandings and competences needed to engage with it over time. Domestication theory offers a useful framework for this because its symbolic, practical, and cognitive dimensions capture precisely these processes of appropriation and incorporation, even where the object being domesticated is not a single device but a recurring socio-technical arrangement.

dimension is primarily about integration into the routines and the physical environment of the households; and the cognitive dimension is about processes of learning and knowledge creation.

Throughout the study, we also use the concepts of *script* and *affordances*. Madeleine Akrich (1992) argues that innovators inscribe their visions and predictions about the world in the technical content of the object they create, thus linking technological design to patterns of usage (Aune, 2001). Affordances refer to possibilities for action (Brause and Blank, 2020; Gibson, 2014) meaning that actions can go outside the script, for instance when the script is difficult to understand, and users need to integrate artefacts into their lives (Sørensen et al., 2012). By incorporating advertising, expert opinions, and broader societal narratives, Bakardjieva's expanded definition of 'script' (Bakardjieva, 2005) highlights the complex interplay of multiple influences in the domestication process, a confluence of designed intentions and external influences, as well as user agency. In this study, we look at how various possibilities for action materialised in the domestication process and the extent to which they aligned with the DFS script.

Finally, we incorporate into the analysis the concept of *warm experts* (Bakardjieva, 2005) as mediators between the technical aspects of a service or technology and a new user whose background and needs are known by the expert by virtue of a close personal relationship. We use the concept to reflect that some of our participants became DR warm experts in domesticating the DFS.

METHODOLOGY (SECTION 4)

Data collection and sample characteristics (section 4.1)

We recruited a total of forty-two participants in September 2022, as soon as the DFS was announced, through posts on specialised social media platforms (e.g. Facebook and Reddit groups focused on DR and micro-generation) and through the authors' professional and personal networks.

Participants received a diary template structured around the three dimensions of domestication reflecting Sørensen's (1996) framework, as shown in Table 13. Annex 6 provides an example diary from one of our participants who gave permission to have it published alongside this article. Conversations about the DFS could have fit under any of the three dimensions. We chose to position them within the symbolic dimension because we wanted to test how participants convey their attitudes towards the DFS.

Table 13: Diary design, using Sørensen's (1996) dimensions of domestication

Dimensions of domestication	**Diary design**
Symbolic	• Meanings and motivations (e.g. for opting in or out of each session) • Perceived ease of participation • Conversations about participation (within and outside the household)
Practical	• Routines and family dynamics (before, during, and after each session) • Technologies used and the way in which they were used • Continuity (e.g. 'do you plan to opt in to the next session?' before and after knowing the outcome of their kWh savings)
Cognitive	• Learning: participants were asked to predict outcomes for each session to test if prediction accuracy improves over time • Sources of information e.g. online forums, DFS official documentation

Participants agreed to fill in the diary electronically after each DFS session and received reminder emails after each session prompting them to reflect their experiences in the diary even in cases where they did not sign up to the session (in which case the diary prompted them to explain why that was).

Twenty-five participants returned the completed diaries in March 2023 alongside reflections on their overall DFS experience e.g. what they found most difficult and frustrating, what went well, how to improve the programme, and any other information they believed would be relevant for the study. We also held informal follow-up conversations with some of the participants in winter 2023 to understand if they would participate in the 2023/24 DFS. The diaries were immediately pseudonymised, so all the names used in the sections below are pseudonyms. We had a mix of depth and detail provided in the diaries and the example in annex 6 reflects in the round the extent to which participants engaged with this exercise.

As discussed by Parag et al. (2023), recruiting a diverse sample is challenging when conducting energy research in a hurry. The urgency with which the DFS launched made it difficult to reconcile sample diversity with the depth we were seeking in our data to align with the domestication theory framework.

Our choice of diaries as a method allowed us to collect a longitudinal dataset covering participants' experience over the entire duration of the DFS in alignment with the analytical framework which views domestication as a process which takes place over time. We prioritised obtaining data from each DFS session (starting from the first one) to be able to track routine formation, learning processes, changes in attitudes etc over as long a period of time as possible. Due to time constraints, we were also unable to recruit beyond specialised interest groups. Despite not being generalisable to the wider population, however, we believe our approach is valuable in that it gives insight into the raw and detailed reflections of the DR experiences over time. This complements wider studies (e.g. Centre for Sustainable Energy (2023)) more representative of the general population because it provides an in-depth longitudinal view of the DFS experience.

Although not representative of the GB population or of DFS participants overall, our sample does cover a mix of socio-demographic, technological and geographic characteristics.

Participants were aged between 25 and 70, including five students, two retired couples, and ten professionals. In terms of geographical location, twenty participants were based in south-east England, two in Wales, and three elsewhere in England. Ten participants had rooftop solar, and five also had home-batteries. Seventeen participants used gas for heating and cooking, and two had heat pumps. Eight participants used technologies which allowed them to automate or remotely control appliances. We have provided detailed participant characteristics in annex 7.

Given we recruited most participants from specialised interest groups, we believe they had above-average interest in and understanding of the energy sector and energy-related technologies. Reflective of wider DFS participation, most of our participants signed up to the DFS through Octopus Energy, one of the first energy suppliers to join the DFS. We therefore have little insight into the impact of the DFS beyond Octopus Energy's customer base. Moreover, the sample does not cover participants with pre-payment smart meters (sometimes used as a proxy for energy vulnerability), and no questions were asked about participants' income or vulnerability to avoid losing participants in the recruitment process. The diaries also reflect the perspective of the main participant rather than that of their entire household, albeit participants did reflect on the impact of the DFS on others in the household. We reflected in the discussion section the main impacts of these limitations.

Data analysis (section 4.2)

Step 1: We started our analysis from Hargreaves and Wilson's (2017) characterisation of the three domestication pathways they had identified (successful, precarious and rejection). Wilson and Hargreaves built their pathways largely on frequency and perseverance of engagement with smart home technologies and perception of and interest in using these technologies. In a similar vein, we looked at continuity and consistency of engagement with the DFS as well as perceptions of the experience, so we defined success in relation to the number of sessions opted in to and looked at whether DFS sessions developed into a fixture of the home e.g. how/if participants planned their actions to accommodate the sessions, how participants and other household members perceived the DFS.[19] This is reflected in Table 14 below.

Table 14: Successful, precarious domestication and rejection of the DFS (adapted from Wilson and Hargreaves, 2017)

Domestication outcomes	**Characteristics**
Successful domestication	Participants opted in and took action to reduce demand in the majority of DFS sessions with mostly positive or fluctuating attitudes and perceptions.
Precarious domestication	Participants either did not opt in to most sessions, or opted in to most sessions, but did not take much action to reduce demand in most of those sessions with perceptions either fluctuating or negative.
Rejection	Participants opted in to very few sessions and took little or no action to reduce demand (e.g. they forgot about the session) with mostly negative perceptions of the experience.

We also considered whether the kWh reduction in demand by each participant should weigh into whether they successfully domesticated the DFS. The DFS' objective revolved around reducing peak demand in winter 2022-2023, without prescribing what kWh shift in peak is preferred. Since DFS was open to residential users, we inferred that any volume reduction is relevant – otherwise the DFS would have applied only to the I&C sector which can traditionally achieve higher volumes of demand reduction. The ESO rewarded, thus valued any kWh reductions, no matter how small. DFS providers and the ESO also favour certainty,

[19] The primary unit of analysis in this paper is the household's engagement with the DFS over the winter 2022–2023 period. More specifically, we analyse episodes of engagement with individual DFS sessions as instances through which broader domestication processes become visible. Each diary entry captures how a household interpreted a DR signal, decided whether and how to respond, drew on particular routines, technologies, or competences, and reflected on the experience afterwards. We therefore do not treat isolated responses to DFS events as the phenomenon of interest in themselves; rather, we use repeated episodes of engagement to examine how DR was, or was not, incorporated into everyday life across symbolic, practical, and cognitive dimensions.

so a user who is reliably shifting demand away from peak, offers value via that certainty, even if maybe not via volume. Moreover, the DFS may not have provided these participants with significant financial savings, but most will have had an overall positive experience with the DFS e.g. by feeling like they are contributing to a societal goal or using the experience for fun or family time as will be shown in Section 5. For these reasons, users who continuously shifted away from peak, even though the volumes they shifted were small, were qualified as having successfully domesticated the DFS.

Step 2: We summarised the diaries into short narratives to reflect participants' experiences holistically and organised them under each of the three pathways: sixteen diaries reflected successful domestication, seven reflected precarious domestication, and two reflected the rejection of the DFS.

Step 3: Under each pathway, we investigated if/how diaries differ in terms of the features that led them to qualify under their respective pathway. We concluded that motivations and access to technology are the defining features which explain why and how our participants domesticated (more or less successfully) – or rejected – the DFS. We split the successful domestication pathway in two to reflect these different factors.

Step 4: We considered outliers. Three participants successfully domesticated the DFS, but with outcomes that came into conflict with the spirit of DR, as we discuss in Section 5.3. We created a separate pathway to reflect their experience. We found it difficult to fit this pathway in either successful or precarious domestication. To accommodate this ambiguity, we abandoned the idea of presenting the pathways as discrete and instead set them out on a spectrum from successful domestication to rejection. Annex 9 provides a visual representation and summary of how we defined our five pathways on this spectrum. We thus ended up with a total of five pathways which we detail below.

FINDINGS (SECTION 5)

The five pathways into which we organised the twenty-five diaries correspond to the diverse ways in which participants domesticated the DFS. We named each pathway by its most salient characteristic to refer to it more easily in this analysis. The five pathways we identified are: (1) Motivation-Driven Success, (2) Tech-Enabled Success, (3) Gaming, (4) Not Worth the Effort, and (5) Disillusioned. We analyse these below, following the structure in Table 1 whereby we present participants' interaction with the DFS on the symbolic, practical, and cognitive dimensions of domestication.

Motivation-Driven Success pathway (section 5.1)

Our eight participants in this pathway had in common a desire to reduce CO_2 emissions through the DFS. They were also aware of, and knowledgeable about, the need for flexibility in a low-carbon electricity system, although they did not all have specialised expertise in this field. For a few participants, environmental motivations went hand in hand with concerns for energy security and a sense of contributing to resolving a national problem.

All participants regarded financial gains as secondary benefits, and no one was deterred by small reductions in peak demand or low financial rewards.

Roberta, for instance, reported that '*I'm not expecting to save much, but I'm keen to keep participating in the name of contributing to wider system benefits and seeing how it all works.'* Patrick noted he is motivated '*mainly by contributing to a more efficient and decarbonised grid than [by making] financial gains;'* and Thomas reported a '*desire to contribute to reduction in peak demand (and associated use of less clean energy sources).'*

Additionally, Sandra and her partner thought it good to '*have our fridge-freezer on a smart plug for demand-response, even if we can contribute very little flex apart from that.'*

The strength of motivation of these participants made an imprint on all dimensions of domestication.

On the **symbolic** dimension, participants perceived reducing electricity demand overall, and shifting demand away from peak times as normal rather than exceptional behaviour. Jennifer, for instance, noted that:

> *We are used to adjusting our usage. I am part of a local energy scheme […] which charges a premium between 4pm and 8pm, and the cheapest tariff is 8pm to 7am. […] I have been committed to lowering our energy use for many years. I think having a variable tariff for all would make people think about when they use energy […].*

Participants tended to give the experience a positive connotation. For instance, they found their participation in the DFS served as an opportunity to reconnect, framing the experience as '*family time'* or '*dinner by candlelight*.'

Jessica, who has small children and a hectic schedule, used the sessions to bring the household together, reflecting the affordances of the DFS. She created a game in which the children used a phone light to find their toys, noting that *'the boys loved it and were sad when it finished.'* Jessica also capitalised on the positive media commentary around the sessions for an educational opportunity: explaining to her children that their participation was helping to save the planet from *'dirty coal.'*

Their attitudes and resolve warmed other members of the household to the DFS even when this did not seem likely to happen. Roberta initially found it difficult to encourage her partner to switch off *'without nagging'* and noted that *'there is an interesting relationship dynamic to these trials'* when she discovered he had not turned off the items that he claimed he had. Thomas too initially found that when his wife oversaw making dinner it was *'harder to get* *her to do the smaller things as a) she is less committed to the initiative b) she doesn't have the details.*' Jessica's husband initially described the DFS as a '*pain*.' All three partners however joined into DFS efforts as it progressed. Roberta's partner because of her explanations, and Thomas' and Jessica's spouses in conjunction with the positive media messaging around the two consecutive January 2023 sessions publicised as essential for replacing coal generation on those two particularly cold winter days.

Reflecting their attitudes and motivations towards the DFS in conversations outside the household, several participants also became warm experts, enabling friends and family to participate in the DFS. Sandra helped her daughter sign up with a DFS provider, and Jennifer stated that she had been able to explain the importance and benefits of DR to her wider family. Thomas convinced his mother to get a smart meter and join the DFS.

On the flip side, they expressed dissatisfaction with the DFS methodology – which they understood better than average – because they perceived it as penalising them for *habitually* using less electricity at peak times, which they considered normal virtuous behaviour. However, unlike participants in the Gaming and Not Worth the Effort pathways, they were unaffected in their commitment to opt in to DFS sessions and continued making efforts to shift demand.

From a **practical** perspective, many participants already knew from experience what actions they needed to take during the sessions. Jennifer already knew which appliances to turn off during the events because they were the same appliances she would regularly avoid using at peak times. Sandra had already been using a smart plug on her refrigerator on a regular basis pointing out that '*smart plugs will be of most use on appliances that are always on or very frequently used.*'

These participants also found it easier to make small adjustments to their routines when needed e.g. working in a sun-lit room to avoid heating the house during DFS events, watching TV on their phone, or boiling water on the stove instead of the kettle.[20]

It was the practical dimension – particularly the things outside of their control – that most tested their resilience. Jessica's smart meter had an intermittent connection which caused her worry that her efforts are not accurately reflected in the savings: '*I'm a bit concerned our saving hasn't been captured properly as the Octopus app is saying it can't connect to our smart meter this morning :('* A few sessions later she wrote: *I am annoyed that my smart meter has stopped working again and so I was given an average number of Octopoints.*[21]*'*

Thomas found it difficult to accommodate longer sessions, sessions on consecutive days, and short notices whilst balancing work and the schedules of three small children. For most of the DFS he found creative solutions to accommodate these constraints e.g. he installed smart plugs, or texted his wife clear instructions and reminders of what to power off and when.

In November 2022, he wrote:

> *Having not had email from Octopus I signed up via the Hugo app, so I was able to take steps to prepare. Had I not seen via Hugo the Octopus email would have been too late to allow prep. […] I get all the kids at 5pm and then have to go straight home to cook tea (right in the window of demand reduction). I will try to start dinner at 6pm but that makes it hard to get them to bed on time. So, my prep has been to get a pre-made meal (homemade!) out of the freezer that can be microwaved + microwaved packet rice. I assume this saves at least some energy vs heating in oven / induction hob.*

By March 2023, however, he reported:

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[20] It should be noted that behaviour-based DR may remain fragile even where participants engage positively in the short term. Because such engagement often depends on repeated attention, motivation, and the continued willingness to reorganise domestic routines, it may not persist over time or develop into fully stabilised domestication. In this sense, participation in DR should not be assumed to become durable simply because households respond successfully during an early trial or programme period.

[21] Octopoints were the way in which Octopus Energy rewarded participation after each DFS session

> *Bad day for a short notice one. Kids were at home due to strike. Both parents stressed trying to juggle work and childcare. Could not bring myself to think about cooking dinner on a special schedule.*

On the **cognitive** dimension, participants in this sample proved curious and eager to learn about DR and the impact of the DFS more broadly.

Sandra noted after one of the January events:

> *This was the first 'for real' (non-trial) event and it was well-publicised in several media, including online reporting during the event by the BBC. So I did pay a bit of extra attention, e.g. going to https://grid.iamkate.com/ to see if there was a visible change in demand […] and whether the ESO had had to bring on either of the two coal-fired plants that had been warmed up in readiness for the evening peak. No extra coal-fired power was needed […] which I felt good about. […]*

Most participants in this group already had established ways of monitoring their usage (e.g. through mobile apps) and had above average understanding of how much electricity their appliances use. However, due to the calculation of the baseline which we discussed in Section 2, they did not fare any better than all other participants at predicting their energy savings or rewards – which caused them disappointment. They also felt frustrated by the three- or four- days it typically took for their DFS provider to calculate the results of their saving session which made it more difficult to compare results between sessions and thus learn how to further reduce demand. Our only participant who switched DFS providers after a few sessions also spotted inconsistencies between the information received from the two DFS providers which caused him to question its accuracy.

Tech-Enabled Success pathway (section 5.2)

The five participants in this pathway had in common the fact that they re-domesticated existing technology to provide DR via the DFS – either large shiftable loads (e.g. electric heaters), or a combination of generation and storage technologies (solar panels and batteries).

They relied on automation more than other participants, but still planned their use of technology around the DFS sessions and created new routines to provide DR.

On the **symbolic** dimension of domestication, participants formed similar positive framings for the DFS like the previous group, with added enthusiasm around using existing technology in new ways. Mason developed what he framed as a '*battery strategy,'* which involved checking the weather ahead of each session, charging the battery to an adequate level, and keeping an eye on consumption during the session. Phillip was able to enact a similar routine with apparent ease, framing it as *'one minute's work.*'

Most of the time participants successfully provided DR without other household members even noticing. They enlisted the support of household members only when needed and mostly at the beginning of winter until they figured out how to minimise disruption for the rest of the household.

Philip, for instance, only asked for cooperation from the household once in November 2022, and took a measured approach on where to focus their efforts:

> *I was working in the office on the day. There was some sunshine on the day, meaning 1.8kWh of solar PV had been used to charge the battery by mid-afternoon. It was touch and go as to whether the battery would still have enough power by the time of the session, so I contacted my wife at lunchtime, and we agreed that she would cook dinner using the gas hob, avoiding our electric oven, electric pressure cooker etc. I also asked her to make sure that we weren't using the washing machine and dishwasher at the time. We didn't take any action with lighting and other electricity uses, as they are minimal, even though we have a large number of Phillips Hue lamps that can be controlled remotely.*

Back in November 2022, Mason too *'told family to get them in the habit for next time mostly,*' but then only mentioned it a couple of other times the whole winter.

The participants in this group had mixed motivations which carried little weight in predicting successful domestication. Henry was primarily motivated by financial gains: when asked after each session if he would opt in again, he noted '*Yes, especially knowing financial* *incentives.'* Alisson too had some financial motivations since she attempted to estimate her savings based on what she thought her baseline was for each session and was motivated to participate again when she received significant rewards. However, she gave her rewards to charity via an Octopus Energy-led scheme and noted other motivations like maintaining her streak and because she *'committed to the cause.'* Like most participants in the previous pathway, Phillip, Matthew, and Mason were already using little grid electricity at peak times, so gained almost negligible rewards, but this did not deter them from participating.

These participants too became warm experts in their personal or social media networks, but their framings were not always as positive as the group above. Mason, for instance, '*shared saving with [a] friend on WhatsApp (also has solar panels so interested)'* and signed up to a new social media group to discuss his results. However, when Alisson discussed the DFS at work she *'complained to a few colleagues about the baseline calculation algorithm'* after having gone online to understand why the outcomes of the first two sessions differed so much from her expectations.

On the **practical** dimension, participants gradually created new routines to re-domesticate existing technologies. Alisson and Henry used their electric heating and ground-source heat pump, respectively, ahead and after each session, as opposed to using them throughout the 4-8pm evening peak as they normally would.

Alisson tried various strategies to automate her smart heaters – which she had previously used without automation – tinkering with the GPS and the automated schedules functions on the app. She also tinkered with the smart light bulbs automations and re-defined their interaction with the Google Assistant to re-gain control over some functions that she had effectively delegated to the automations e.g. she de-activated the lights turning on automatically at dusk as this may have coincided with some of the DFS sessions.

For most sessions, Henry noted that he '*switched off the ground-source heat pump for the hour, simple to do but needs to be done in the house and can't do remotely.'* On several occasions he came home from work early to turn it off. He also '*bought some smart plugs as well on things which can easily be switched off.'*

Similarly, Mason adjusted previous routines and tinkered with automations to accommodate DFS sessions:

> *Battery will have plenty of charge. We won't put on tumble dryer / dishwasher / washing machine until after 10am today. Probably won't use kettle / coffee maker either. Might turn off heater in conservatory (it's triggered by temperature). Set timer to remind me to turn heater back on.*

Most participants planned their use of technology around the DFS sessions in quite a bit of detail. Phillip for instance noted:

> *The day before, I looked at the status of my battery and the weather - it was clear that there would be no sun and therefore no chance of powering my home from the battery, rather than the grid, during the session. So, I changed the settings on the Tesla app to allow grid charging and temporarily changed the backup reserve on my battery to 50% capacity. The battery therefore charged overnight to 50%. A few hours before the session, I changed the backup reserve level on the battery back to its normal level of 16%. This meant the battery would discharge from 50% to 16% and I was confident this would have more than enough power to cover the 5-7pm period.*

For all the planning and automation, this group too found it harder to participate in short notice sessions so either sought to pre-empt the sessions with information from elsewhere (Alisson) or did not bother to accommodate the session at all (Henry and Mason).

On the **cognitive** dimension, these participants too showed a real eagerness and enthusiasm to learn. They learned from one session to the next how to refine and improve their approach and described this process with uncanny consistency and detail across winter.

Even with above-average understanding of and interest in technology and DR, these participants too found it difficult to predict their rewards. This is despite using technologies such as apps to review their consumption in near real-time, just like participants in the previous pathway. After the first two sessions, Phillip for instance found it:

> *Very difficult to predict, because I am not clear how Octopus calculate the reference consumption to compare to. This is complicated by my battery - if Octopus use times when we were using battery power or solar PV, rather than grid consumption, as the reference, then it will be really hard to demonstrate savings above this.*

Even after seeing the results of the penultimate session, he wrote: '*this is a surprisingly large amount, much bigger than any previous session and I have no idea why this is the case.'*

With little information available at the start of the DFS on how the baseline is calculated, Alisson noted she feels *'scammed'* for having received fewer Octopoints in the second session than in the first one despite greater effort. After understanding that the baseline also accounts for in-day consumption, as discussed in Section 2, Alisson noted how difficult she found it to translate this into practice and reconcile it with the messaging around the DFS.

Gaming pathway (section 5.3)

We created a separate pathway for participants who, at least on a few occasions, increased their electricity demand in the hours running up to a DFS session (e.g. by charging a home-battery) to reap higher rewards. Borrowing the term from the media, we considered it *gaming* of the DFS when the increase was both artificial (i.e. participants otherwise would not have used electricity for that purpose at that particular time) and deliberate (i.e. they increased their usage before the session to increase their financial gains during the session). As discussed in Section 2, the methodology used to calculate the baseline made gaming possible.

Our study included only three such participants, although the phenomenon generated discussion and debate on special-interest groups on social media, suggesting that it may have been common amongst smart-energy enthusiasts. Gaming, however, appears to require significant effort on behalf of individuals to understand and manipulate the DFS methodology, and to coordinate smart devices so we do not expect it to have been widely employed. A Centre for Sustainable Energy (2023) survey found 16% of respondents attempted to shift usage in the t-4 interval, though it is not clear how many of these did it with the intention to increase their DFS rewards.

We found the **symbolic** dimension more complex for this pathway than others. Like other participants in the two previous groups, they felt motivated to participate and attributed the DFS with positive meanings which smoothed its incorporation into everyday lives.

William's family branded the sessions '*power hour'* and he even noted his '*wife was a bit stressed about forgetting about 'power hour'* on one occasion. Pierce '*spent some time talking to the children about what we were doing today and the reason - reducing the need for three coal plants. Talked about pollution aspects of coal given high carbon to low hydrogen content.'*

When asked if he would opt in to the next session at the start of the DFS, Gilbert noted that '*yes, I like it and it is a bit of fun. I don't think the scheme is aimed at people like me who already use very little, but I will give it a go and any money I earn I am just going to give to charity.'* Gilbert even felt frustrated he could not contribute more; for one of the January sessions, he left home all day to work in the office because he *'felt that there was ongoing pressure on the electricity network*' and thought this could help.

Positivity however turned to frustration or opportunism when participants learned the methodology can be gamed. Gilbert felt *'punished'* for having left home the whole day when previously he had thought he was helping the grid.

He completely changed tack for the next session, a January morning one when he noted:

> *Given my recent experience of finding out about the in-day adjustment, I was determined to maximise my rewards on this session despite not doing anything different during the actual saving session 9-10. At 6:30am I put on the washing*

> *machine and made my breakfast. At 7am I made my lunch for the week. At 7:30 I hoovered up and put on the electric fire for 30mins. I did all this to see if my saving session rewards would increase just for doing tasks between 5-8am […].*

He estimated this would be his highest saving yet – which it was – and posted the results on Facebook.

Driven by environmental motivations, Pierce had discussed at length with his friends and family the objectives of the DFS and even exported electricity from his battery into the grid during the sessions to provide additional support. In February 2023, however, he noted:

> *Reviewed DFS documentation and realised that additional usage between t-4 and t-1 is counted as a saving. Consequently, fully charged battery, heated home to higher temperature etc in this time.*

He also noted he felt *frustrated that only net imports were measured during this process which doesn't incentivise people to support with extra capacity,*' and was '*surprised by how poorly structured the formula was for calculating savings. It turns out this was very easy to game, which you used to compensate for exporting during the peak period.'*

William's notes were less explicit, but we could see his results spiking up in the second half of the winter. His rewards went from an average of c. £8 per session in the first part of the DFS to an average of c. £60 per session in the second half and earned a total of c. £260 for the winter, by far the highest total reward we have seen in our sample.

With regards to the **practical** dimension of domestication, the approaches employed by these three participants were not much different from the previous groups, showing robust signs of having domesticated the DFS.

William established a routine of '*cooking dinner before the session using the oven and induction hob [and adjusting the] smart thermostat so the air-sourced heat pump wouldn't come on during the session.'*

As in the previous pathways, he used smart controls to enable the routine: '*I switched my air-sourced heat pump off via my smart thermostat app prior to the session from my desk in London (I set a reminder on my phone).'* Pierce too consistently noted how he *'set battery to remain at full capacity prior to the session. Set battery to ensure net export to grid of 100w. Cooked meal before session started. Preheated rooms before the session.'*

Gilbert noted how he '*changed the heating schedule so that it started after the session. Put both sky boxes into deep standby mode. Ensured almost everything switched off and baseload = 22w. Charged my phone.'*

On the **cognitive** dimension, participants were equally enthusiastic to learn as the previous groups, and even a bit more thorough. They learned both from their own past behaviours and went online to learn from others. Gilbert and Pierce additionally combed through official DFS documentation to clarify their understanding of the methodology – about which they then either posted online or discussed with family and friends.

Our findings thus show that participants in the gaming pathway domesticated the DFS successfully in the sense of forming routines, collaborating with household members, acting as warm experts, and learning from one session to the next how to better accommodate the DFS into their everyday lives. However, when looking at affordances, or the possibilities for action that they could choose from, we find that the actions they preferred may have run counter to wider energy security, affordability, and decarbonisation objectives.

For instance, in charging his battery from the grid instead of from his solar PV, Pierce artificially increased overall system demand and, to some extent, his own bill – although the latter was compensated for from the additional reward he made during the session. If enough users behaved in this way, the cost of the system overall would increase because more generators would have to come online to feed the additional demand. Emissions too may increase if the generators called upon are gas plants instead of renewables, whose ability to feed the additional demand will depend on the weather. Finally, if this creates a new peak in the interval preceding a DR session, it will have security of supply implications whilst the grid adjusts to the new peaks.

That said, participants who gamed the DFS did not necessarily act in a way counter to the DFS script which rewarded and thus prescribed demand reduction in a specified interval only (and not overall demand reduction). And, in any case, domestication theory does not view successful domestication as contingent upon acting in accordance with the script. Based on this reasoning alone, we have considered the gaming pathway a subset of successful domestication, like the two pathways above.

We noticed however that other participants in our study, when pondering on their affordances, made different choices which accounted for wider values than just the DFS script or their personal gain.

For instance, Roberta in our first pathway, noted:

> *I noticed that when I'd been using more energy in the previous days, I could save a bit more when it came to participating in the DFS. […] This created a small incentive to use more energy, overall – but I resisted because that goes against my values, and (honestly) the small £ amount I seemed to save after each event was not enough to assuage any guilt for having deliberately used more energy…*

Alisson too did not think it would make sense to increase her bill overall for the sake of making more money during the sessions and, unlike our gaming pathway participants, did not make the effort to test whether she would be better off overall. Even Albert, in the Not Worth the Effort pathway which we discuss below, said: '*for us the demand events displaced some energy use and overall probably reduced it (as we turned off some devices we don't normally). We didn't game it!'* This shows he was aware of gaming, decided against it, and found the overall demand reduction a notable enough observation to mention it in our study.

We thus believe that the way in which Gaming participants domesticated the DFS, whilst successful from a pure domestication perspective, is not quite in alignment with the spirit of DR. We discuss the implications in Section 6.3.

Not Worth the Effort pathway (section 5.4)

Most of the seven participants in this pathway were not energy experts and were less likely to express environmental motivations behind their initial decision to take part, and less likely to have domesticated the technologies which made participation easier for those in the second and third pathways. These participants were more likely to express financial motivations, and the pathway is characterised by declining levels of commitment, especially when they perceived the financial reward to be out of balance with their effort. We associated this with precarious domestication of the DFS.

On the **symbolic** dimension, Nora's comment succinctly summarised a typical attitude, which is that *'other things got in the way*.' For instance, participants chose to opt-out if guests came over, to avoid social awkwardness – as opposed, for instance, to Sandra in the first pathway who boiled water for her guest's tea on a gas stove instead of a kettle.

Nolan noted that he '*unexpected[ly] had guests over during the savings period, so had on more lights, used the heating, and appliances when I should have been saving.'* Scott had family staying over but didn't tell anyone about the DFS because '*the in-laws were being very helpful doing our cooking and laundry, and I didn't want to appear ungrateful by asking them to NOT do those things for an hour!'*

All participants considered the savings to be too modest. Angela even made a pragmatic calculation: '*The reward didn't seem worth it - it was 5 minutes of my time to go round switching everything off so that's worth 80p even at minimum wage.'*

Their contributions to peak demand reduction were in fact, not negligible because, as discussed in Section 4.2, the ESO derives value from any reduction, regardless how small. Their results from the individual sessions in which they tried to reduce demand were comparable with those obtained by participants in the first three pathways. However, even when they participated in DFS to reduce carbon emissions or contribute to energy security, their exclusive focus on financial reward as a proxy for success, resulted in feeling demotivated.

As such, most participants concluded their lifestyles are not conducive to effective participation in DR. Reasons included a tendency to be away from home during peak times, or because they rarely conducted energy-intensive practices (e.g. laundry) during peak hours. This is, again, a result of how the baseline was calculated to account for demand during the previous ten days at the same time as the DFS session.

A few things however did keep these participants engaged. Most prominently, the two January 2023 sessions that made headlines for being key in keeping coal off the grid motivated participants to try anew.

Maxwell wrote:

> *This time […] communication from Octopus Energy clearly encouraged people to participate in the exercise as coal-powered energy plants were needed to rebalance the grid if demand was not reduced. This aspect of communication certainly motivated us to make an extra effort.*

Angela too *'got the message about this session being really key and the reward being higher so just before the start I went round and turned off all the lights and all appliances except the fridge.'* Norah was additionally motivated by *'maintaining a streak'* and Angela found that delegating responsibility for the sessions to her partner is another way to maintain participation in the DFS. Neither of these however were sufficient to sustain commitment throughout the winter, though interestingly, follow up conversations with these participants showed that all but Maxwell signed up to the DFS in the second winter.

They made little or no effort to convince other household members to partake in the DFS and where they did talk about the scheme, they were unlikely to try to persuade others or advocate for it.

On the **practical** dimension, participants typically opted in to less than half of the sessions and did not tend to form routines beyond switching off low-energy consuming, easy to access devices such as laptop chargers, monitors, and some lights.

When they ran into an obstacle, they made little or no effort to overcome it. Nolan, for instance, a young tech-savvy participant, said he missed most sessions because he was not receiving push notifications on his smartphone, but had made no deliberate effort to address this, even once he had realised it.

Despite a strong start in Maxwell's household where all four flatmates

> *Switched off as many electric devices as possible (no lights, heating in all rooms). Ensured no device was on stand-by. Cooked tea shortly before. Charged battery of laptop to a sufficient level beforehand. Only devices which stayed connected [were]: fridge/ freezer, Wifi, and TV on standby (plug was unreachable sitting behind a bookshelf).*

By the second session Maxwell already noted:

> *Personally, I was not home. Housemates decided not to participate again (two days in a row seems to be too much disruption/ interference with daily routines, especially during that time of day). One housemate has to attend a virtual Zoom meeting requiring lights, monitor and laptop charging – important limitations!*

Scott too started out enthusiastically and for the first session he noted:

> *Turned off all but a few lights during session. TV and computer were the only things on. My daughter was at home so needed the TV. Avoided making tea during session. Unplugged laptop charger (although I knew this would be miniscule). Checked IHD*

> *and felt frustrated not to be able to get usage below 430w. Everything I was aware of was turned off.*

He did not delegate responsibility for the sessions he was not at home for and having eventually noticed no rewards for any of the sessions, he gradually disengaged without having built any routines.

For the first session, Angela noted:

> *I felt quite positive about the prospect of getting a discount on my energy bill by using less energy, as well as helping the grid. Just before the session started, I went round and turned all electrical items, switched off sockets, except the fridge (which I switched to Economy mode). I turned off all the lights except one.*

From the second session onwards, however, she started to feel discouraged about how little she had earned, so her behaviour changed too: '*so although I turned off a couple of easy to reach items – my laptop charger and monitor – I didn't do as much as the first time.'*

We saw less focus on the **cognitive** dimension of domestication in this pathway. Participants made little or no effort to learn how to improve their saving, despite all of them having complained about it.

Only Angela '*dug into her smart meter data'* and concluded that she was not making any savings '*because these times of the day aren't usually when I use a lot of electricity.*' Most participants came to the same conclusion intuitively but did not look to validate it or improve the outcomes. Unlike previous participants they did not seek additional sources of information, and they did not compare outcomes of each session against the actions they had taken.

Disillusioned pathway (section 5.5)

This pathway only had two participants, which was expected given the sample bias and the fact that the analysis only included those who returned their diaries at the end of the DFS.

Like participants in the 'Not Worth the Effort' pathway, the two were not energy experts and were mostly motivated by financial gains, albeit one did also have an interest in reducing carbon emissions. They made little or no effort to domesticate the DFS and expressed mostly negative feelings about the experience, so we associate this group with the rejection of the DFS.

The **symbolic** dimension of domestication is most striking for this pathway because participants' wider negative experiences with or perceptions of the energy sector reflected on their engagement with the DFS.

Reflecting on her overall experience, Grace noted:

> *During the energy saving sessions this winter I was going through an unnecessarily complicated gas supplier switch which impacted my desire to join in with these sessions/made it much harder!*

Sebastian pondered on his struggles to receive email notifications of the sessions without being the account holder:

> *It's designed for individuals – the account holder only gets notified but the whole family need to be involved for it to work. Getting notifications was way more of a hassle than I had predicted.*

This extended to musings on how DFS might impact family life:

> *I'm not always home at the times…so it's kind of patriarchal… I imagine more men are account holders (would be good to know stats) and more women are homemakers, so the man decides to save money at work but it's the poor person at home who actually has to make the sacrifice.'*

He went on to reflect his resentment towards Octopus Energy '*I feel like I just want to boil a kettle unnecessarily to make the little Octopus cry,*' and government:

> *I dislike the personal responsibility [in that] it's up to me to use less power and ignore the fact the UK gov has a shit energy security plan and hasn't invested in renewables.' How much did Greg Hands* [i.e. a former energy minister] *save on those nights…eh?*

Like most other participants, Grace and Sebastian also reflected on the imbalance between financial reward and effort: '*I like the theory behind it but saving £4 wasn't worth the hassle'* (Sebastian); '*I didn't save a huge amount of energy and so the points didn't create a huge amount of money off future bills and so the incentive for me wasn't that high'* (Grace).

We did not get a sense from their diaries that they had discussed the DFS beyond the household.

On the **practical** dimension, neither participant opted in to enough DFS sessions to create a routine.

Grace and her partner missed the first DFS session because she '*thought it would be hard to complete as we would both be at home.*' She then joined the second session and wrote:

> *Neither of us was home so it made sense to join this session. Did not use oven/lights/any appliances during this time. I charged my work and personal phones at work. I kept the heating as it is gas powered and as Octopus aren't currently supplying the gas, this didn't affect the session. I didn't think to turn off sockets.*

For all other sessions, she wrote that she either forgot or missed that they were happening.

Sebastian opted in to the first and last three DFS sessions but mostly forgot about them. It was only in the very last session that he noted *'we didn't use dishwasher for a bit.'*

On the **cognitive** dimension, neither participant sought to learn from their experience or from outside sources, nor did they have any prior DR experience to draw from. Grace assumed that turning off her gas boiler would have no impact on DFS outcomes because she was paying the gas bill through a different supplier – in fact, the boiler will have used some electricity which would have still counted for DFS purposes, even if not a lot. She did not discuss this assumption with any warm experts or seek to test it on her own between different DFS sessions.

Sebastian rationalised not opting in to sessions as *'I get no app alerts or emails. It's in my wife's account so no idea when it's going on.'* Unlike other participants, however, the diary did not reflect that the couple had discussed any solutions to share the information, to facilitate participating in the DFS.

DISCUSSION AND IMPLICATIONS (SECTION 6)

Analysis of findings helps to answer the two research questions posed in this study. The first relates to understanding how, and with what success, did participants domesticate the DFS; the second seeks to identify learnings for similar initiatives and for broader DR policies. This section summarises the diverse domestication pathways observed in this study, identifying key insights into householder motivations, obstacles encountered, and opportunities to sustain engagement over time. It provides recommendations for designers of future DR initiatives to appeal to a wider, more diverse population.

Pathways to domestication: motivations, obstacles, and opportunities (section 6.1)

We found that even within our relatively small sample of households, engagement with the DFS was surprisingly varied, driven or enabled by factors such as motivations, access to specific technologies, prior exposure to DR, or family dynamics. This allowed us to identify five distinct pathways for domesticating the DFS which we believe could apply to the wider population, although we do not expect a similar distribution across the pathways to the one in our sample (where most participants were successful in domesticating the DFS), since our participants probably had above average DR *capabilities* (Roberts et al., 2020) or *flexibility capital* (Powells and Fell, 2019). In a sample more representative of the wider population, we would expect to see much lower occurrence of successful pathways.

In terms of what enables successful domestication of DR, we noticed that our participants motivated primarily by financial gains were successful only if they believed those gains were worth the effort (e.g. if they had large enough loads) and they tended to be easily disheartened otherwise. This aligns with findings from Bradley et al. (2016) who conclude that perceived barriers to providing DR depend on the financial incentive received. Because domestication theory enabled us to track continuity of participation in DR, we confirm findings in existing research that expectations of financial savings are significant motivators for participation in DR initiatives (White and Sintov, 2018), but also find that they are insufficient for *sustained* participation. We find that in our sample, the successful domestication of the DFS is largely enabled by *non*-financial factors, namely motivations (particularly environmental), prior experience of DR, and the availability of DR-enabling technology.

These results corroborate research which indicates that perceptions of social and environmental responsibility outweigh financial motivations as determinants of successful participation in DR (Buryk et al., 2015; Strengers, 2010). We saw that our participants who followed *precarious* or *rejection* pathways tended to be less well-informed about the system benefits of DR, while those committed to the DFS were aware of the growing importance of demand-shifting to reduce greenhouse gas emissions and system costs. Additionally, we found that our participants with strong environmental motivations were more likely to continue providing DR even in adverse circumstances e.g. low rewards, frustration with perceptions of injustice. They were also more likely to frame their experience of the DFS in positive terms and act as warm experts and advocates of DR; whilst also finding innovative and ingenious ways to domesticate DR, constituting, as discussed by Nyborg (2015), a source of unrecognised potential for delivering decarbonisation.

One key challenge for successful DR policies is to promote the *continued* engagement by householders over time.[22] This issue has attracted little attention in academic literature to date, and our findings contribute some key insights. We found, for instance, that even our most motivated users found it difficult to maintain participation in the face of technical glitches. Ten out of twenty-five participants in this study experienced some sort of technical malfunction, including smart meters malfunctioning, account lockouts, and supplier switching delays. Ideally, energy suppliers would work harder to prevent such issues where it is in their gift to do so, but where that fails, customers should feel able to reach out to the relevant person who can help, with confidence that their issue is handled in a timely manner and with little hassle. Poor customer care can easily result in rejection of DR programmes.

Our results highlight the need to normalise DR amongst households if it is to contribute meaningfully to the transition towards a fully decarbonised power system. Participants who had previous experience of TVTs found it easier to create routines around the DFS and were more likely to see it as nothing out of the ordinary. Surprisingly, some participants who had followed the *precarious* pathway informed us that they had enrolled in the DFS in the following winter (2023/24). This suggests that exposure to DR helps normalise it even for users who struggle to domesticate it the first time around.

In the context of normalising DR, our findings reveal two distinct pathways for successful domestication: manual (first pathway), and automated/technologically-enabled DR (second pathway). This aligns with Darby and McKenna (2012) who theorise the many forms that residential DR can take, from manual to Direct Load Control. There is value in harnessing

[22] It should be said that the paper captures the beginnings of domestication processes rather than their completion. Given the short timeframe and limited number of DFS sessions, the study cannot establish whether observed forms of engagement would endure, stabilise, or unravel over a longer period. References to domestication in this paper should therefore be understood as referring to early incorporation and negotiation, not settled long-term integration.

both types of DR to avoid exclusions (i.e. households which, at the moment, can only provide manual DR) in the nascent rollout of residential DR in GB. Even if the contribution of manual DR to demand reduction is relatively low at present (first pathway), its contribution is likely to become more significant as householders increasingly switch from gas to electric heating and adopt EVs. Rewarding manual DR helps users form routines and learn from experience what strategies best fit their lifestyles. It also prevents exclusions and risk of lock-in to automated-only DR at this early stage in the DR journey. Incentive-only schemes such as the DFS are well suited to normalising DR amongst householders, especially compared to punitive scheme designs which risk generating resistance (Nicolson et al., 2018).

Promotion, feedback, and rewards (section 6.2)

Our results on motivations and prior experience of DR highlights the value of raising awareness and normalising DR amongst households. The DFS received wide news coverage as a novel intervention in the electricity system, but there is a need to raise awareness using broader informational or educational campaigns, and to develop a broader range of initiatives that can enable householders to take part in DR. We believe it worthwhile to raise awareness of the benefits of DR and provide arguments and evidence in favour of demand shifting programmes that warm experts can use in their interactions with friends and family. Our results also show the importance of providing prompts for such discussions to take place – many participants noted that they talked to friends and family about DFS in the context of it being in the news.

Besides general promotional campaigns, there is a need to manage expectations about the potential for energy and financial savings. As discussed by Strengers (2016), energy consumption statistics cannot reflect the complexities of household practices in a satisfactory manner. Even amongst our early-adopter participants, knowledge of the measures that will have most impact on demand reduction was limited, especially in the Not Worth the Effort and Disillusioned pathways. Providing clear, timely and personalised feedback on DR sessions is essential. Combining energy and financial results with personalised suggestions for impactful actions is likely to reduce the risk of frustration by participants, resulting from the unrewarded effort – as exemplified by Gilbert's experience.

Additionally, the potential to earn £100 was widely promoted, but few participants came even close to that. Most of the savings we saw in our sample were under £20. Knowing that the potential for savings is a significant motivator for signing up (White and Sintov, 2018), scheme designers must also take care not to generate unrealistic expectations, which may in turn lead to defection as we saw particularly in our fourth pathway.

How best to raise awareness of DR and improve users' capabilities in this space is, however, an open question. Relying on energy suppliers alone can result in uneven spread and potential confusion especially where a household selects a DFS provider other than their energy supplier. For instance, the one participant in our study who switched DFS providers questioned the accuracy of the information he was receiving because it differed between the two companies. Relying on DFS providers could also be problematic, if they prioritise cheaper communication methods (email, social media) which risk excluding less digitally literate users. We thus note the risk of users disengaging because of confusion and/or excessive information as found by Christensen et al. (2020) and Öhrlund et al. (2019).

Octopus Energy, the largest DFS provider, rewarded participation with Octopoints, which many of our participants struggled to understand despite self-reporting relatively high levels of energy literacy and capabilities (Roberts et al., 2020). Many also felt frustrated with the delay in feedback which prevented them from learning how to improve outcomes between sessions. With 24 DFS providers in the first year, fragmentation in terminology, explanations, and rewards was inevitable. Looking forward, it may be necessary for scheme designers to coordinate or even regulate the provision of feedback from third party providers, building on evidence of effective messaging and engagement processes.

Flexibility justice (section 6.3)

Another enabler of successful domestication in our sample was access to technology, be that large loads or automation. Our findings contribute to the flexibility justice debate. We can infer from the data we have on participants in our Tech-Enabled Success pathway that they likely sit in the upper right quadrant (i.e. more financial resources, more flexibility capital) on Powells and Fell's (2019) generalised representation of the interaction between flexibility capital and financial resources. As their research predicted, we noticed that technologically-derived flexibility capital (a subset of flexibility capital) in the form of batteries, solar PV, and smart controls meant these participants mostly did not need to sacrifice convenience to provide DR. We saw, for instance, that some of these participants did not need to involve household members in the sessions, whereas domesticating the DFS for most of our other participants meant negotiating, convincing or collaborating with household members. Interestingly, access to relatively little flexibility capital in our Motivation-Driven Success pathway did not hinder domestication, but it did so in our Not Worth the Effort pathway. This again relates to the discussion above about motivations. We also noticed, however, that many participants in these two pathways had little flexibility capital because they were already using little electricity at peak times. In our sample, this was mostly because they were already on a TVT, or because their lifestyle meant they were not home at peak times. However, in the wider population we might see this because of the cost-of-living crisis or other socio-economic factors leading users to decrease overall electricity demand. DR, as we discussed in the introduction, is valuable to the system, but many users may have less flexibility capital because they have already reduced as much as they could. This means they get less benefit from participating in programmes like the DFS which reward only per kWh (i.e. they only value the final result) instead of also rewarding participation and consistency (e.g. routine formation) which are important for normalising DR. Rewards do not always need to be financial, and we found for instance that streak-framing worked well in keeping some of our participants motivated.

In the introduction section, we presented the case for DR in the transition to a decarbonised power sector. In our analysis of the Gaming pathway, we noted that the way in which participants understood and interpreted the role of the DFS in this transition had an impact on how they domesticated it. Our takeaway is that, at least for participants with above-average understanding of, or interest in, energy and/or decarbonisation, the DFS script created confusion by not always aligning with wider societal values and system objectives. In some cases, this confusion correlated with behaviours that led to an increase in overall demand – in particular, where batteries were involved. Moreover, it created frustration for several of our participants and the wider population (as reflected in the media). This may have wider impact on public perception and future participation in DR programmes, as acknowledged by the Centre for Sustainable Energy (2023) study. Perceived injustice risks undermining both users' appetite for DR and political will to support DR policies (Roberts et al., 2020). Gaming behaviour on a wider scale could also risk diminishing the indirect benefit that all users would be expected to get from peak demand reduction (Uddin et al., 2018). Our evidence suggests that some 'gamers' share the concerns over fairness. Targeted messaging around the negative consequences of gaming therefore could be explored to address this issue on the symbolic dimension in case setting less gameable baselines proves difficult.

One of the reasons why the DFS script and the overall implementation of the DFS caused some confusion and frustration is likely due to the multitude and variety of actors influencing the DFS whose agendas may not have entirely aligned e.g. the ESO, government, DFS providers, energy suppliers, user groups etc. The ESO, for instance, tested short notice periods and consecutive sessions which put pressure on and frustrated many of our participants. Like Nicholls and Strengers (2015), we found that the evening peak coincides with a 'family peak' of activities. Our participants found it hard to navigate this peak of activities at short notice. It is understandable from the ESO perspective that shorter notice periods are preferable, but we noticed in our sample that this has had a negative impact on our participants and may not be the best way to keep users engaged in the longer term e.g. by enabling routine formation. We thus suggest that paying attention to recognitional justice by *'asking whose interests are accounted for in the design of the intervention and whose are ignored'* (Winther and Sundet, 2023) will be important for future DR programmes. Like Powells et al. (2014), we find that DR changes the relationships between various system actors and users, and we find that without further exploring this there is risk of misalignment between imagined users and actual users' daily lives and contexts.

CONCLUSIONS (SECTION 7)

This study used domestication theory to show how GB households incorporated the 2022/23 DFS programme into their everyday lives, and to draw the lessons from their experience. These lessons will be important as domestic DR is still nascent, so it is essential to establish an evidence base to aid its implementation. The study suggests that designing electricity DR programmes, as a staple of secure low-carbon energy systems, will need to take full account of users' non-financial motivations, previous experiences of DR and access to technology. Success of future DR programmes thus depends on a combination of symbolic, practical, and cognitive dimensions (Sørensen Knut H., 1996).

The study showed that domestication theory can be extended beyond artefacts to apply to DR. We also believe it valuable to have applied domestication theory on a nation-wide live programme (as opposed to a trial) in a country where residential demand at this scale is less established than in the United States (US), the source of much evidence on DR programmes.

We also extended the understanding of how domestication pathways (Hargreaves and Wilson, 2017; Juntunen, 2014) could be conceptualised, adding the nuance that successful, precarious and rejection pathways may be viewed on a spectrum rather than as discrete categories. We leave open, however, the question of some successful domestication pathways running counter to the spirit of the original script. We view our approach of creating a spectrum that accommodates this ambiguity as a first step towards a future debate on the tension between domestication and script.

By using domestication theory to inform our data collection and analysis, we were able to bring a unique view of continuity of engagement with DR and insight into factors that go beyond dominant framings of DR e.g. changes in technology (Jensen et al., 2019). Instead, we discussed the roles of attitudes, motivations, routine-formation, artefacts, learning etc and the complex interactions between these and other factors that lead to successful and lasting engagement with DR programmes.

To complement the findings of this study and to support the design of future policies around flexibility, there is a need to understand the characteristics of households taking part and identify those least likely to enrol in the DFS. Our findings help to reveal the reasons why some enrolled participants failed to domesticate flexibility, but there may also be barriers and obstacles to enrolment which warrant investigation. It would also be useful to understand the interplay between financial and environmental motivations in sustaining participation in DR programmes. Research on smart homes and their contribution to DR, including the domestication of smart technologies to deliver DR would also be interesting and would complement Hargreaves and Wilson's (2017) findings. Further research on flexibility justice and vulnerability would also be welcomed, particularly single parent households which were not represented in this sample. It would also be helpful to explore a potential flexibility divide between those who have assets for this type of programme and those who do not. This would highlight the areas where protection or government intervention may be needed to avoid unwanted consequences of DR. Finally, the study made some suggestions around how DR programmes could be designed and communicated in the future. These could benefit from being tested on larger and more diverse samples.

Why piecemeal is not enough: a Technological Innovation Systems analysis of residential demand response in Great Britain and the case for a strategic coordinated approach (paper 3)

Sir Arnold: He's suffering from politician's logic.
Sir Humphrey: Something must be done, this is something, therefore we must do it.

(Yes, Prime Minister, Series 2, Episode 5: Power to the People)

This chapter integrates the perspectives of industry experts and DR users into a historical account of how DR has evolved in GB over the last 15 years. Using a TIS approach and EHA, the chapter traces how successive policy interventions collectively enabled DR to emerge, but not to scale, as interventions were often pragmatic responses to specific problems rather than aimed directly at accelerating DR scale-up. The analysis shows that a piecemeal, problem-by-problem approach can generate activity, learning, and momentum without delivering the structural conditions required for transitioning DR into a growth phase. The chapter ends with policy recommendations to support rapid DR scale-up in liberalised markets.

HIGHLIGHTS

- GB's piecemeal approach enabled DR to emerge, but not to scale
- Fragmented markets, inconsistent signals, and weak legitimation constrain DR growth
- A strategic coordinated approach is needed to accelerate DR for decarbonisation
- Novel use of Technological Innovation Systems for energy demand rather than supply
- Findings offer transferable lessons for countries designing flexible energy systems

ABSTRACT

Residential DR is increasingly recognised as a critical component of the transition to a decarbonised, electrified energy system. Yet, even with significant innovation, smart meter deployment, and growing policy attention, residential DR has not scaled in line with its technical potential or its expected contribution to clean power. This article investigates the development of the residential DR TIS in GB between 2009 and 2024, drawing on an EHA of over 300 documented developments and 12 expert interviews. Using the TIS framework, the study traces how policies, markets, technologies, and user practices co-evolved, how the system's seven functions were fulfilled over time, and why DR remains in a formative rather than a growth phase. The analysis shows that GB's piecemeal approach – centred on market-led experimentation, incremental regulatory adjustments, and reliance on foundations like smart meters and HHS – enabled DR to emerge but not to scale. Fragmented markets, inconsistent policy signals, weak legitimation among incumbents and the wider population, and diffuse institutional accountability constrained the system's ability to transition into a self-sustaining growth trajectory. The paper argues that accelerating DR to meet GB's clean power and electrification goals requires a strategic coordinated approach that places users at the centre, sets a clear direction and objectives, strengthens market formation, and provides

governance arrangements capable of aligning functions across the TIS. The findings offer transferable lessons for countries seeking to design flexible energy systems to support rapid decarbonisation.

INTRODUCTION

The transition to a low-carbon energy future is a global imperative. As the world strives to meet ambitious climate targets, innovative solutions are essential to managing electricity demand and easing the integration of renewable energy sources into the grid. DR, broadly defined as *'the change in electricity consumption patterns in response to a signal'* (Element Energy, 2012, p. 9), is one tool to address this challenge (Eyre et al., 2018).

The International Energy Agency's Net Zero by 2050 Scenario expects 500 GW of DR globally by 2030, corresponding to a tenfold increase in 2020 deployment levels (International Energy Agency, 2024b). Despite notable progress to advance DR in places like Australia, the EU, the US and GB[23], the International Energy Agency notes that more effort is needed and recommends implementing policy frameworks and innovative approaches to swiftly scale up new technologies, solutions and business models (International Energy Agency, 2023). The residential sector is responsible for about a third of global energy use and most greenhouse gas emissions come from electricity use in buildings (Mata et al., 2020; Quintana and Cansino, 2023). Residential DR thus plays a key role in decarbonisation

[23] This study refers to Great Britain, the political term for the part of the United Kingdom (UK) made up of England, Scotland, and Wales, including the outlying islands that they administer. The UK, on the other hand, encompasses all of Great Britain and the region now called Northern Ireland. This distinction is important because UK government energy policy only applies to Great Britain. Northern Ireland energy policy is a devolved matter. However, some broader policies like net zero apply across the UK

(Wimalaratna et al., 2025) and is especially relevant as more households buy EVs and heat pumps.

GB has made considerable progress in developing residential DR, especially with the rollout of smart meters accompanied by user feedback devices, TVTs[24], and smart appliances (Carmichael et al., 2021; Davarzani et al., 2021; Nubbe et al., 2020). A 2025 report assessing countries' readiness for large-scale deployment of aggregated DR classed GB third in the world in terms of readiness based on its technical, regulatory, and commercial characteristics (Blunomy, 2025). Over 2.4 million households signed up for the DFS, a DR programme, in winter 2023-2024, delivering up to 400 MW peak reduction (National Energy System Operator, 2024b) during some of the coldest days of the year. An additional 1.5% of GB residential peak demand responds to TVTs (National Energy System Operator, 2024a). Finally, in December 2024, the government set out a clean power by 2030 target underpinned by a four- to five-fold increase in the amount of DR, from 2.5 GW to 10-12 GW of DR by 2030 (HM Government, 2024a).

Residential DR has been extensively studied, producing a diverse literature that spans system modelling, user behaviour, social practices, and technology adoption.

System-level analyses estimate the technical potential and system benefits of shifting household demand (Roscoe and Ault, 2010; Wang et al., 2014), while a rich socio-technical and behavioural literature explores how DR interacts with the meaning of home (Darby, 2018), user preferences (Dütschke and Paetz, 2013), everyday practices (Goulden et al., 2018; Nyström et al., 2024), and behavioural drivers of flexibility (Gyamfi et al., 2013). Parallel strands examine fairness, consumer protection, and the distributional impacts of DR

[24] The notion of time-varying tariffs is used throughout this study to reflect any type of tariff that accounts for the time when electricity is being used. When a specific type of time-varying tariff is in focused, this is clearly stated

(Borenstein, 2013; Hanser, 2010; Hogan, 2010), and an emerging body of work focuses on dependencies between DR and the deployment of ESAs like EV charge points, home batteries and heat pumps with smart controls (Nicolson et al., 2017b; Pallonetto et al., 2016; Schibuola et al., 2015). Many studies extract learnings from DR trials (Flaim et al., 2013; Nicolson et al., 2018; Wang et al., 2020) and large-scale DR initiatives (Maggiore et al., 2013; Mihalache et al., 2024), with several studies distilling policy implications from specific interventions (Calver and Simcock, 2021), or synthesising empirical findings (Parrish et al., 2019).

Building on this rich body of work, this study looks to answer the following research questions: *What factors have contributed to the development of residential DR in GB? How can policy accelerate the development of residential DR to support decarbonisation?* In doing so, the study contributes to existing academic literature in three ways. First, it provides a longitudinal, system-level analysis of residential DR in GB, tracing how policies, technologies, markets, and user practices have co-evolved from 2009 to 2024 using over 300 documented developments. Second, it develops actionable policy recommendations for accelerating DR into a growth phase, drawing on historical patterns, governance dynamics and the balance between bottom-up experimentation and top-down coordination. These insights offer transferable lessons for countries seeking to scale demand-side flexibility in support of decarbonisation. Finally, as will be shown in the next section, it applies the TIS framework to residential DR, offering a rare demand-side innovation perspective that integrates technical, institutional, and social dimensions into a single analytical approach. Here, innovation is understood broadly rather than as radical technological invention. In residential DR, the main challenge is often scaling and coordinating existing solutions like smart meters, tariffs, automation, and commercial offers through incremental institutional, regulatory, and market change. The paper therefore treats innovation as including market formation, business model development, standards, data access, and governance reform, not only the emergence of new technologies.

The article unfolds as follows: the next section presents the TIS approach which provided the theoretical framework of this analysis; it then discusses EHA and interviews which form the methodological framework of the work; the results section presents a narrative of DR's evolution in GB over the past 15 years which is then explained and interpreted in the discussion section to draw out its policy implications; the article then concludes and highlights further areas of research.

ANALYTICAL FRAMEWORK: TECHNOLOGICAL INNOVATION SYSTEMS

Over the last decades, innovation systems literature developed the notion of TIS defined as *'socio-technical systems focused on the development, diffusion and use of a particular technology'* (Bergek et al., 2008). *Technology* in this context refers to material objects and the immaterial aspects accompanying them (e.g. products, procedures, protocols) (Das and Van de Ven, 2000).

A large body of TIS research has focused on the evolution of material supply-side technologies aimed at reducing green-house gas emissions from the energy sector e.g. wind power (Bergek and Jacobsson, 2003; Jacobsson and Karltorp, 2013; Jacobsson and Lauber, 2006), solar power (Jacobsson and Lauber, 2006; Rahimi Rad et al., 2022) and biofuels (Suurs and Hekkert, 2009a, 2009b). More recently, Annala et al. (2022) and Wachs et al. (2023) used TIS for point-in-time assessments of DR: the former looking at DR business models' portability to foreign markets, the later zooming in on viability of industrial DR in the US. This study further expands the application of TIS to the demand-side, analysing both its evolution and its point-in-time performance, drawing out material and immaterial aspects of residential electricity DR.

The TIS framework was created to inform policymakers about obstacles to the development and deployment of technology (Jacobsson and Karltorp, 2013) and has been used to derive policy recommendations that support the development of various technological innovations, as shown for instance by Johnson and Jacobsson (2001), Carstens and Cunha (2019), Rahimi Rad et al. (2022) or Hacking et al. (2019). Following this tradition, this study applies the TIS framework to analyse the evolution of TIS for residential DR and provide policy recommendations that support its development, based on a GB case study.

A TIS is made up of *actors, networks, and institutions*, some of which may also form part of other TIS (Jacobsson and Johnson, 2000). According to Jacobsson and Bergek (2004) *actors* may be firms, non-commercial organisations, or individuals. *'Prime movers'* or *'system builders'* are particularly important because they are financially or politically powerful enough to influence the development and diffusion of the technology (Hughes, 1993). *Networks*, which bring together commercial and non-commercial entities, have a fundamental role in knowledge-transfer, problem-solving, resource build-up and influencing perceptions. *Institutions* refer to policies, regulations, and norms that constrain interactions between actors and society (Edquist and Johnson, 1997), thus influencing the path a technology takes (Jacobsson and Bergek, 2004).

A defining feature of the TIS framework is its focus on *functions*, understood as the *activities* or *processes* that result in the development and diffusion of the technology analysed (Hekkert et al., 2007). The TIS framework thus looks beyond static *structures* and maps out the activities that lead to technological change over time i.e. the functions of the system and their interaction with one another and with actors, networks, and institutions.

Functions thus link the TIS' components with its performance (Jacobsson and Bergek, 2004) because analysing the fulfilment of functions can explain and evaluate the performance of a TIS. Bergek et al. (2008) argue that *'there is no reason to expect structure will be related to performance,'* so policymakers should intervene to support the fulfilment of functions rather than in '*the set-up of the structural components (actors, networks, institutions)'* (Jacobsson and Bergek, 2004).

Hekkert et al. (2007) and then Bergek et al. (2008) mapped out seven functions a TIS may fulfil, based on a synthesis of earlier literature. The fulfilment of these functions in the GB TIS for DR is shown in the results section and in annexes 10-12.

1. *Knowledge development and diffusion* is concerned with how the scientific, technological, and commercial knowledge within a TIS changes over time and is exchanged, for instance, through networks
2. *Influence on the direction of search* refers to visions, expectations and perceptions that dictate whether new actors will join the TIS, thus acting as process of selection
3. *Entrepreneurial experimentation* reduces uncertainty in the TIS by probing into new applications, some of which may fail
4. *Market formation* allows the technology to take off and adapt to user needs through the creation of temporary markets for specific applications of the technology, favourable tax regimes, or subsidies for the technology
5. *Legitimation* refers to acceptance of the technology which can take considerable time to develop, benefiting from the formation of networks, but can be complicated by potential opposition from incumbents defending existing TIS
6. *Resource mobilisation* refers to the build-up of human and financial capital, competences, and assets into the TIS

7. *Development of positive externalities* refers to how the development of one function can strengthen one or more of the other six functions.

Studies like Bergek and Jacobsson (2003) and Jacobsson and Bergek (2004), drawing on literature on cyclical models of industry development (Tushman and Anderson, 2004; Utterback and Abernathy, 1975), argue that evaluating how the functions are fulfilled should not be disentangled from the stage of evolution that the TIS is in. These studies differentiate between two main phases in the development of a TIS. The discussion section uses the features of each phase to assess the stage of development of the GB TIS for DR.

1. A *formative period of experimentation*, when scepticism around the TIS is high as its outcomes are unknown. Many actors with varied backgrounds enter and exit the TIS, resulting in many competing technological options and leading to division of labour, and accumulation of resources. Problem-solving networks and advocacy coalitions start to develop, contributing to the technology's legitimation and driving institutional changes as knowledge accumulates through trial-and-error. Market formation is key in this phase because the technology is not yet able to compete on equal footing with more established technologies
2. A *market growth or expansion period* is characterised by fewer new entrants, the emergence of dominant designs and incremental rather than radical innovation. The system and markets develop in a self-sustaining way thanks to a series of positive feedback loops between the TIS' functions and its components.

In line with this literature, this study analyses *the TIS for residential DR in GB* – from here on, GB DR TIS in shorthand – a socio-technical configuration of actors, networks, institutions, and material and immaterial aspects of technologies concerned with the development, diffusion, and use of residential DR solutions. The results section maps out the performance of the TIS over time (i.e. how and how well the TIS' functions have been fulfilled over its lifetime) and based on that functional performance assessment the discussion section identifies the TIS' phase of development and makes policy recommendations to improve its performance.

METHODOLOGY

This research used a combination of EHA and expert interviews. EHA helped track the dynamics involved in the development of residential DR over time, whilst expert interviews validated the conclusions of the EHA and helped explain the TIS' pace of progress.

Event history analysis

According to Suurs (2009), EHA was developed to extract theoretical insights into the dynamics of innovation by monitoring the daily activities of firms. Van de Ven (1993) adapted EHA to large systems as an ex-post analysis which identifies events important to the system, rather than just to individual actors or projects. EHA conceives change as a sequence of events which it integrates into a systematic analysis. This approach allows the TIS researcher to operationalise system functions by linking their fulfilment with series of events (Suurs, 2009).

An event, as a unit of analysis, is understood as *'an instance of rapid change with respect to actors, institutions and/or technology, which is the work of one or more actors and which carries some public importance with respect to the TIS under investigation'* (Suurs, 2009). This study identified approx. 300 events matching this definition, including policy decisions, regulatory consultations, funding allocations, commercial product launches, market entries and exits, major DR trials, and DR publications. Borderline cases were included if they influenced at least one TIS function. The intention was not to identify *all* events that influenced the TIS, but rather the most significant ones, which aligns with existing good practice in TIS and EHA literature (Hekkert et al., 2007). In line with other TIS research, the results section weaves these events into a narrative which explains the development of the GB DR TIS between 2009-2024. When an event ran counter or added nuance to the narrative developed up that point, the narrative was modified to incorporate it, as opposed to the event being discarded because it did not match the narrative.

Given its focus on a single country, the research is not generalisable. However, by highlighting the main events that influenced DR's development in GB, EHA allows future research to break down the evolution of DR in other countries and compare it with GB.

Interviews

The EHA analysis was triangulated against expert interviews which helped verify the narrative and minimise its bias, whilst adding insight that explained the TIS' pace of development. Twelve interviews were held between May 2022 and December 2023 with GB DR experts, seven of whom were at that time policy officials working in BEIS,[25] the central government department responsible for energy policy. Most interviews were conducted before the EHA and helped guide its subsequent development. A few interviews were conducted during the development of the EHA and interviewees were asked questions that helped explain EHA preliminary results.

The study used a purposive sampling approach which allowed interviews to cover almost all senior BEIS officials responsible for DR policy at the time. These were complemented with interviews with flexibility experts from the two largest electricity supply companies in GB – Octopus Energy and British Gas – chosen because together they serve almost half of GB residents (Ofgem, 2025). Two additional interviews were held with industry experts with over 15 years of experience in DR, one of them chosen because they had helped set up the first DR trade body in GB and were familiar with the early development of the DR TIS. Interviews were semi-structured, beginning with questions around what respondents see as

[25] BEIS became the Department for Energy Security and Net Zero in February 2023

the potential of and barriers to residential DR in GB, then open questions guided by respondents' focus areas. Interviews also explored the role of factors like policy and regulation, technological development, and economic and political context in the development of DR. Data were pseudonymised as soon as collected. Excerpts from the interviews are available in annexes 1-3.

Research process

The research process is described below as a series of steps, but the process itself was iterative with each step leading to reconsideration of outputs from the previous one until conclusions were sufficiently developed to support making policy recommendations. The process broadly followed the scheme of analysis proposed by Bergek et al. (2008) which starts with defining the TIS in focus and ends with specifying key policy issues to be addressed.

Step 1: Defining TIS boundaries. The study defined the boundaries of the TIS and identified its main structural components based on the author's in-depth knowledge of the residential DR industry and policy environment. Whilst the boundaries of the TIS are explicitly drawn in the results section, its structural components will become evident from the narrative of the TIS' development in the same section and from the events timeline detailed in the annexes.

Step 2: Identifying key events. A desk research exercise comprising academic and grey literature, as well as government publications was conducted to identify the key activities influencing the development of residential DR in GB between 2009 and 2024 ie, the events of the EHA. To identify the academic references to DR, the desk research followed a snowballing approach, beginning with a set of foundational publications (Hart et al., 2017; Parrish et al., 2020) and iteratively expanding the corpus by tracing references, citations, and related documents. A similar approach was used for non-academic sources, starting with the main policy publications relevant to DR in GB (HM Government, 2021a, 2017) and NESO's historical annual reports tracking the main commercial and political developments related to DR. Working backwards from these, over 200 sources were reviewed, including expert reports, grey literature, policy documents, websites, and specialised energy-sector news platforms. Inclusion criteria required that documents described a development that directly affected residential DR in GB. Documents focused solely on I&C DR, international DR without GB relevance, or purely theoretical work without policy or empirical implications were excluded.

The reviewed material was organised into five databases covering: GB policy publications with a direct impact on DR; academic and grey literature referring to GB or authored by GB-affiliated researchers; market entries and exits of DR-relevant firms (suppliers, demand aggregators, ESA providers); residential DR innovation trials undertaken in GB; and TVTs available to GB consumers in 2024.

The approx. 300 events in scope of the research were extracted from these databases[26].

The desk research also informed refinements to the boundaries of the DR TIS.

Step 3: Interview coding. Interviews were coded in Nvivo using codes mapped against the seven TIS functions.

Step 4: Mapping the events timeline against fulfilment of functions. Insights from the desk research and the coding of interviews were combined into a timeline of the TIS' evolution. Events in this timeline were then categorised under each TIS function in line with

[26] A draft version of these databases can be made available for verification or for use in future research upon request. Annexes 10-12 of this thesis however already present a chronologically coherent and sufficiently comprehensive list of the events most relevant to DR's development in GB which can be verified and readily used in other studies.

the Bergek et al. (2008) and Hekkert et al. (2007) definition of the functions and what type of events they comprise. The categorisation of most events under functions was straightforward, with one exception which is explained in the results section. The results section explains how events contributed to the fulfilment of TIS functions.

Step 5: Defining the TIS' phase of development. Conclusions were drawn around the TIS' phase of development, based on the characteristics of the formative and growth phases presented above.

Step 6: Understanding the evolution of the TIS. The timeline was split into three periods to allow a deeper analysis of its development by comparing the three periods with one another.

Step 7: **Building the narrative.** The insight was integrated into a narrative which describes how the TIS' seven functions were fulfilled throughout the TIS' three periods.

Step 8: Drawing policy implications. The fulfilment of the TIS' seven functions was analysed in the context of wider literature to draw conclusions around how policy can speed up the development of residential DR.

Annexes 1-3 provide the timeline of the main events that took place throughout the three periods identified in the 15-year development of the GB DR TIS. A summary version of the timeline for each period is available in figures 2-4 in the results section.

RESULTS

TIS scope and boundaries

This article analyses the development of the residential DR TIS in GB between 2009-2024.

The DR TIS scope spans the main technologies and products that enable DR (smart meters and the DR tariffs and programmes they enable), as well as the user practices related to these technologies. Smart meters are devices which automatically record and can send energy consumption data to an energy utility (the energy supplier in GB). They allow users to sign up to TVTs (implicit DR) or take part in local or national DR programmes (explicit DR) (El Gohary, 2024). GB had rolled out traditional (i.e. non-smart) two-rate meters which enable two-rate TVTs commonly known as Economy 7 since the 1970s to absorb excess overnight nuclear energy generation. These are also in scope to the extent that they continue to exist beyond the start of the smart meter rollout. ESAs like EV charge points, home batteries, and heat pumps with smart controls, as well as non-smart appliances are also in scope of the DR TIS to the extent that they are linked to a household's participation in DR.

The timeframe 2009-2024 was chosen because it tracks the development of the DR TIS from the decision to roll out smart meters as essential enablers of DR across GB in 2009, to the point when government decided a four- to five-fold increase in DR is needed to deliver clean power by 2030 (HM Government, 2024a), a substantive change to the previous approach, as will be shown in the discussion section. The significance of these moments to the TIS' development is explained in the narrative below.

The development of the GB residential DR TIS between 2009-2024

This section provides a narrative of the TIS' development, split into three periods with specific characteristics. Annexes 10-12 provide the detailed events and the evidence supporting this narrative. In line with TIS practice, the narrative references the TIS functions to show how these were fulfilled and how they influenced one another.

Given the large number and complex nature of markets involved in DR, this article analyses markets under two TIS functions: the retail electricity market is analysed primarily under entrepreneurial experimentation; all other markets relevant to DR are analysed primarily under market formation. This does not mean that entrepreneurial experimentation does not exist beyond the retail market, nor does it entail that market formation – in a broad sense – is not important in the retail market e.g. through the creation of retail market niches. The distinction is only drawn for analytical ease.

Entrepreneurial experimentation in this study is thus used to refer to experimental DR products such as TVTs or explicit DR programmes – offered in the retail market because this is where entrepreneurs experiment with making DR products appealing to users. To create appealing products, however, DR providers (e.g. electricity suppliers, DR aggregators) need to enter users' loads into various markets upstream of the retail market to obtain compensation for user's change in consumption. They can for instance, enter loads in the wholesale market, the CM, the BM, frequency response services etc. Some of these markets are national, mostly managed by the NESO, whilst others are local, managed by DNOs. When this article mentions the market formation function, it therefore refers to DR providers' ability to enter and derive revenue from these upstream markets because this is what makes it worthwhile for a business to offer DR products in the energy retail market. Even though entrepreneurs experiment in these markets as well, it is not their experimentation, but rather the functioning of the market itself which primarily determines how attractive a DR product is to users.

DR foundations under a competition-led paradigm (2009-2013)

In the late 1990s and 2000s, GB policymakers outlined a vision for the energy sector which emphasised the role of competition and innovation in enhancing user experience, making energy affordable, and meeting ambitious decarbonisation targets (influence on the direction of search). This strategic direction prompted a surge of market entrants (resource mobilisation) in this period and the next. In this context, in keeping with the direction set by the EU, the smart meter rollout was regarded as an important pillar of decarbonisation (influence on the direction of search) because it would enable demand reduction and DR, including through the feedback effect of IHDs which in GB were installed alongside smart meters.

Academic and grey literature started to develop to model the benefits of DR (legitimation) and offer early insights into DR users and barriers (knowledge development). DR was predominantly viewed as a peak demand reduction tool, rather than a flexibility mechanism essential for integrating higher levels of renewable energy into the grid. These early insights informed smart meter rollout policy positions and next steps.

Concerns regarding the capacity of electricity networks to manage high volumes of smart devices expected to be installed on the back of the smart meter rollout, led to the funding of innovation trials (resource mobilisation) aimed at assessing DR's potential to mitigate these risks (further legitimation). Concurrently, various forums and collaborative initiatives developed around existing DNO networks, which brought together policymakers, energy suppliers, and consumer groups to discuss the potential benefits and risks of DR. This collaboration culminated in the establishment of the UK Demand Response Association (UKDRA), the first dedicated industry body representing DR stakeholders (legitimation).

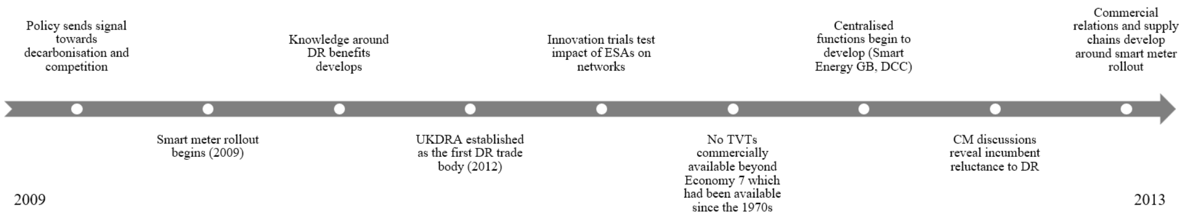
As the smart meter rollout progressed, supply chains and commercial partnerships developed in support of the rollout (resource mobilisation). Smart Energy GB was set up as an independent, government-backed entity responsible for promoting the smart meter rollout across GB (further legitimation, resource mobilisation). Some early positive externalities emerged as insights from the I&C DR sector and from Economy 7 products (knowledge development) supported the design of trials (entrepreneurial experimentation); and preliminary economic modelling (knowledge development) highlighted DR's potential benefits (legitimation).

With the primary focus of research being on economic modelling to inform smart meter rollout decisions, most knowledge development during this phase was largely theoretical and narrow, with limited empirical research beyond innovation trials addressing the challenges of managing large numbers of smart devices.

Beyond trials, entrepreneurial experimentation was constrained, with only Economy 7 tariffs commercially available. Market formation remained undeveloped, as DR providers had little or no access to markets that could generate revenue from offering DR products.

The only meaningful developments for market formation in this initial period were the steps to establish the CM as a security of supply mechanism. The CM opened in 2014, but discussions on its design were held in this first phase of the DR TIS, spurring the development of lobby groups (legitimation) advocating for favourable terms for DR participation in the CM. These efforts caused friction with incumbent industry players, highlighting the upcoming challenge of integrating DR into established energy markets.

Figure 2: DR foundations under a competition-led paradigm (2009-2013)



Experimental diversification and early scaling barriers (2014-2019)

Developments in this second period built upon the foundations established in previous years, with notable advancements in key areas.

The technology model underpinning the smart meter rollout shifted from a decentralised approach to one in which the connectivity of smart meters was centralised through the DCC, thus changing the TIS' direction of search. This transition disrupted contractual arrangements and supply chains established by early movers, causing delays in the smart meter rollout because early movers opposed the new direction to protect their existing business models. Simultaneously, new contractual relationships and supply chains took time to establish.

Further innovation funding in this period and the next (resource mobilisation) expanded the scope of trials compared to the first phase, allowing for a broader exploration of various technologies like peer-to-peer electricity trading and V2G in developing DR products and services (entrepreneurial experimentation). Innovation trials strengthened collaboration among market actors and allowed them to explore new opportunities for DR like community energy (expanding the direction of search). This expansion brought in new players like local authorities and community groups (resource mobilisation) leading to an upskilling of organisations traditionally less involved in the energy sector, like local authorities (positive externalities). Trials also tested distributional impacts of DR, particularly on low-income households, contributing to further knowledge development and raising questions around the direction of search of the DR TIS e.g. whether all households could participate or should be expected to participate in DR.

DR research developed across several universities (e.g. University of Reading, University College London, University of Oxford) with focus expanding to include areas such as consumer acceptance and the integration of DR into social practices (further knowledge development). Government funding (resource mobilisation) supported the creation of the Centre for Research into Energy Demand Solutions in 2018, which brought together research institutions across GB to explore the contribution of energy demand in accelerating the transition to net zero (knowledge diffusion, legitimation).

Growing climate ambitions resulted in a 2019 target of achieving net zero by 2050, with signals emerging in this period with regards to the role of transport and heating in meeting climate goals, including the target for half of all new cars to be ultra-low emissions by 2030 (influence on the direction of search). Alongside primarily government-commissioned grey literature emphasising DR's contribution to climate targets (knowledge development), this context reduced the uncertainty about the future of the DR TIS and reinforced its legitimacy. DR's legitimacy in policymaking and industry circles thus expanded beyond reducing peak demand and addressing network overload to contributing to the electrification of heat and transport and thus to more ambitious climate goals.

This second period also saw significant advancements in network formation. The functions of the UKDRA were absorbed into the Association for Decentralised Energy, a trade body focusing on DR, district heating, and energy efficiency. The ESO launched the Power Responsive platform, aimed at removing barriers to flexibility in ESO markets and serving as a voice for flexibility in the energy sector (market formation, legitimation). The Open Networks Project was initiated to facilitate collaboration between DNOs and other market players to create local flexibility markets (contributing to market formation). Even with these efforts, Power Responsive's focus remained on I&C DR, and no trade body fully dedicated to residential DR developed in either this period or the next.

A key development in this period was the introduction of HHS, first on a voluntary basis (elective HHS), then universal (MHHS) – although the implementation of MHHS is not expected to finalise until 2027. HHS exposes electricity suppliers to the cost of electricity based on real-time usage rather than based on daily or monthly averages (profiles), incentivising[27] suppliers to offer their customers TVTs (influence on the direction of search, entrepreneurial experimentation). MHHS, alongside the continued push for smart metering

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[27] MHHS is not itself an incentive in the economic sense of the word. It is a structural reform that enables efficient DR incentives by aligning settlement with real-time costs. In this article, MHHS is treated as an incentive in the broader sense of the term i.e. a prompt or motivation, rather than reflecting the strict economic meaning of the term 'incentive'

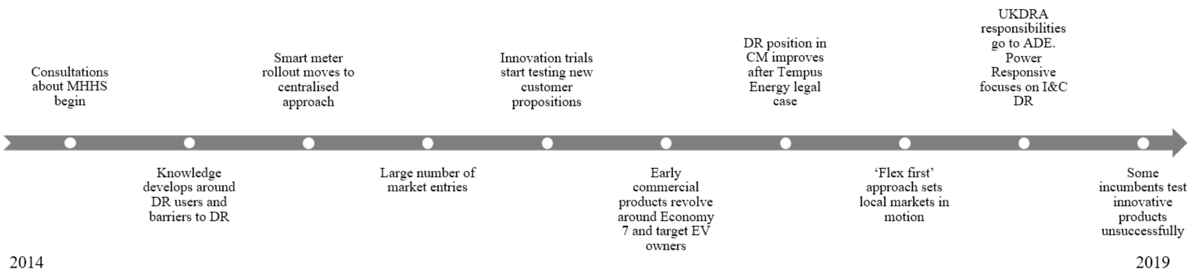
and signals around the electrification of transport (influence on the direction of search), encouraged some incumbents to expand beyond traditional business models, acquiring new businesses or building technical capabilities that would position them to participate more effectively in DR (resource mobilisation).

Market formation in this phase saw slow but tangible progress. DR's entry into the CM on less favourable terms than other technologies highlighted the ongoing challenges faced by DR in competing with incumbents. Intense efforts, such as the Tempus Energy legal case which contested the terms on which DR had been entered in the CM, eventually improved its position by securing lower thresholds for participation and longer-term contracts for DR in the CM. New entrants like Piclo and Electron developed technology platforms enabling system operators to increase the value and volume of DR in various markets (resource mobilisation, market formation). Others, like Kraken and Kaluza, created technology platforms allowing energy suppliers to control and optimise user assets to enable innovative DR products (entrepreneurial experimentation). Some innovative new entrants were acquired by incumbents looking to modernise their own systems.

Although some early commercial DR products started to appear (entrepreneurial experimentation), they were largely based on Economy 7 tariffs. Some incumbents considered or tested DR products but did not find them worthwhile on a commercial scale. New entrants in the retail market offered more innovative DR products, but their customer portfolios were much smaller than those of incumbents. New entrants also struggled to build sustainable businesses around DR products because markets for DR still had many technical and regulatory barriers to entry particularly for non-incumbents (e.g. lack of standardisation between markets, unachievable entry thresholds).

The situation was further complicated by policymakers' realisation that competition was not achieving the desired consumer protection outcomes, leading to the imposition of a temporary price cap. The price cap curtailed the revenues that energy suppliers could generate, increased the complexity of the energy retail landscape for both incumbents and new entrants and, as the next period will show, hindered resource mobilisation and entrepreneurial experimentation.

Figure 3: Experimental diversification and early scaling barriers (2014-2019)



Consolidation, disruption, and early transition signals (2020-2024)

The most recent period of DR development in GB further built upon the foundations laid in the previous years, but the TIS was notably influenced by the surge in gas prices resulting from Russia's war on Ukraine.

Government funding for innovation (resource mobilisation) continued, with several trials extending the trend of integrating DR with various clean technologies such as EVs and heat pumps (entrepreneurial experimentation). Living labs were also established to improve access to electricity usage data, supporting further knowledge development. Academic research, now more closely embedded in networks thanks to innovation efforts in previous years led to further knowledge diffusion, continuing to address issues surrounding consumer participation, flexibility justice, and automation (influence on the direction of search).

The gas price spike raised serious concerns about energy security during the winter of 2022 (influence on the direction of search). In this context, the Turndown Trial, initiated by Octopus Energy and the ESO, stood out for enabling the creation of the DFS, an explicit DR programme, during the height of the gas crisis. DFS is the first – and, to date, the only – DR-dedicated market in GB (market formation), demonstrating DR's potential to contribute to energy security both during the 2022 crisis and in subsequent winters (legitimation). A positive externality of the DFS was that it not only legitimised automated DR, as anticipated, but also manual DR, expanding the direction of search.

In its first year, DFS subsidised DR through a guaranteed acceptance price (resource mobilisation, market formation), facilitating wide participation from both incumbents and new entrants (entrepreneurial experimentation) and demonstrating the appeal of DR beyond just early DR adopters. This broadened the legitimacy of DR across the wider population. Smart Energy GB campaigns further promoted consumer awareness of DR's benefits (legitimation). However, the removal of the DFS subsidy in its second year (undermining entrepreneurial experimentation) raised questions about the system's ability to still enable firms (incumbents and non-incumbents) to develop profitable business models around DR products (influence on the direction of search). Still, some incumbents developed some commercial DR products (entrepreneurial experimentation) thanks to legitimation of DR through the DFS.

The smart meter rollout moved to a target-based regulatory framework that pushed energy suppliers to increase efforts to rollout smart meters (resource mobilisation). However, delays in both the smart meter rollout and the implementation of MHHS slowed the urgency for incumbents to introduce further commercial DR products, slowing the drive for entrepreneurial experimentation.

The government established a Digitalisation Taskforce in 2020 to accelerate the digitalisation of the energy system and published a Digitalisation Strategy in 2021 which kicked off efforts to securely share data between system actors with consumer consent to support the development of innovative products like TVTs (influence on the direction of search).

Concurrently, the government established the Smart and Secure Electricity Systems programme aimed at defining interoperability and cybersecurity standards for smart appliances and extending the responsibility to protect DR users to organisations beyond energy suppliers e.g. to DR aggregators (legitimation). Clearer policy signals on the role of EVs and heat pumps in achieving net zero also helped solidify DR's position as a necessary complement to these technologies (influence on the direction of search, legitimation).

Market formation made strides, with several significant developments. Non-incumbent market players gained access to the BM and the wholesale market, marking a critical step in levelling the playing field for new entrants. A 'flexibility first' approach to network reinforcement – whereby networks are required to prioritise flexible solutions for grid management over traditional infrastructure upgrades (influence on the direction of search) – prompted further development of local (DNO) markets in which DR could participate. This raised questions about the standardisation between ESO and DNO markets to remove lingering entry barriers and streamline firms' participation. In response, policymakers established the role of Market Facilitator which, in 2024, was handed over to Elexon, the entity also responsible for MHHS.

It was expected that overall improved access to markets will make it worthwhile for firms to invest in offering DR products, thus increasing entrepreneurial experimentation. Despite progress however, there are still issues that need to be addressed, such as coordination between markets, baselining methodologies to calculate revenue, and levelling the playing field with traditional technologies. Additionally, questions remain about firms' ability to offer tariffs that vary sufficiently throughout the day to incentivise households to change their demand patterns (whether manually or through automated TVTs). This is because most components of a household bill (the bill stack) are not time-reflective (e.g. policy costs) or generate only a very dim time signal (e.g. network costs). The only element of the bill stack that fluctuates with demand and supply is the wholesale cost of electricity, and this makes up less than 40% of the bill (Nesta, 2024).

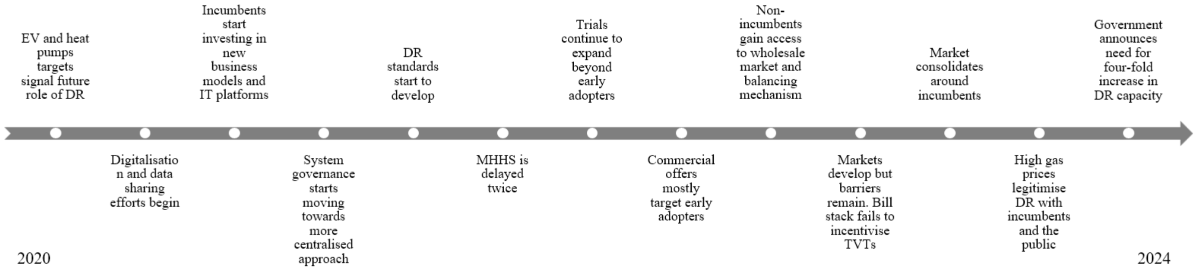
The high gas prices, combined with the price cap, led to an unprecedented wave of market exits, many of which involved the new entrants that had been offering innovative DR products (hindering entrepreneurial experimentation). This accelerated the market consolidation trend that had begun in the previous period when incumbents acquired some innovative technology firms. Consolidation in this period, however, took the form of incumbents inheriting the portfolios of smaller and more innovative competitors through a regulator-controlled process, resulting in the reconsolidation of the electricity supply market under the control of five or six large incumbents, similar to how it looked in the early 2000s. This reversal undermined previous efforts to reduce incumbents' market power through competition policy (influence on the direction of search). However, some re-arrangements among incumbents did occur, such as Octopus Energy – originally a new entrant with tech-sector expertise (resource mobilisation) – becoming the largest electricity supplier in GB in 2024.

This consolidation marked a shift away from competition as the primary means to achieve decarbonisation, affordability, and energy security. Beginning in the previous period but most evident in this one, the government increasingly adopted a more direct approach to delivering its energy and climate ambitions (influence on the direction of search). This transition began with the imposition of the price cap in the previous period, and continued with the nationalisation of the ESO (now NESO) and plans to introduce policy instruments like Regional Energy Spatial Plans and the Strategic Spatial Energy Plan, which aim to align local and national energy strategies to meet climate targets (influence on the direction of search). In this evolving governance environment, Ofgem, the GB energy regulator, also received a net-zero mandate (influence on the direction of search).

However, policymakers did not delineate clear accountability for supporting DR development in this new institutional landscape, leaving open the risk that DR may be sidelined in favour of other, broader government policies. The move away from competition toward a more direct and coordinated approach to decarbonisation was also underpinned by promises of economic growth through job creation and a more equitable distribution of wealth and investments across the UK, though DR was not a central feature of these plans, a missed opportunity for DR's legitimation.

The Labour Party assumed power in 2024 with a mission to make Britain a clean energy superpower, having brought forward the clean power target from 2035 to 2030. In this context, the Clean Power Action Plan published in December 2024 for the first time set a clear ambition for DR: to increase DR capacity from 2.5 GW in 2024 to 10-12 GW by 2030 (influence on the direction of search). The Clean Flexibility Roadmap published in July 2025 – outside the scope of this research which only tracked DR development until 2024 – consolidated existing and new actions aimed at supporting DR development and set out a governance framework to track their implementation. At the same time, the government published a consultation on DR user engagement, including on the potential to better coordinate and amplify accurate DR messaging. The former publication supports the DR TIS' market creation function by setting out how the system operator is expected to level the playing field between DR and other technologies; the latter publication is aimed at improving DR's legitimation with users beyond early adopters. Both documents refer to DR as consumer-led flexibility and discuss at length the benefits of DR to users, a shift towards a more user-centric approach to the development of the DR TIS.

Figure 4: Consolidation, disruption, and early transition signals (2020-2024)



In conclusion, the development of the GB DR TIS between 2009 and 2024 has been characterised by gradual evolution shaped by the interaction of policy drivers, market dynamics, and technological advancements. Despite progress across all functions, the journey has been marked by challenges such as the fragmentation of markets, delays in implementation of policy decisions, and issues of DR's legitimation with incumbents. The TIS is at a critical juncture, with new policy publications signalling the need to accelerate the development of the DR TIS.

DISCUSSION

Building on the insights from the previous section, this section explores how policy can accelerate the development of residential DR to further support decarbonisation goals. It starts by assessing the current phase of development of the GB residential DR TIS, then it evaluates the effectiveness of the strategies and approaches employed thus far in driving accelerated development within the system, ending with policy recommendations to accelerate DR's development.

GB DR TIS: phase of development

The analytical framework section distinguished between a TIS' formative and growth phases. Applying these concepts to the GB DR TIS, this section argues that the last 15 years of the GB DR TIS are representative of a formative phase of development.

Tushman and Anderson (2004) argue that a potential feature of a TIS' transition from a formative to a growth phase is the crystallisation of a dominant design which resolves some of the uncertainty around the technology's direction of development. In GB, the entrepreneurial experimentation and knowledge development functions of the TIS evolved steadily over the last 15 years, with multiple trials and experiments resolving some of the technological uncertainty associated with offering DR products. For instance, trials answered questions around what role DR could play in preventing network overload as transport and heat electrify. However, trials tested a high variety of DR products on relatively limited numbers of participants, resulting in conflicting signals and uncertainty around user preferences for certain products over others, a typical outcome of trials (Kemp et al., 1998). Questions remain, for instance, on the role that manual DR for security of supply (Mihalache et al., 2024), or on whether and how DR could contribute to reducing bills for households in fuel poverty.

Entrepreneurial experimentation beyond trials remained confined to tariffs that replicate Economy 7, most of these available only to EV and heat pump owners. This marks a standardisation of components in line with Utterback and Abernathy (1975) dynamic model of innovation and could be indicative of an emerging dominant design for implicit DR. However, it is not clear that this dominant design matches the direction of search that will propel GB to 10-12 GW of DR by 2030. To integrate higher amounts of variable renewables, implicit DR will likely require much more dynamic products than Economy 7-like TVTs. Moreover, this emerging dominant design could still be influenced by regulatory developments and changes in markets, as well as by the rate of adoption of EVs, batteries and heat pumps. Even with speedy mass rollout of EVs and heat pumps, it is uncertain whether their owners, beyond early adopters, would also accept a DR product. Moreover, even in the third period of the DR TIS it is not clear if the bulk of DR will come from TVTs (implicit

DR), national programmes like the DFS (explicit DR), local programmes, or a combination thereof.

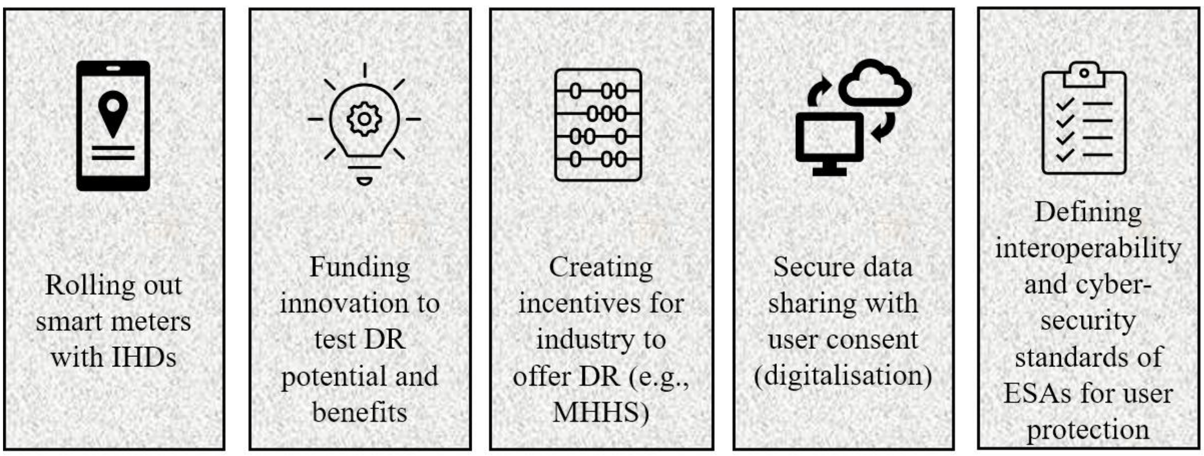
According to Bergek and Jacobsson (2003), a growth phase is characterised by self-sustaining diffusion and expansion of the technology, with concentration and growth in firm size, either organically or through mergers and acquisitions. As described in the results section, some market consolidation occurred organically in the second period of the DR TIS and was accelerated in the third period by the 2021 market exits. This consolidation, however, has yet to lead to rapid and self-sustained proliferation of mass-market DR products. Even incumbents who acquired innovative start-ups or upgraded their IT platforms to enable DR, are still only offering limited types of TVTs to early adopters. This shows the limited legitimation of DR with incumbents and its knock-on effect on legitimation with users beyond early adopters as will be discussed below. There is a nearly universal expectation across industry experts interviewed that MHHS will force incumbents to extend offers of TVTs to most of their client base, but MHHS is not expected to finalise until 2027, half-way through the period to 2030.
These features align with the core attributes of a formative phase, where multiple technologies, business models, and market structures compete and evolve before settling into a more stable and standardised system which can support sustained growth of the technology in focus.

It was highlighted in the introduction section that GB is one of the more advanced countries in terms of DR development, but this section shows that the GB case study should not be read as evidence of full success in developing residential DR. Rather, GB is a leading case in a relative sense: compared with many other liberalised markets, it has assembled unusually strong preconditions for residential DR, including smart meter rollout, TVTs, dedicated experimentation, national DR programmes, and an increasingly explicit policy focus on flexibility. Yet these achievements amount to partial success rather than complete system formation. Residential DR in GB has clearly emerged and gained visibility, but it has not yet transitioned into a self-sustaining growth phase characterised by stable market formation, strong legitimation, aligned institutions, and durable commercial scale. Framing the case in this way helps reconcile the apparent tension: GB is analytically valuable precisely because it combines comparatively advanced development with incomplete system formation, making it possible to study why substantial progress in enabling conditions and experimentation did not translate into full TIS maturation.

The piecemeal approach to DR development

The GB case study shows how DR developed over the last 15 years thanks to a series of foundational enablers: the rollout of smart meter with IHDs starting in the first period, the start of MHHS implementation from the second, and the onset of digitalisation and definition of ESA standards and user protections in the third period. Throughout all three periods, innovation funding also played a consistent role. These foundational enablers, depicted in Figure 5, showcase the minimum policy interventions required for developing DR – which serve as an example of policies that countries may want to emulate.

Figure 5: Foundational DR enablers in the GB DR TIS



Whilst necessary, the foundational enablers have not however been sufficient to transition the GB DR TIS into a growth phase because their development and implementation have been piecemeal, lacking, until recently, a strategic coordinated approach. Whilst policy documents discussed the barriers to DR and provided some steps to remove these barriers, they did not present, during the period analysed, a strategic coordinated approach for how DR will develop. This led to frequent shifts in the TIS' influence on the direction of search function over the 15 years analysed here.

In GB, the first signs of a strategic coordinated approach appeared in the 2025 Clean Flexibility Roadmap which provides a blueprint to achieving the 10-12 GW of DR ambition by 2030 by assigning clear actions with deadlines to system actors. Other ways to support the development of DR and avoid frequent changes in the direction of search could include defining actual DR targets (rather than ambitions) and specifying who is accountable for their delivery or establishing a dedicated body or function accountable for DR development.

In GB, the smart meter rollout alone resulted in three different estimates of DR potential across the period, and although various flexibility scenarios were developed either independently or commissioned by government, policymakers did not set clear expectations regarding the volume and type of DR needed in the system for the first 15 years of the DR TIS' development. As interviews with government officials revealed, policymakers assumed that the smart meter rollout and MHHS alone would be sufficient to foster DR product development through market forces, a perspective that Nystrom et al. (2024) also identified in Sweden's approach, where smart meters were assumed to automatically encourage household participation in DR without a supporting policy vision.

There is no inherent reason to believe that a piecemeal approach would not eventually lead to DR TIS growth. In fact, it stimulated the development of all the TIS functions, generating positive feedback loops like those observed in other TIS literature (Jacobsson and Bergek, 2004; Suurs and Hekkert, 2009b). For example, the smart meter rollout contributed to the direction of search function by defining the type of metering technology that underpins DR, helped legitimation through the feedback function of IHDs and through the creation of Smart Energy GB, and supported resource mobilisation by training a pool of smart meter installers who can now support the installation of EVs and heat pumps. The emerging standards in the third period, aimed at ensuring the interoperability and cybersecurity of ESAs, helped legitimise DR by building trust in the technologies supporting it, while digitalisation facilitates entrepreneurial experimentation by enabling data sharing among industry participants.

Generous innovation funding, combined with a policy context encouraging competition and new market entries, fostered knowledge development and diffusion through entrepreneurial experimentation. The TIS attracted many firms which brought competencies from their original fields, a feature regarded by Bergek and Jacobsson (2003) as fundamental to the development of a TIS. The accumulation of innovation through such organisations is key to scaling up a TIS (Naber et al., 2017). One such example is Octopus Energy, initially a technology company, which became a prime mover of the DR TIS by initiating the Turndown Trial that led to the creation of the DFS and by demonstrating through its supply business how Kraken, its DR-enabling IT platform, can support innovative TVTs, later selling its platform to energy incumbents.

The approach also fostered the creation of partnerships and networks, strengthening the TIS' legitimation function beyond new entrants and early adopters. Like Hargreaves et al. (2013), this study found that organisations involved in trials played a critical role in aggregating lessons, influencing policymaking, establishing data repositories, and brokering partnerships, especially with major energy companies.

Moreover, DR was able to meaningfully contribute to security of supply during the 2022-2023 gas price crisis, less than 15 years after its inception, raising hopes about its contribution to decarbonisation.

A strategic coordinated approach to accelerating DR growth

The government's ambition to at least quadruple DR capacity over the next five years shows the urgent need to transition the DR TIS into a growth phase. While a piecemeal approach has been effective in many respects, it has also left gaps in key TIS functions that must be addressed to support this accelerated expansion. Like Johnson and Jacobsson (2001) this study argues that the absence of a strategic coordinated approach can impede the development of essential TIS functions. Moreover, as Carstens and Cunha (2019) note, clear long-term goals are critical for advancing the TIS into a growth phase. The following sub-sections identify areas where a more defined strategic coordinated approach is especially important for the successful scaling of the DR TIS.

Legitimation and user perspective

Proliferation of DR products relies on buy-in from incumbents to offer DR products. However, delays in the smart meter rollout and MHHS, along with shifts in the direction of search, allowed incumbents to delay resource mobilisation into the DR TIS. Additionally, broader policies such as the price cap further legitimised incumbent inaction. Instead, policy must counter opposition from incumbents whose interest may be misaligned with the adoption of DR technologies, as found by Grunewald et al (2012) in the context of distributed electricity storage.

Beyond the challenge of securing legitimacy from incumbents, the broader proliferation of DR products also requires gaining legitimacy with the wider population. The piecemeal approach thus far has worked to establish legitimacy with end-users through standards ensuring interoperability and cybersecurity of ESAs, aiming to build user trust in the technology and the DR processes. However, this approach has not fully addressed the diversity of user needs, by looking for instance at user groups beyond early adopters, or those not yet owning an EV or heat pump. Annala et al. (2022) found a similar lack of legitimacy with DR end-users when applying the TIS framework in Finland. As Nystrom et al. (2024) observe in a Swedish case study, neglecting user diversity risks reinforcing simplistic models of consumer behaviour, such as Resource Man or Homo Economicus (Strengers, 2014) performing rational and active decisions based on a good understanding of their energy consumption. The approach risks overlooking the complex and varied ways in which DR could develop. This study, like that of Verbong et al. (2013) advocates for the incorporation of diverse user perspectives when shaping DR policy.

Moreover, the economic benefits of transitioning to DR must be clearly communicated to local communities and local governments, whose support is crucial for stimulating participation in DR. As Jacobsson and Bergek (2004) and Goulden et al. (2018) suggest, without direct benefits for local communities, market incentives may fail to generate sufficient momentum for the DR TIS to scale effectively.

Coordination and accountability

The piecemeal approach revealed in this study mirrors what El Gohary (2024) identified as *the price signal paradigm* in the EU's development of demand-side flexibility. Similar to El Gohary's analysis, this study highlights a potential consequence of this approach: a diffusion of responsibility among system actors, where policymakers and regulators shift responsibility for the TIS' development onto DNOs, energy suppliers, and aggregators who, in turn, pass it on to end-users, many of whom may not be aware of, prepared for or interested in DR.

A significant issue was the failure to establish clear accountability for delivery of DR outcomes among system actors and to effectively coordinate efforts between institutions to achieve these outcomes. Previous research by Torriti (2024) and Mihalache et al. (2024) underscores the lack of institutional coordination, which has hampered DR development. This coordination gap jeopardised the smooth transition of the TIS into its growth phase and diminished policymakers' control over the pace of this transition and their ability to align DR policy with other areas of policy like electrification of heat and transport.

The absence of a clear and visible pathway for transitioning DR into a growth phase, combined with uncertainty regarding the impact of delays in key DR enablers like smart metering and MHHS, can complicate policy efforts. Additionally, the absence of coordination increases the risk of single points of failure. For instance, Elexon, which was appointed as Market Facilitator, a key role in developing the markets function of the TIS, is also responsible for the delayed but fundamental MHHS programme, as well as other core government programmes, despite government and the regulator not having many levers over Elexon’s quality of delivery, beyond reputational incentives.

Market development

It is noteworthy that, up until 2022 when the DFS was initiated, the GB DR TIS evolved without the establishment of dedicated markets for DR – markets that are typically considered essential for fostering learning, improving price/performance, and shaping user preferences during formative phases (Jacobsson and Bergek, 2004). This challenges Sonsaard et al.'s (2023) suggestion that attractive incentives and high returns are necessary to encourage user participation in DR programmes at the initial stages. In GB, business models developed without dedicated incentives, driven instead by innovation trials and other enablers.

It is questionable however if the approach will suffice to accelerate DR's growth for 2030. While government subsidies for technologies like EVs and heat pumps have indirectly stimulated demand for DR products, significant barriers to generating revenue from DR in various markets persist. DNO markets are still in their infancy, and the newly created Market Facilitator role aimed at standardising DNO and NESO markets may take years to deliver meaningful change. With the removal of the DFS guaranteed acceptance price in 2023, there is also uncertainty about the future viability of the DFS and the type of DR it will attract.

Accelerating DR growth: policy recommendations

Given the urgency of climate change, the rapid development of a residential DR TIS is crucial for GB and other countries aiming to electrify heat and transport while integrating large amounts of renewable energy. Drawing from the lessons of the GB case study, this section outlines how policy can accelerate DR growth both in GB and internationally.

The primary policy recommendation is to adopt a strategic coordinated approach from the outset. This means identifying all the foundational DR enablers for a specific country context (see Figure 5 for GB specific enablers), setting out clear delivery timelines and approaches to delivery to avoid unnecessary shifts in the TIS' direction of search, thus providing greater investment certainty. A strategic coordinated approach also means proactively identifying gaps in function fulfilment, preventing issues like those observed in GB, where the legitimation and market formation functions lagged. Policymakers can reduce delays and mitigate the risk of failure in advancing the DR TIS into a growth phase by addressing these gaps. A strategic coordinated approach could start with clear end-goals and work backward from those to help policymakers determine the level of intervention required, such as the need for opt-out TVTs, mandating utilities to offer them, or implementing subsidies if needed.

Placing the user at the centre of the policy framework from the outset is also important to making sure that user needs and preferences are fully integrated into DR system development. This entails making early policy decisions about which types of users are expected to participate in DR as discussed by Mihalache et al. (2024) to clarify the TIS' direction of search; and clearly communicating the benefits that users should expect from participation, as well as potential risks and mitigations, to secure early and wide legitimation of DR with users.

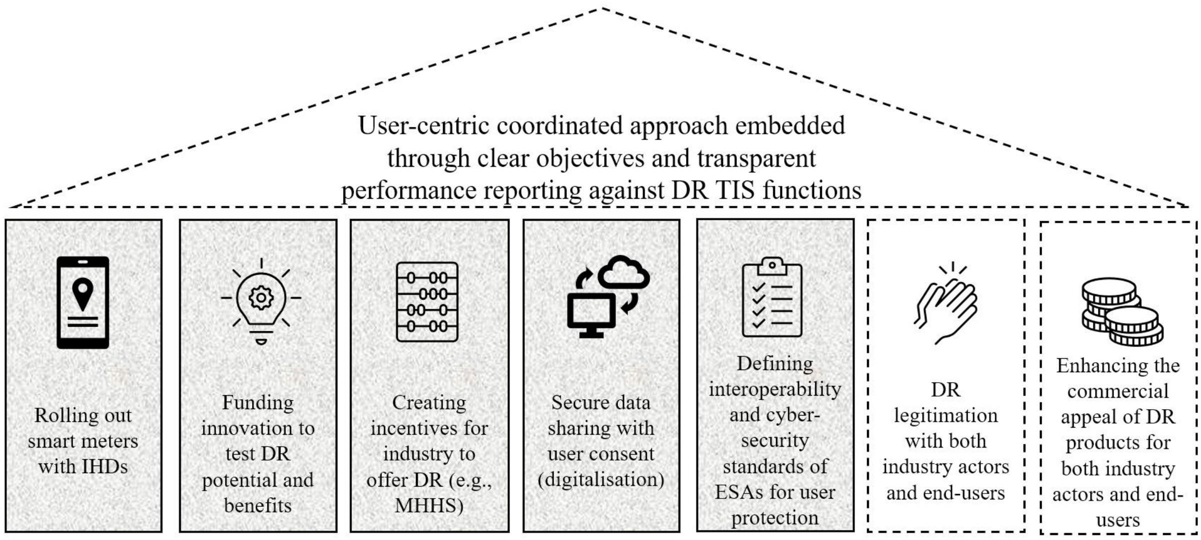
A strategic coordinated approach could set out performance standards for each of the TIS' seven functions. Publicly reporting on DR TIS' performance indicators can support quick intervention to address barriers and gaps when needed. The approach could provide early sight of functions where progress is lagging and could help identify positive externalities that allow functions to build on one another.

Defining clear roles and responsibilities for relevant system actors would create coordination between them and accountability for delivering DR commitments. In GB, this means clearly delineating the DR responsibilities of central government, the energy regulator, the national system operator, the Market Facilitator, and local governments.

Finally, coordinating DR policy with other long-term policies would ensure all initiatives work synergistically to drive the DR TIS forward. This could mean, for instance, linking EV and heat pump subsidies to participation in DR. An integrated approach can bring together formerly disparate TIS, allowing them to build on each other's functions.

Figure 6 below highlights the difference between a piecemeal approach (in darker grey colour) which assumes that DR enablers like rolling out smart meters and funding innovation will organically lead to DR development, and a strategic coordinated approach (added in dotted lines) which is intentional from the outset in terms of what DR enablers it needs to set up and how these need to come together towards a common goal.

Figure 6: Piecemeal approach to DR development v. strategic coordinated approach



Areas of future research

Future research could deepen understanding of residential DR and further refine the application of the TIS framework to demand-side innovations. For DR specifically, more work is needed on the implications of a strategic coordinated approach, including its potential downsides such as reduced flexibility in experimentation or the risk of prematurely locking in technologies or business models. Studies could also investigate how DR targets or incentives influence user participation, resource mobilisation, and the pace of entrepreneurial experimentation. Further empirical work on the costs and benefits of different DR incentive mechanisms, including guaranteed acceptance prices, could support more intentional market formation. In addition, research examining DR's wider economic and social impacts – such as its contribution to local economic development, distributional outcomes, and community energy models – would help clarify the role of DR in supporting equitable decarbonisation.

From a TIS perspective, the GB case study highlights several conceptual and methodological questions. Applying the TIS framework to demand-side technologies revealed a more complex legitimation function than typically found in supply-side analyses, due to the need to gain legitimacy both with incumbent actors and with large and heterogeneous user groups whose everyday practices may be disrupted by DR participation. Future research could examine how legitimation evolves across different user segments, and how social practices, trust, and perceived risks shape the fulfilment of this function. The market formation function also proved difficult to disentangle from entrepreneurial experimentation given the multiplicity of DR markets and products; comparative studies across countries could help clarify how these functions interact in demand-side contexts.

More broadly, expanding TIS studies to other demand-side technologies – such as HEM systems or flexibility from heat – would help consolidate understanding of how TIS dynamics differ between supply- and demand-side innovations. Such work could help refine TIS theory to better capture user heterogeneity, local contexts, and the critical role of economic growth narratives in shaping legitimation and market formation for demand-side transitions.

CONCLUSIONS

This study examined the evolution of the GB residential DR TIS between 2009 and 2024 to understand how residential DR has developed, why it has not yet scaled, and what this implies for future policy. Drawing on over 300 documented developments and 12 expert interviews, the analysis showed that although all seven TIS functions have progressed, the system remains in a formative phase. DR enablers like smart meters, MHHS, or innovation funding successfully initiated DR activity but did not lead to self-sustaining growth.

Across the three periods analysed, knowledge development, resource mobilisation, and entrepreneurial experimentation advanced steadily, supported by ongoing innovation funding and the entrance of new firms bringing diverse capabilities. However, inconsistent policy signals, delays in implementing DR enablers like the smart meter rollout, and shifts in governance arrangements weakened the influence on the direction of search and reduced firms' incentives to invest. Legitimation also remained a persistent challenge, particularly among incumbents who faced limited commercial drivers to prioritise DR. Among users, DR remained poorly understood, and propositions often targeted only early adopters with specific technologies, constraining diffusion. Market formation was the weakest function throughout the 15-year period. Until the creation of the DFS in 2022, GB lacked a dedicated DR market, and barriers to national and local flexibility markets prevented providers from building consistent revenue streams. Even with recent progress, fragmented markets, unclear benchmarking methodologies, and uneven access for non-incumbents limit the development of sustainable business models.

Taken together, these dynamics explain why GB's DR TIS has not achieved a dominant design, consistent user proposition, or strong positive feedback loops. The system accumulated experimentation but not scale. The piecemeal approach – largely reliant on incremental regulatory adaptations, competition policy, and the expectation that smart meters and MHHS would naturally lead to DR uptake – proved insufficient for accelerating DR development to the levels required for decarbonisation and electrification.

Meeting GB's ambition to increase DR capacity to 10–12 GW by 2030 requires shifting from a piecemeal to a strategic coordinated approach. This study identifies several components of such an approach. First, DR policy must place users at the centre. This entails designing DR products for diverse households – not just for early adopters, or those with EVs and heat pumps – clearly communicating their benefits, risks, and protections, and iterating their design based on user feedback. Strengthening legitimation with users is important for scaling participation. Second, policymakers should provide a clear, consistent direction of search. Setting long-term objectives and performance indicators for each TIS function would give firms and investors greater certainty, reduce repeated shifts in expectations, and support more intentional resource mobilisation. Public reporting on progress would help identify emerging gaps early. Third, institutional coordination and accountability must be strengthened. The current governance arrangement lacks clear responsibility for DR outcomes, creating risks of duplication, misalignment, and single points of failure. Clear delineation of roles across central government, the regulator, the national system operator, and local governments would support more coherent development of the DR TIS. Fourth, market formation requires sustained attention. Removing barriers to national and local flexibility markets, harmonising approaches across markets, and ensuring fair competition between DR and traditional technologies will be essential for firms to offer DR products at scale and for DR to deliver its full system value. Finally, DR policy should be aligned with wider long-term strategies, including EV and heat pump deployment and local energy planning. Coordinated policy design can create positive externalities across TIS functions and avoid fragmented development.

Overall, the GB experience demonstrates that foundational enablers are necessary but not sufficient for scaling residential DR. Accelerating the transition from a formative to a growth phase requires intentional, strategic coordination across policy, markets, technologies, and user engagement

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Discussion

Sir Frederick: [...] there are four words to be included in a proposal if you want it thrown out.
Sir Humphrey: Complicated. Lengthy. Expensive. Controversial. And if you want to be really sure that the Minister doesn't accept it, you must say the decision is 'courageous.'

(Yes, Minister, Series 1, Episode 6: The Right to Know)

This chapter synthesises the findings from the three empirical papers to answer the thesis' overarching research question and translates the analysis into policy-relevant conclusions. It sets out the empirical and conceptual contributions of the thesis, clarifies the international relevance of the GB case, and identifies future research areas. The chapter recognises the practical and political realities that influence how policy recommendations are evaluated, prioritised, and turned into action.

SYNTHESISING THE FINDINGS

The thesis set out to answer the following research question: *How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation? U*sing a GB case study, it combined industry perspectives on DR (paper 1), users' lived experience of DR (paper 2), and an integrated system view of DR's development in GB over the last 15 years (paper 3). Together, the papers provide one of the most thorough and up-to-date examinations of residential DR in GB, allowing policy recommendations to be extracted to support DR development in liberalised markets at pace.

Paper 1 shows how the development of residential DR in fully liberalised energy markets is shaped by persistent misalignment between commercial interests, customer realities, and regulatory frameworks. Electricity suppliers tend to design DR products for a narrow segment of early adopters, particularly technologically-savvy EV owners willing to accept automation, because they assume limited interest in DR from wider customer groups and insufficient financial rewards to motivate mass-market participation. This commercial strategy jeopardises the mass-scale DR rollout needed to support electrification and decarbonisation by ignoring the future EV and heat pump owners who may behave differently from early adopters of these technologies. Absent an early normalisation of DR amongst future EV and heat pump owners, DR may struggle to scale and may entrench already visible distributional inequalities. At the same time, suppliers face weak incentives to scale DR: elective HHS has not proved commercially worthwhile; legacy IT systems constrain innovation and uncertain MHHS timelines delay the incentive to upgrade them; and the commercial value of DR fails to materialise due to insufficiently time-reflective bill stacks and broken markets. Demand aggregators, on the other hand, struggle with complex market rules, and face administrative barriers and limited access to customer data. DR's potential for integrating renewable energy and reducing system costs remains underexploited despite widespread recognition of its benefits. The paper argues for policy frameworks to provide stronger, clearer, and more coherent incentives for commercial actors to offer mass DR products to accelerate residential DR scale-up in liberalised markets.

In contrast to industry's perceptions of DR users in paper 1, households beyond early adopters do engage with DR under the right conditions, as shown in paper 2. The paper examines the varied ways in which households engage with DR and how differences in motivation, technological capacity, everyday routines, and interpretations of DR's purpose shape engagement. Across the five domestication pathways identified – from motivation-driven and tech-enabled success through to gaming, disengagement, and rejection – the paper demonstrates that integrating DR into daily life is a dynamic socio-technical process that requires alignment among user values, domestic practices, and DR programme design. While many participants enthusiastically incorporated the DFS into their routines, motivated by environmental concerns, curiosity, or access to enabling technologies, others gave up because of low rewards, confusing baselines, technical glitches, and family or work constraints.

The paper argues that sustained residential DR cannot rely solely on financial incentives. It requires messaging that resonates with users' non-financial motivations, feedback systems that support learning, and programme designs attentive to flexibility justice and the risk of unintended behaviours such as gaming. Mass-scale uptake of residential DR in liberalised markets thus requires normalising DR as a routine household practice through DR products that accommodate the diversity of household capabilities and constraints.

Paper 3 explores what happens when residential DR policy develops in a piecemeal, uncoordinated fashion in liberalised energy markets, which assume the market will deliver DR on its own if specific enablers are put in place. The approach is shown to jeopardise the speed and scale of DR development. Foundational enablers – smart meters, MHHS, innovation funding, digitalisation, and emerging ESA standards – can initiate DR activity and stimulate knowledge development, experimentation, and the entry of new actors. However, the paper provides evidence that fragmented implementation of these enablers results in inconsistent policy signals, which weaken DR's legitimation among incumbents and the wider public. As such, flourishing entrepreneurial experimentation does not automatically translate into widespread commercial DR offerings and remains hostage to retail market disruptions and regulatory delays which can reduce incentives for commercial actors to invest in DR. Market access barriers and non-time-reflective pricing further constrain viable business models. With a market-led approach, DR remains far from achieving a dominant design, stable revenue environment, or self-reinforcing growth dynamics. The paper concludes that a strategic coordinated approach – as opposed to a market-led approach – is needed in liberalised markets to accelerate DR scale-up: one which provides clear direction, strengthens institutional accountability, accelerates market formation, and places diverse user needs at the centre of DR design.

ANSWERING THE OVERARCHING RESEARCH QUESTION

Taken together, the three papers provide a multi-layered explanation of how DR in GB emerged, why it has yet to scale, and what is required to do so. The findings converge on a few areas, exposing three themes fundamental to accelerating DR scale-up in liberalised markets: strategic coordination, commercial appeal, and mass-market rollouts and designs. I explore below how the three cross-cutting themes are reflected in the thesis and discuss their policy implications to answer the overarching research question: *How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation?*

Strategic coordination

In GB, liberalisation enabled innovation and commercial experimentation but generated fragmented governance and uneven capabilities across actor types. The thesis suggests that while liberalised markets can deliver early DR innovation, achieving DR scale-up requires strategic coordination. By contrast, a piecemeal approach to DR policymaking creates:

- Regulatory uncertainty and market fragmentation, which prevent incumbents from investing in DR (papers 1 and 3) and innovators from scaling (paper 1)
- Risk of lock-in to DR product designs not fit for scale, like lifestyle tariffs (paper 1) and easy-to-game DR products (paper 2)
- Single points of failure, like assigning responsibility for both MHHS delivery and market coordination to a single, non-licensed entity, Elexon (paper 3)
- Risk of weak compliance with regulatory obligations like moving to MHHS and rolling out smart meters (papers 1 and 3), ultimately causing customer detriment.

In effect, the approach hurts the potential for mass-market DR product development and uptake. The policy recommendation is to adopt a strategic, coordinated DR policy approach *from the outset*, which requires policymakers to:

- Set explicit end-goals for DR scale and type (e.g. how many GW of implicit DR from EVs by when) and work policy design backwards from those
- Identify all foundational DR enablers upfront (e.g. smart metering, settlement reform, digitalisation, innovation funding) and establish clear delivery approaches and timelines for each enabler, avoiding repeated shifts in direction to prevent investor uncertainty
- Publicly monitor and report progress – using the TIS framework and/or performance metrics adapted to context – to support rapid corrective intervention and identify opportunities

- Actively intervene when functions/performance lag, rather than assuming markets will self-correct
- Clearly define roles, responsibilities, and accountability between central government, the energy regulator, system operators, local governments, and other relevant system actors, avoiding overlaps, accountability gaps, and single points of failure
- Coordinate DR with other government policies and avoid siloed working

The Clean Flexibility Roadmap I helped develop is one example of emerging strategic coordination but must be backed by sustained implementation and may need to be updated to maintain progress pace.

Commercial appeal

Improving the business case for residential DR is essential for accelerating its development. In liberalised markets, DR may struggle to gain commercial appeal due to:

- Limited time-reflectivity of the bill stack (papers 1 and 3)
- Limited DR value stacking across energy markets (papers 1 and 3)
- The scale of investment needed to upgrade legacy IT systems (paper 1)
- Competing regulatory burdens (paper 1)
- Uneven impact of data sharing and protection frameworks on business models (paper 1)
- Difficulty motivating users to engage with DR when rewards are small (paper 2).

Whilst outliers like Octopus Energy – building on their competitive advantage of having developed and commercialised Kraken – may manage to scale a DR business in spite of the challenge, there is no guarantee that wider scaling is possible without also bringing incumbents on board. DR's limited commercial appeal undermines its legitimation with incumbents (papers 1 and 3) and the wider public (papers 2 and 3).

Policymakers could therefore look to strengthen the value of DR and improve revenue certainty to support legitimation with new and incumbent business models:

- Reform energy markets to allow broad participation and revenue extraction, facilitating value stacking between markets
- Level the playing field between incumbent and new business models to harness the full benefits of competition (e.g. equal access to customer data with customer consent)
- Introduce carrots and sticks as needed, e.g. subsidised DR-only markets like the first year of DFS; MHHS; enforcement against non-delivery of regulatory requirements like rolling out smart meters
- Provide more predictable and durable revenue conditions for DR, rather than relying on short-lived schemes or fragmented market opportunities. This recommendation follows directly from paper 3's finding that market formation remained weak, that providers lacked consistent revenue streams, and that fragmented markets and benchmarking approaches limited sustainable business models; and from Paper 1's finding that weak value stacking, slim margins, and investment uncertainty reduced commercial appetite for DR.
- Complete and complement MHHS with time-reflective network and policy charges

Mass-market rollouts and designs

Across all papers, ownership of large, automated electricity loads proved central to scaling residential DR. Industry experts tie ESA ownership to the commercial viability of DR products because households with ESAs make more savings from DR (paper 1); households with large, automated loads participate more consistently and with less effort in DR programmes and get higher rewards (paper 2); and signals of impending electrification of heat and transport shift the value of DR from just reducing peak demand, to aligning demand in real time with variable generation to support decarbonisation (paper 3).

Scaling technological rollout and harnessing its DR potential beyond early adopters in liberalised markets may require:

- Scaling government support for EVs and heat pumps (e.g. through subsidies) and making it contingent on engagement in DR (papers 1 and 3)
- Balancing temporary support for DR through subsidies and dedicated markets (paper 2) with long-term sustainability of such support
- DR product designs to cater to the diversity of user motivation and domestication pathways and to ensure sustained customer engagement in DR over time (paper 2)
- Standards for interoperability and cybersecurity of ESAs, HEMs, and other smart control options to ensure customer protection and system reliability (papers 3)
- Ensuring ESAs, HEMs and other smart controls work in practice and clarifying who is responsible for their maintenance (paper 1)
- Consideration of fairness and equity, as most DR products are likely aimed at early adopters with high flexibility capital (paper 1); households without flexible technologies or predictable routines find it challenging to participate (paper 2); and policymakers have yet to credibly spell out how everyone benefits from DR and what it means for communities and local growth (paper 3).

The contrast between industry's imagined users (paper 1) and users' lived experience of DR (paper 2) shows that inclusive, easy-to-adopt mass market DR products are unlikely to develop in liberalised energy markets absent policy intervention. Paper 2 proposes pathways which could inform more inclusive user segmentations to support mass-market commercial product design.

Below are a few recommendations on what policy frameworks and commercial DR product designs could do to accommodate the diversity of users and their experiences with DR:

- Ensure mass access to DR-enabling technologies like smart meters and ESAs
- Decide early on which types of users are expected to participate in DR, depending on projected system needs and calculations of individual cost/benefit of participation
- Clearly communicate direct and indirect benefits of participating in DR – including risks of participation – to secure early legitimation and avoid backlash and mistrust. Account for users' motivations and prior experience with DR when communicating DR benefits and risks
- Design DR products and programmes for long-term engagement rather than as one-off events – normalise DR through routine formation which fits household rhythms
- Standardise ESAs' interoperability requirements to streamline the user experience
- Streamline data and cyber protections to build confidence
- Extend customer protection frameworks to capture complexities related to ESA's and HEM's maintenance
- Embed equity in DR product design and access to technology, e.g. through subsidies. Avoid programmes that reward only high-consumption households
- Integrate DR design with broader social and housing policy to mitigate inequalities.

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To answer the thesis research question in short, liberalised markets will likely deliver DR at scale and at pace only if government policy provides strategic direction, commercial appeal, and mass-market technological and DR product rollouts.

Some of the policy recommendations in this thesis may appear intuitive, while others may seem to challenge the logic of liberalised markets. Yet my experience demonstrates that even seemingly obvious recommendations are difficult to implement, and theoretical assumptions often fail to hold in practice. In my experience, policy success depends heavily on policymakers' ability to navigate the political and institutional systems in which they operate.

Securing ministerial focus, for instance, is always challenging because of competing demands on ministers' time. Gaining cross-government alignment is equally difficult, especially securing Treasury funding. Framing DR in relation to politically salient issues like affordability can help attract interest, but it can also create unrealistic expectations.

Matters are further complicated by communication barriers. Policy experts are often focused on the technical detail, but senior decision-makers rarely have the time or bandwidth to engage with such complexity. Important subtleties can get lost in translation.

Government structures tend to reinforce siloed working, making it challenging to persuade teams across government departments and other organisations to realign their priorities for the sake of DR, let alone sustain such alignment over time. Industry lobbying adds another layer of fragmentation, given the diversity of interests and inconsistent messaging.

The political environment also introduces instability. Changing political agendas and frequent ministerial turnover mean that the case for DR needs to be repeatedly re-established. Meanwhile, large workloads – ministerial briefings, stakeholder management, parliamentary activity, correspondence, and other reactive tasks – reduce the time available for proactive policymaking. When legislative change is required, securing parliamentary time is another hurdle. Statutory processes like consultations are key to democratic accountability, but they demand considerable time and resources, stretching already limited capacity and making it even harder to coordinate the many interdependent policy strands necessary to advance DR.

Resource constraints further hinder progress. Budget cuts, crisis-driven staff redeployments, and a high rate of staff churn erode institutional memory and disrupt continuity. In countries where the civil service is made up mostly of generalists – as is the case in the UK – building up expertise in complex areas such as DR can be slow, and expertise is often lost when staff move roles to secure promotions if the system does not reward long-term specialisation. At the analytical level, reconciling cost-benefit analyses with legal risk assessments adds significant complexity, while modelling limitations make it challenging to quantify DR impacts with confidence.

For civil servants and politicians alike, grasping the full scale and breadth of the change required to embed DR fast and at scale can be daunting. The complexity of the system, the competing pressures on decision-making, and the fragmented structures of governance all make it hard to see the whole picture. The policy recommendations developed in this thesis provide a structured way to manage that complexity. They offer a framework to guide planning, support more coherent decision-making, and ensure that efforts to accelerate residential DR are both systemic and enduring.

EMPIRICAL CONTRIBUTIONS

The thesis extends the three bodies of literature discussed in the literature review chapter, filling the gaps they had left in answering the overarching research question.

Barriers to DR scale-up literature

With regards to the body of literature on barriers to residential DR, this thesis extends the predominantly static barrier literature by shifting the focus from *cataloguing* obstacles to *explaining* how obstacles arise and how policy can actively remove them. Existing studies tend to either map barriers at a general level or to examine individual barriers. By contrast, this thesis captures both the breadth and depth of barriers to DR within a liberalised market and evaluates how policy interventions can remove barriers to mass-scale commercial DR product design, household participation, and system-level market formation over time.

The thesis shows how commercial, organisational, technological, and regulatory barriers impact commercial decision-making processes that determine DR product development. It demonstrates that digital infrastructure failures at the firm level constitute a critical bottleneck to scale-up, explaining why policies ignoring organisational capabilities for DR are insufficient to mass-market residential DR development. This extends the literature by linking abstract barriers to their operational consequences and by evaluating the real-world impacts of policy intervention, rather than treating barriers as static conditions.

Regarding household participation, the thesis further reveals how specific DR product design choices – like baselining methodology, reward structure, and feedback mechanism – can themselves become persistent barriers to mass-scale DR by undermining sustained household engagement. This advances existing work on participation barriers by showing that poorly aligned market rules and DR product design reduce DR uptake and erode the commercial viability of residential DR.

At the system level, the thesis explains why repeated reforms in GB have failed to transition residential DR from niche experimentation to mass-market deployment. It shows that barriers persist because market formation, legitimation, and strategic direction have repeatedly lagged behind technological capability. In doing so, the thesis addresses two key literature gaps: it identifies the lack of coordinated governance *across policy domains* and the absence of effective policy sequencing as central structural barriers to DR scale-up, and it proposes ways to address them in practice.

DR business models literature

The thesis advances the literature on residential DR business models by moving beyond diagnostic accounts of aggregator roles, business model diversity, and institutional constraints. While existing studies richly describe how DR business models vary and why they struggle to gain traction, they remain largely non-prescriptive about how liberalised electricity markets can transition from niche experimentation to mass-market commercialisation.

This thesis addresses this gap by identifying the policy and governance conditions required for business model scale-up, regardless of whether it comes from incumbents or new entrants. It shows that the success of DR business models hinges on both innovative commercial propositions and on the implementation of regulatory reforms across metering, settlement, billing, network pricing, and market access. The findings demonstrate that piecemeal reforms have systematically confined DR innovation to early-adopter niches. The thesis provides a prescriptive account of how specific regulatory levers must be coordinated to support widespread proliferation of innovation.

The thesis further demonstrates that retail incumbents remain gatekeepers for DR commercialisation. This challenges the literature's assumption that aggregator competition will naturally expand consumer choice or drive rapid DR uptake.

At the system level, the thesis reframes aggregators not as the primary mechanism for scale but as one component within a broader governance architecture. It shows that without clear allocation of system responsibility – over baselines, consumer protection, data interoperability, and supplier–aggregator conflict resolution – no business model can achieve mass-market penetration. The research identifies the structural power asymmetries embedded in liberalised market design and specifies the governance interventions required to counteract them.

DR user experience literature

The thesis extends the fragmented literature on DR user experience by bridging behavioural, socio-technical, and governance perspectives to explain how users engage with DR, and how policy must be redesigned to embed these insights. While existing research illuminates how households perceive, negotiate, and are affected by DR within everyday life, studies predominantly remain diagnostic: they describe patterns of engagement, resistance, and inequality, yet offer limited insight into how policy and product design can build on how users make DR workable in the home.

This thesis addresses these limitations by showing that current patterns of household engagement and exclusion are not simply behavioural phenomena or results of certain practices and routines. They are, instead, also a result of DR product designs shaped by institutional assumptions and market rules. It demonstrates that suppliers frequently design products around imagined early adopters, embedding assumptions about automation and household capabilities that misalign with real users' experience.

The thesis also provides an empirical account of how DR product design choices shape user experience in real time. Because it traces how mechanisms such as baselining or rewards structure participation, the thesis reframes such issues as failures of institutional responsibility rather than shortcomings of individual users.

At the system level, the thesis explains why DR user experience becomes a systemic barrier to DR scale-up in liberalised markets: the innovation system offers weak legitimation and incomplete market formation. Even where households are willing, and technologies are ready, DR cannot scale because institutions do not assign clear responsibility for coordinating market creation, ensuring consumer protection, or embedding households as reliable system actors. The thesis changes the positioning of user engagement with DR from being a bilateral issue between the user and the electricity supplier to a core system function that policymakers must design for intentionally.

CONCEPTUAL CONTRIBUTIONS

The thesis makes two conceptual contributions, one to domestication theory and one to TIS.

First, paper 2 continues the tradition of expanding domestication theory's application beyond artefacts and shows that it can be applied successfully to DR. It extends the conceptualisation of the three domestication pathways identified by Hargreaves and Wilson (2017) – successful, precarious, and rejection – by placing them on a spectrum rather than treating them as discrete categories. It opens a debate on the conceptualisation of successful domestication pathways that run counter to the spirit of the original script. Creating a spectrum that accommodates this ambiguity is a first step towards addressing the tension between domestication and script.

Second, the thesis contributes to transitions frameworks by demonstrating that demand-side innovations like DR have a different evolution from supply-side technologies. Paper 3 expands the application of TIS, which has traditionally been applied to supply-side technologies, to electricity demand-side technologies. It is the second study to apply TIS to analysing DR, but the first one to apply it alongside EHA to offer a longitudinal perspective on DR development and assess its overall performance. Applying the TIS framework to DR revealed a more complex legitimation function than typically found in supply-side analyses, due to the need to gain legitimacy both with incumbent actors and with large and heterogeneous user groups whose everyday practices may be disrupted by DR participation. The market formation function also proved difficult to disentangle from entrepreneurial experimentation, given the number and complexity of DR-relevant markets and products. Paper 3 thus opens the debate on how to apply TIS most effectively to track and assess the development and performance of demand-side technologies.

INTERNATIONAL RELEVANCE

While this thesis is grounded in the GB electricity system, its findings have broader importance for countries pursuing decarbonisation in liberalised or liberalising electricity markets. The international relevance arises from the structural dynamics the three papers reveal – the limits of market-led DR development, the centrality of household capabilities and lived practices, and the need for strategic coordination to align actors around system goals – rather than from GB's specific institutional arrangement, which is why this thesis does not over-emphasise it.

Many advanced economies — including Australia, several EU Member States, parts of the US, and Japan — have embraced retail competition and supplier- or aggregator-led DR innovation. Research shows similar dynamics to those in papers 1 and 3 play out in countries like Italy and Spain (Torriti et al., 2010), Germany (Koliou et al., 2014), Sweden (Vallés et al., 2016), Belgium, Greece (Forouli et al., 2021), Denmark (D'Ettorre et al., 2022) and the US (Liu, 2017). Such environments often display fragmented DR value streams, inconsistent temporal price signals, and legacy billing and settlement infrastructure that restricts suppliers' ability to translate system value into household propositions. The limitations observed in GB are characteristic of liberalised markets where the burden of innovation falls on commercial actors rather than on market architecture or governance. Countries with liberalised or liberalising markets can therefore look at GB to anticipate that DR is unlikely to scale fast enough without policy interventions that integrate value streams, push IT infrastructure to modernise, and lower barriers to entry. The caveat, however, is that the findings are transferable to countries moving toward similar market arrangements as GB rather than universally generalisable.

The experience of households participating in the DFS (paper 2) also has broad relevance. Some jurisdictions have pursued DR through dynamic pricing or critical peak events (Herter, 2007; Herter et al., 2007; Herter and Wayland, 2010) or have enacted trials (D'hulst et al., 2015; Vesterberg and Krishnamurthy, 2016) working on the assumption that households will respond predictably to financial incentives.

The GB case reveals a more complex picture in which motivations, routines, symbolic meanings, and fairness concerns shape participation as much as – and sometimes more than – direct bill savings. These insights align with findings from North American (Buryk et al., 2015), European (Friis and Haunstrup Christensen, 2016; Nyborg, 2015; Winther and Bell, 2018), and Australian (Nicholls and Strengers, 2015) trials showing highly heterogeneous household responses to DR. The GB case, therefore, adds weight to the emerging international understanding that successful DR hinges on user-centred design, recognition of uneven flexibility capital, and accessible automation support, rather than on tariffs alone. Countries aiming to scale residential DR can take lessons from how GB households domesticate DR, including the importance of clear communication and programme structures that do not reward only high-consumption households. The caveat, however, is that the DFS was an unusual form of explicit DR: short, event-based, heavily publicised, and layered with symbolic meanings that may not replicate in everyday DR programmes. The sample did not include single-parent households and it underrepresented households without flexible assets. As such, the identified domestication pathways provide conceptual insights but should not be read as representative of all DR contexts.

Finally, the TIS analysis in paper 3 highlights systemic factors with global DR relevance: the difficulty of scaling DR through incremental reforms, the risks of diffused accountability across multiple actors, and the lack of coordinated frameworks that bridge incumbent practices and emerging DR needs. The GB case demonstrates that strategic coordination is key for translating technical potential and localised innovations into system-level DR capability, and that piecemeal policy measures are unlikely to accumulate into a self-sustaining growth trajectory.

This thesis did not aim to compare GB DR uptake with DR uptake in other countries, even liberalised ones. Such comparison would be difficult since there are no harmonised metrics to rely upon, and factors like weather patterns, level of electrification and the energy mix of a country can vary widely. Still, there are countries where DR uptake may be higher than in GB – depending on what metrics are used to measure that – or where aspects of DR (like participation in certain markets) are more advanced than in GB. South Korea, for instance, launched an explicit DR programme, People DR, in December 2019 – two years before GB (Hwang et al., 2025). France has a long-standing tradition of direct load control and was the first European country to open markets to all consumers; California and New England have mature aggregation markets and wholesale market participation. Future research could explore these comparisons, as well as the areas below.

AREAS OF FUTURE RESEARCH

This thesis opens several avenues for future research that would deepen the understanding of residential DR and support effective pathways to scale it up.

It would be good to understand how commercial actors adapt their strategies as DR markets mature. Paper 1 identified substantial variation in organisational capabilities and risk appetites across electricity suppliers and demand aggregators. Future research could look at how firms adapt once MHHS is fully implemented and markets in which DR can participate are streamlined. This includes understanding if new business models developed in these circumstances reinforce or mitigate distributional inequalities. More practically, it would be interesting to evaluate if MHHS will produce its intended outcomes once fully implemented, or if electricity suppliers will find ways to game it. This should shed light on whether incentives stronger than MHHS are needed, like mandating electricity suppliers to offer at least one TVT to their customers.

Further work is also needed to understand how households' flexibility capital evolves over time and across technologies. Longitudinal studies could explore how flexibility capital develops as households adopt ESAs and HEMs; how it is influenced by changes in market design or social norms; and how it varies across socio-economic groups and life stages. Such research would strengthen the empirical foundation for equitable DR policy and support more precise targeting of support measures. However, gaining access to relevant datasets would not be trivial, at least in GB, given that DNOs do not yet hold registers of the ESA connected to their networks. Participants would thus have to be recruited individually, as done for paper 2, which is a non-trivial task.

Future research could also investigate the institutional arrangements needed to sustain DR at scale. Paper 3 highlights the challenges of coordinating multiple actors within a liberalised system, but the precise governance configurations that create effective direction-setting and accountability are underexamined. Comparative studies across countries with differing regulatory traditions would help identify which combinations of institutional authority, market oversight, and stakeholder involvement best support rapid DR scale-up.

DR's legitimation with households also needs further exploration. As paper 3 shows, legitimation processes remain fragile even with growing public awareness programmes like the ones that accompanied the DFS. Research could examine how community energy projects or the involvement of local authorities in DR cold shape its legitimacy, especially if DR is shown to support affordability and local economic growth.

A final limitation is that the thesis does not examine I&C DR directly, even though that segment has historically reached scale earlier than residential DR. Some lessons from I&C DR would likely strengthen the answer to the overarching research question, particularly around standardising baselines, building aggregator capabilities, automating response, and creating clearer routes into balancing and capacity markets. However, those lessons are only partially transferable. Residential DR involves far smaller sites, weaker per-customer economics, more heterogeneous routines, and stronger equity and user-legitimation concerns than I&C DR. The implication is not that I&C experience is irrelevant, but that it cannot simply be transplanted into the residential space without adaptation to household practices and consumer-protection objectives already identified in papers 1 and 2.

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In summary, this thesis has shown that DR's slow progress reflects not a lack of technical potential or household willingness, but persistent misalignment between market incentives, commercial strategy, programme design, household experiences, and system-level coordination. Three cross-cutting requirements for rapid DR scale-up recur across the papers: strategic coordination to align actors and sequence reforms; improved commercial appeal through stronger and more reliable value streams; and mass-market rollouts and designs that normalise participation and accommodate diverse household capabilities. The chapter, therefore, concludes that liberalised markets are likely to deliver residential DR at pace only where policy provides clear direction, creates investable conditions for firms, and embeds user-centred design and equity into the pathway to scale.

Conclusions

Civil servants have an extraordinary genius for wrapping up a simple idea to make it sound extremely complicated.

Jonathan Lynn – Yes, Minister co-writer

This concluding chapter brings the thesis together by distilling a complex body of evidence into a clear set of insights about scaling up residential DR in liberalised markets. The chapter seeks not to add further complication, but to clarify what matters most and how policy can move towards decisive and coherent implementation.

BRINGING THE THESIS TOGETHER

When I began this research, I believed that residential DR could become one of the fastest, fairest, and most valuable tools for decarbonisation – if policy can create the conditions for its growth. Six years later, I see more clearly why DR has remained slow to scale in liberalised markets, and what must change for it to reach its potential. Across the three papers, I traced industry perspectives on, household experience with, and the evolution of residential DR in GB. I found that DR does not fail for lack of technical potential, innovation, or household goodwill. Instead, its progress stalls because the institutional, commercial, and operational systems required to support it have not been designed with sufficient coherence, direction, or pace.

This thesis, therefore, answers the overarching research question *How can policy support the rapid scale-up of residential DR in liberalised markets to support decarbonisation?* by showing that scale requires strategic coordination, commercial viability, and mass-market DR product and programme designs, boosted by governance that recognises the realities of both markets and everyday life.

THESIS MAIN FINDINGS

Liberalised markets are not designed to deliver DR at scale on their own

Paper 1 shows that industry actors recognise DR's value in principle yet struggle to operationalise it within a retail system characterised by thin margins, legacy IT systems, weak value stacks, and regulatory uncertainty. Electricity suppliers and demand aggregators face constrained commercial incentives, uneven digital capabilities, and high investment opportunity costs. These conditions favour experimentation but inhibit scale.

Weak market signals undermine DR's legitimacy among incumbents and users. Without reliable revenue streams, electricity suppliers deprioritise DR relative to regulatory obligations, cost pressures, and more commercially promising activities. The thesis demonstrates that innovation and competition alone cannot scale up DR if foundational enablers (e.g. smart metering, MHHS), market design, and regulatory clarity lag behind technological advancements.

Households domesticate DR in ways that reflect everyday constraints and motivations

Paper 2 argues that residential DR is not simply a technical shift in consumption patterns, but a process of *domestication* shaped by symbolic meanings and practical constraints. Households did not respond uniformly to the 2022-2023 DFS because their flexibility capital – material, cognitive, and social – varied widely.

Successful domestication of DR relies on electricity suppliers' and demand aggregators' ability to provide their customers clear and intuitive signals, timely feedback, opportunities to make DR meaningful beyond financial savings, and access to automation. Conversely, small rewards, complex instructions, or poorly aligned programme design erode trust and long-term willingness to participate. These findings show that *sustained* DR participation requires normalising DR and embedding it into everyday life, not just incentivising behaviour on the margins.

Piecemeal policy accumulation does not add up to system change

Paper 3 demonstrates that DR in GB has developed over 15 years through incremental reforms, pilots, and enabling technologies. Yet the system remained stuck in a formative rather than a growth phase. Foundational enablers (smart meters, HHS, innovation funding, ESA standards, digitalisation) have generated experimentation but not stable markets.

Fragmented governance, diffuse accountability, and inconsistent policy signals have weakened DR's legitimation with both incumbents and the public. The analysis warns that momentum should not be mistaken for progress. Without strategic coordination that sequences reforms, aligns institutions, and integrates user perspectives, DR remains vulnerable to retail shocks, political cycles, and operational challenges.

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Three cross-cutting themes emerged as essential to scaling up DR at pace in liberalised markets: strategic coordination, commercial appeal and mass-market rollouts and designs.

To scale DR fast, policymakers must articulate clear end-goals for the types and scale of DR required, and design policy backwards from those goals. This includes defining roles and accountability across government, the regulator, system operators, and other relevant actors; identifying foundational enablers up front and sequencing their delivery; aligning DR with wider policies, such as EV and heat pump deployment; and publicly monitoring progress to determine rapid corrective action.

Strategic coordination allows markets to function effectively rather than replacing markets. If DR is to gain scale, firms must have confidence that investments will yield returns. This requires improved time-reflectivity of costs throughout the bill stack, access to multiple value streams, fair and consistent data-sharing frameworks, and regulatory certainty that rewards investment in digital capability and automation.

Finally, DR products that ignore users' technological capability, everyday routines and meanings will not sustain participation, regardless of incentives. Policy must therefore ensure equitable mass access to DR-enabling technologies like smart meters and ESAs, and DR products; clear communication of direct and indirect benefits – and risks – of participating in

DR; DR product designs that favour long-term engagement rather than one-off events to normalise DR through routine formation.

IMPLICATIONS FOR POLICYMAKERS

As a policymaker, I have experienced first-hand the difficulty of designing and implementing lasting and impactful DR policy while working under political pressure, limited resources, and complex governance arrangements. DR competes with multiple priorities and requires sustained attention and collaboration across institutions that often operate in silos. The framework developed in this thesis offers policymakers a structured way to manage that complexity. It clarifies the scope of the challenge, highlights the interdependencies that shape DR, and suggests how to build the institutional conditions for long-term progress. It also helps create the political and organisational space necessary to move beyond short-term fixes toward lasting system change.

CONTRIBUTIONS TO SCHOLARSHIP

This thesis makes three primary contributions. First, it integrates industry, user, and system perspectives to offer the first holistic explanation of why residential DR has struggled to scale in a liberalised market. Second, it advances the two theoretical frameworks used: domestication theory by extending the domestication pathways framework, and TIS by explaining how legitimation and market formation differ fundamentally from supply-side cases. Finally, it provides a prescriptive, system-wide framework for sequencing reforms, coordinating governance, and designing mass-market DR products, transforming DR scholarship from descriptive accounts toward actionable policy guidance.

FINAL REFLECTIONS

Achieving decarbonisation at the pace required is difficult without making use of residential DR. Yet DR will not scale simply because it is technically feasible or economically efficient. Its success hinges on institutions capable of strategic coordination, firms with viable business cases, and households whose lives accommodate – rather than resist – the practices DR requires. Liberalised markets can deliver innovation, but governments must deliver direction. If policymakers can mobilise these conditions, residential DR can become a central pillar of a flexible, affordable, and equitable energy system. Otherwise, DR risks confinement to niches for early adopters, never fully contributing to the clean power future it could help secure.

Annex 1: Customers theme and sub-themes

Sub-theme	Respondent quote
Customer interest in DR	Large electricity supplier (5 May 2022): Would you want a tariff where every day you have to think when you're going to switch on your washing machine on or when you are going to cook because of your energy cost? It becomes too complicated; it needs to be easy. You're actually giving value to the single rate because then you could say to the customer you can save x, which isn't much in most simulations, by controlling your applications with your phone or don't bother and just get the single rate and then you're actually turning it on its head because the single rate becomes very valuable because I don't need to worry about anything. So, unless it's easier than not having to worry about anything, it's going to be very hard to have time-of-use (TOU)[28] because suddenly the single rate becomes very attractive. […] Hard to say how many would take on TOU outside of EV. Maybe Octopus is actually proving the case with Agile because they are the only one offering a tariff of that sort. So, if a customer wants one, they go to Octopus. Large electricity supplier (6 May 2022): [We haven't done more dynamic TVTs] because Octopus are Octopus and have a brand for that and will attract certain customers. They're evidently the market leader and the first to do it and we aren't convinced that if we were to replicate it, we would get a lot of people interested. […] Our customer base already is quite complicated so offering them this would just add more complications to that complicated group. […] The people who have been with us for a long period are those with more complex meter needs, people who don't want paperless bills, who pay on credit terms, who are more entrenched. And it's great that they're not interested in their energy supply, they want to stay with us, but it just means that whenever we want to do something new there's always a bit more complexity to it. I think if we had more internet-savvy customers who were all on the front foot and wanted to join our dynamic new brand, then they would probably take a bit more fluctuations in case things go wrong, whilst if one thing goes slightly wrong for us it absolutely snowballs. Our ability to act dynamically with our customer base is something that's very challenging. […] Another thing to say is there's only thousands of people in the UK who are interested in their electricity supply cost generally. I know that things are really expensive now, so everybody's really worried about it but generally electricity does not get much attention and there's only several thousand people who want Octopus Agile in the whole of UK so there's no point opening it up for every single supplier if there's not that many people. Large electricity supplier (15 Jul 2022): I think the terminology in this space is also quite antiquated. People talk about demand response (DR) or demand side response (DSR), [29] and it's kind of viewed in a mental framework that hasn't really evolved in

[28] Respondents used the term *time-of-use tariffs* rather than TVTs in the original interviews, so the term was kept in the transcripts

[29] Respondents used the term *demand-side response* rather than DR in the original interviews, so the term was kept in the transcripts

	15-20 years. And the reality is that there's been huge progress: customers can be engaged customers, actually a lot of customers want to be engaged to one level or another. But the historically incumbent industry does not treat their customers as anything other than passive bill payers. I think that's one of the core challenges to unpack. Large electricity supplier (20 May 2022): Octopus have a relatively low number of half-hourly settled customers, so it makes you wonder how popular their innovative products are. […] We did look at Octopus and the data we got for them showed there were not huge numbers of customers on Agile for example. They had maybe [confidential number] customers on elective half-hourly settlement (HHS), making us think that if you're a customer who wants to get half-hourly billing and settlement you would probably go to Octopus and only [confidential number] out of millions have done that so maybe there's not a huge market at this present time. Large electricity supplier (18 Nov 2022): We have a lot of very elderly customers who have been with us for like 40 years or something. And I don't want to discriminate in that sense, because, you know, some of our elderly people are very tech-savvy and switched on but, on the whole, they're largely less open to such offers, while people like young families and young professionals are far more likely to be open to this sort of tariff. Especially young suppliers, like Octopus will have far more young families and young professionals on their books than we do, naturally. And we also have a large prepayment portfolio and a large, vulnerable customer portfolio. So yes, not all of them, will this appeal to. Small electricity supplier (27 May 2022): Everything is competing for your attention at the moment, and people don't really want to be thinking about the price of energy for this half-hour or the next half-hour. They want to be thinking about how their kids are getting on at school, where they're going on holiday, so more important stuff. For people like us, we're interested in innovation because we can see the potential, but actually, most people day to day don't want that kind of cognitive load. And I think it's asking too much. It's a different category. There are prosumers and there are people who are engaged and then there's the average majority of consumer that don't want that, they have different needs. […] There's also a question about our customer base and the appetite they have. We have kind of older customers, although everybody is tech-savvy these days, I suppose, they're not innovators by nature. Ovo and Octopus look to attract those types of customers, but we generally don't. That's just not the type of consumer that we target. Small electricity supplier (9 Sep 2022): I put together […] a customers' hierarchy of tariffs. So, at the bottom of the pyramid is your single rate tariff that all customers can understand and use. And then as you move up the pyramid, you have your Economy 7s and your heating load tariffs, and into that you might put your electric vehicle (EV) tariffs as well because they're like a switch load. And then as you moved up again, towards the top of the pyramid, you have people with batteries who are really interested in energy. 90% of customers aren't interested apart from their bill, so they will sit on that single rate tariff at the bottom of the pyramid. And then as you move up, when you get to the top 1 or 2%, who are really interested, they like Octopus' half-hourly tariff.

	Small electricity supplier (30 Sep 2022): I think probably the biggest barrier overall that we need to overcome is customer understanding and buy-in in these things. We're pretty geeky in the energy industry, and I don't think customers really care. Consultant (17 Jun 2022): When it comes to customer pull, in most cases, it's definitely still your tech-savvy customers at this point.
View of customer journeys	Large electricity supplier (6 May 2022): What we're thinking about in the design of those journeys is that it's really important that customers have a good onboarding experience where we can engage them at the right times for those buying decisions to link in the TOU product to the car. So, it might not all be done at one point, it might be that we come back to it in the journey. […] for me, the key thing is to land the customer journey and make sense to the customers. The other area we also looked at was things like change of circumstance products, I don't know, a family dynamic might change, a baby might come into the house or people might have a change in lifestyle from a job perspective and could we create dynamic products that the pricing rates were different to reflect maybe different behaviours in the home. […] As we move more into a HHS type of world can we start to tailor dynamic tariffs for the customers to configure their own energy plan really for a week and if you know that you're working from home on a Monday and Tuesday you may be able to do certain things around consumption. We're quite a way off from getting anything in development on those areas at the moment. Large electricity supplier (15 Jul 2022): You have a couple of key moments and the customer journey of getting an EV is an interesting one in terms of insight because assume that you're a three-person household with one car and you switch from an internal combustion engine to an EV. Suddenly that incremental increase in electricity demand means that from your fixed cost base as a household of your monthly budget your biggest cost suddenly becomes electricity because mortgage/rent is first, car rental or lease and then electricity. In the past it was petrol or diesel, and the utilities quite far down. So, you have this important consumer awareness moment – what can I do to reduce this cost and that's where the opportunity comes to lock people into getting smart tariffs or smart equipment thinking that if they do that they're sorted. The same thing applies to heat pump customers because suddenly your gas consumption goes to zero, but your electricity consumption trebles and the key thing is removing the friction. Large electricity supplier (24 Jun 2022): Messages need to be easy to understand […] and something Ofgem always say is to make sure that all your customers can understand what you are doing regardless of their literacy levels. [In a trial like ours] you want to give people real-time feedback when they open the app, you don't want to tell them how they were doing last week, you want to say maybe one hour ago this is how much you've used, and this is how much the sun was shining – you need to give these types of things. Another thing you may want to investigate is how often do you need to give feedback to your customers to keep them engaged? Is it half-hourly, hourly, every day? We thought it has to be half-hourly. Small electricity supplier (14 Oct 2022): You've really got to get under the skin of the customers and understand where they are now. And really, whether you can move them as well, because I think where they are now isn't the place that would

	allow this to work. So, it's not just a matter of measuring where you are now, you've got to think of things, clever things in terms of communications and motivation that will get them to where they need to be. Demand aggregator (14 Dec 2022): There is a journey that people go through when using a technology and we see this with EV owners. Initially, charging anxiety is a big thing because it's a change. But once they've charged a few times, they realised where you can charge, they figured out how to use the RFID cards on public charges, then that anxiety goes away, because you've kind of gone through the change curve.
Equity and fairness	**DR and electricity bills** Large electricity supplier (18 Nov 2022): This is the bit that concerns consumer groups because there were a lot of people who thought they could [change usage], but they couldn't. Because there's a lot of things between 4pm and 7pm, like dinner, TV time, especially children, that's not going to shift. […] And the other thing is also the distributional effect of, you know, you want to not penalise, but you want to cost reflectively charge people who don't shift but you don't want to impact the people who can't shift and that's really tricky. And I feel like the likes of Ofgem and Citizens Advice want to have their cake and eat it because they say 'I'd be great if you did a tariff that encourages people to shift, but the people who can't, they can't be charged more.' And it's like, 'well, that's not how it works. You know, if you want to charge someone less for shifting, someone else has to be charged more. That's how it works. So, you can't have it both ways.' And that's the difficulty actually. […] HHS has the same problem. And we'll see what happens when it goes live. Because let's say you target customers who use off-peak, then you'll be offering them deep discount tariffs. But then the customers who are on-peak for you, you'll have to compensate by increasing their tariffs. Large electricity supplier (26 May 2022): [Events like those in Texas] where customers are suddenly exposed to really high prices result in really bad customer experience and really bad news. And ultimately if we were giving customers that kind of exposure, I'm sure there would be a whole load of fairness queries and complaints and stuff. You're suddenly giving customers exposure to a wholesale market which they wouldn't understand. Small electricity supplier (14 Oct 2022): If you've got a situation where there's extreme price uncertainty, so prices can go up as well as down, you've got the possibility that you actually expose end user customers to huge price spikes, which is exactly what can happen on some of the more exotic products in the industrial and commercial (I&C) market. Demand aggregator (25 Nov 2022): [With a tariff like] Agile you may save over a year, but if you compare week by week or month by month and you can't pay your bill once, it doesn't matter that you save over a year. So, Agile is tailored for people who have a reasonable amount of money, and they have a salary. It's risk-sharing between the supplier and the customer.

	<u>Technology company (7 Jul 2022):</u> I think there's definitely an increase in the demand [for DR products] in people who want to reduce their energy bills because [electricity] is not affordable. **<u>Postcode lottery</u>** <u>Consultant (11 Oct 2022)</u>: [Localised price signals] could lead to a sort of postcode lottery whereby because you live in a constrained street, the network charge when you want to use the network is very, very high. If you happen to live two streets away with a brand-new substation, or new cable or whatever, it'd be very, very low, just based on where you live. Equally, if you are a customer on that constrained road with flexible demand, so, you've got an EV charger, maybe you've got a battery. So, you're lucky because you don't need to use the network between 6pm and 9pm because you can use your battery and then you can recharge it overnight. Whereas then you've got the vulnerable family who's cooking for six children at that time, and they don't have a battery. They'll be exposed to very high charges because they don't have the ability to be flexible, whereas the more affluent customer can. <u>Distribution network operator (13 Dec 2023)</u>: I think one of our challenges as network operators will be this view of fairness and the postcode lottery which I think we're at the take off at the moment, so how fair is flexibility. […] [The decision to offer flexibility tenders] is basically driven by our forecast of demand at each substation. So, we have [confidential number] substations, and each of those gets its own forecast, each of those has its own capacity. And so, where we spot or forecast that it can go above the capacity, that's where we will go out and say, 'We need flexibility in this area.' Now, if that's a big substation, it might serve a whole town. If it's a small pole-mounted transformer on someone's street, it might only serve 50 households, which might not be even like the whole street. So, there you can end up with people who are geographically very close together, but one of them is connected to this substation, one of them is at that substation, this substation has bags of capacity, and they can do what they would like with EVs. And this one, we're prepared to pay Octopus or someone else in order to say, 'Please don't charge that between 5 and 7pm, charge it whenever else you like.' So, depending on how people at Octopus package that onto customers, it could feel quite exclusive. Now, we would argue it's cost reflective. But there is a question about how do you socialise some of these kinds of costs and benefits, which, for the most part is left to suppliers and aggregators to decide. <u>Demand aggregator (13 Nov 2023)</u>: There's a limitation of flexibility servicing by the need of flexibility in the postcode area, specific postcode area, which makes your contribution as a user, whether that's industrial, commercial, or domestic… but if you're not within the area that has constraints that you can alleviate, then you're not necessarily valuable, which means that I can be super happy as a consumer to provide my flexibility, but then if I'm not in the right postcode where the constraints are happening, then I'm gonna be like, 'thank you, but no, thank you,' and you're not going to be paid. But the neighbour across the street is getting paid. **<u>Flexibility capital</u>** <u>Large electricity supplier (18 Nov 2022)</u>: When it comes to any energy initiative, people with big, detached houses are always the easiest, because they have room for

	solar panel, room for a battery, room outside for the heat pump. Yeah, people in small flats are not great. My brother is on Octopus Agile, he's got a giant six-bed house, he works at a bank, but he's got solar and battery. During the summer he doesn't use any electricity, it's all from the battery and solar panels. So, he would classify as a low using consumer. So, these sorts of things you have to be concerned about. But yes, I don't think there's an easy way. And I think the distributional impact of energy is always a problem. Small electricity supplier (27 May 2022): The things that move the dial aren't electrified yet. For instance, heating. Demand aggregator (25 Nov 2022): We're looking at how to support people who can't join in, but realistically there will always be people who can't join. When handholding you actually uncover a whole lot of other problems like social inclusion etc. This is very important, or else only 'energy nerds' can benefit. If you want large scale system benefits, you have to include beyond the tech-savvy. Consultant (11 Oct 2022): Why don't we see more TOU tariffs? There's not much supply of flexibility yet, so, why bother? There's not that much demand for flexibility. But as we get those kinds of assets in households where suddenly lots more of a consumer's energy use is electrified, and that includes their car that they're quite emotionally attached to, it includes their heat for the house, and comfort and so on. That will then drive an encouraging story. So, you now suddenly have demand for these kinds of tariffs to drive those propositions. Distribution network operator (13 Dec 2023): I think where we do have some challenges on the domestic side, is around the demographic of that participating group and the barriers that exist for some people. [We are looking into] what are the barriers to people with low income, lower digital literacy, disabilities, etc, from getting involved in the benefits of flexibility. And I think it's hard to avoid… one of the big issues is low carbon technologies are very expensive. So, if, as a flex user, I'm mostly interested in EVs and heat pumps, there aren't very many to go through from a large proportion of the population.
Automation	**Automated and manual DR** Large electricity supplier (6 May 2022): I do agree with it [the assumption that automation is a pre-requisite for TVT acceptance]. Maybe five or six years ago we did a pilot, and we installed in about 50 to 100 homes a number of devices, things like smart thermostats but also some white goods and installed smart meters and gave customers an incentive to move their usage patterns to out-of-hours via essentially an Economy-7 type product. What we found was there was some benefit, but customers just didn't want the hassle of putting the dishwasher on before they go to bed or put on the timer and then they forget. Large electricity supplier (20 May 2022): The price elasticity and behaviour forming are tricky. We see a strong adherence to load shifting behaviour from our customers, but reality is (and this is true for our customer base or other markets for dynamic tariffs) that what you really need is your largest loads to be directly integrated into the price signal so that your behaviour is just incremental icing on top. In a flat, the largest loads are heaters, dishwasher and washing machine so you

	want those controlled with that price signal being ingested so that you have to consciously override, and that any other behaviour is just incremental. Large electricity supplier (18 Nov 2022): I think until it gets to a point where it can be done remotely, automatically, it will never go anywhere. It has to get to a point where people are… either automation within the home or automation via the supplier is happening at scale, then people get comfortable with it. Small electricity supplier (9 Sep 2022): What you don't want is the customer to have to plug the EV in and then sit there waiting for each half-hour to switch it on and off. Customers don't want to do that. You and I don't want to do that, and we're interested in this industry. There needs to be a gadget. It might be a Google Nest type gadget, it might be an Amazon Alexa type gadget that does it for you, that you just program in what you want, and it will just optimise it for you. But until that exists, I don’t think DSR will take off as much as people think it will. Small electricity supplier (30 Sep 2022): In my experience, customers like things that are predictable or that they just don’t have to think about. So, if you ask a customer to do something, it generally fails and we have a very niche group of customers that will engage, but actually for the mass market it just won’t go anywhere. [We found in] that a trial [critical peak pricing] tariff we offered […] didn’t really get the engagement we needed, and I think what it demonstrated was that, especially in the domestic space you need automation to get customers to really make the most of TOUs. Small electricity supplier (14 Oct 2022): […] either you've got to change people's behaviours, or you've got to automate it. So, the thing about automation is what can you do that could automatically switch loads around? Put EVs to one side, you've got fridges and freezers, which potentially could look after themselves a little bit, but not the ones that are in people's houses. So, there's a massive investment before you can get them doing something meaningful. So, I guess my message from experience is scepticism about getting people to change their habits because that's actually really difficult. […]. You can't predict absolutely in advance when it's going to be a period of stress when you might want people to do something, so you're left with ‘I’ll text you now, would you mind turning things down.’ I'm guessing some people will do that. I've seen evidence of people saying, ‘yeah, it's a good thing. But not because I saw the price signal. I think it's good for the planet, or it might save the UK from going into a blackout’ but not on the price signal itself. […] I think most people, including me, come back to the thought that actually it’s difficult. Automating this is probably a more promising route forward than trying to get millions of people to do the same thing all at the same time. With one or two notable exceptions in history, that's never really happened. Demand aggregator (14 Dec 2022): The behavioural DSR – which is obviously like sending someone a message or notification telling them about something and then seeing how their behaviour changes – definitely has some place, but I think is limited. And when we talk about like different flexibility services, particularly if this stuff gets required [a lot] … If it's a few times over winter, and it goes on the news and people get excited about it, I think that could work. But if you start using this every week, people will very quickly get bored and disengage. Because

	flexibility is going to be required more and more on a day-in-day-out basis to help balance renewables, we think the majority of flex is going to come from automated response, and then what we can do is top it up with behavioural. Technology company (7 Jul 2022): […] for the big loads (EVs, heat pumps) you need automation especially as we move away from predictable peak and off-peak periods as we get more renewables. There have been times even in the previous weeks when on some Saturday afternoons there's been negative pricing. As you move to less knowable peak and off-peak periods you need automation because you can't expect people to keep track of what's going on in the wholesale market. Distribution network operator (13 Dec 2023): I was sold on, 'you need automation to make this work,' [before the 2022-2023 Demand Flexibility Service or DFS] although it's showing from a very small cohort of Agile customers that you don't necessarily need all that… people can get quite excited, at least the early adopters can get quite excited. I guess my new assumption around manual versus automated is it's quite hard to maintain that same enthusiasm around manual that we saw last year in quite, hopefully, quite unusual circumstances of gas supply and Russia-Ukraine. I think the other thing that I witnessed last year was a bit of a sense of community around stuff like the DFS that isn't normal for flexibility I would say. People were talking about it… it felt like you were doing it together. And that maybe added something to just the pure finance or the pure carbon reduction benefits. So, I think that there's something interesting around the social side of flexibility that's I think underdeveloped. Consultant (17 Jun 2022): We're not seeing your everyday customers actually looking to go on these [dynamic] tariffs for the single reason that it is riskier. If you have a dynamic tariff you need to have some type of knowledge in terms of how you consume and how you want to manage your consumption. We're not really in a market right now where that can be done automatically for the customers and so that's not something that will actually be attractive for customers until they actually can get that automatic management of their consumption. When it comes to DSR, it will need to get done automatically or be optimised for the person, especially if it gets to dynamic pricing – it's easier now with just day and night. Consultant (24 Jun 2022): An autonomous system can definitely achieve more energy cost savings than just a behavioural change of the homeowners, because you know when to charge and when to stop and you know what's the best way to operate one of your devices. […]. If no autonomous system exists, if you're just depending on your own behaviour change, I think that will be extremely difficult. I think there is also research, customer surveys, on the internet. I think the revenue you can create from pure behavioural change is much less than an autonomous system because, first of all, from a behavioural science [perspective], people's behaviour is really difficult to change. The peak demand period exists for a reason because people get back home at that time. You can't really ask them to change things when they're not at home. That's why when people are opting into TOU, then they realise that I have to change perhaps 50% of my consumption to the time I don't usually do that at. They will feel it's very complicated, and they will struggle to finish that kind of task. […] There are ways to solve [the problem of people not engaging with DR]. But how to engage customers to change behaviour themselves, to get value from

	TOU, I think you can provide some incentives through the app offered by the energy retailer – it's what we call energy insights, you can just push a notification and say 'okay, you could do this, do this, it will save you this much money, let me know if you want more details on how to do this.' You can do some kind of gamification. Like set up a price or give them medals or badges if they achieved some kind of challenges. And there are already many gamification trials in the UK as well and also all over Europe. Consultant (21 Sep 2022): Whilst there is evidence that consumers will change their behaviour, I think it's stronger evidence that that they need to engage with some kind of automation to make it happen, even if it's simply engaged in the automation step on the appliance so, you know putting a delay on to a dishwasher. And there is evidence from trials that there are ways that you can default to automation that make this much more effective. I think that's what the trials said. So, if you have to opt to delay that's very different from automatically delaying but having the option to kind of override the delay. Consumers typically want the right to override that and say, 'No, I need to drive off in in two hours. I need my energy now.' But there's a big difference in whether that's automatic, or which of those two versions is the default. Consultant (11 Oct 2022): Octopus always pushed much more of a consumer behaviour lens, saying we want to give the consumer choice and expose them to price signals, and then let them do what they want. Whereas Kaluza was basically saying, no, we want to be at the top of the switching site, we'll automate everything. That's it. There were two completely different philosophies. And I think what we're seeing now is Octopus starting to move towards the Kaluza approach with Kraken and realising that the consumers, yes, sure, we want to give them a choice, but the extent of the choice they want to make is opt in and tick a few boxes and forget it. **Customer acceptance of automation for DR** Large electricity supplier (18 Nov 2022): Our customer research told us that you can have [automation] as an option, but it cannot be turned on by default because customers think it's too Big Brother to have something that's learning from what you're doing. […] People are very concerned about what level of data is accessed. And obviously post Cambridge Analytica that's much worse, understandably. Large electricity supplier (20 May 2022): I've never seen any evidence of people refusing automated TOU tariffs of EVs, that's somebody in the industry who has an opinion. We believe that's the direction of travel and if you're saving 50% on your electricity bill which is going up 30-40% every six months at the moment then I guarantee you that people will want that product that is making them a saving. Demand aggregator (14 Dec 2022): The majority of what we do is controlling EV charging to be automated, so it's more of a fit and forget solution. You just set up the app, and then we will automatically shift your load for a DFS event or for other stuff happening on the grid, so the behaviour change required is very different. It does not require active participation in the same way. What it does require though, is understanding and trust at the beginning, and understanding the value of doing it and the benefits and trusting a third party to manage something on your behalf. So

	that's the big hurdle. But the big hurdle is like more of a one-off thing at the beginning. Consultant (11 Oct 2022): I think that what I've observed in the last 10 years or so is everyone thought that getting consumer buy-in would be a big barrier, but what I think was observed is yes, consumers aren't going to go around and switch appliances on and off, or lights on and off for a £50 a year saving or £100 a year saving, but they'll switch for that. And so, if you can switch to a different supplier who's got a proposition that automates things for you, then you'll do that, and you won't blink twice.

Annex 2: Markets theme and sub-themes

Sub-theme	Respondent quote
Value of DR to the system	<u>Large electricity supplier (5 May 2022)</u>: I think there will be a use case for TOU especially when you think about renewables and adjusting demand according to supply. [...] It's waste if there are one million batteries in a country and they're not being used. <u>Consultant (11 Oct 2022)</u>: From a whole system perspective, if we consider the cost of renewables that you absorb because you don't have enough network capacity, we might say we've kind of clipped our own wings [by not building more networks]. We've worried so much about a really efficient build of the network, that we're now in 2030, we've got all of this renewable generation, we can't use half of it. And actually, the cost of non-utilised generation may be much, much higher than it would have been. […] You need enough network capacity in the right locations to enable you to make the best use of the generation. So, how are we going to do that? And doing it in a way that gives customers choice, via their service providers, takes you down a route of variable pricing. <u>Distribution network operator (1 Dec 2023)</u>: Flexibility is a societally important thing; it's an ethical question of who should pay for that [network] reinforcement. So, if we reinforce that network, and it's not going to get used for 50-60 years, it's probably unfair for us today to pay for that reinforcement. <u>Distribution network operator (13 Dec 2023)</u>: Historically, most of our flexibility has been to reduce demand. And over the last six months or so, we've been increasingly using flexibility not just for reducing demand, but for actually soaking up excess renewables in parts of the network where we have abundant solar and wind that otherwise would probably be curtailed.
Value of DR to customers	<u>**Customer benefits and costs from participating in DR**</u> <u>Large electricity supplier (18 Nov 2022):</u> Quite a few customers did [make a saving on a TVT]. Yes, they made savings, but we realised that to motivate savings even at 99% uplift in prices isn't always enough. Yeah, because within day it's still pennies, that's the problem. <u>Large electricity supplier (5 May 2022):</u> We struggled to get to £50 per year [saving from a lifestyle tariff] but you can change that. I can obviously set the price to whatever I want and the two rates – the saving is based on the difference between the two. But purely on costs, if we were to say we'll just pass the savings onto our customers, the savings would be tiny, £20-30 per year [later clarified the average saving per customer was £40]. So you're actually selling the single rate because for £30 you don't need to think about anything. You need at least £100. <u>Large electricity supplier (6 May 2022):</u> Savings [on a TOU] were relative between how much customers were saving and how much they were consuming. I think we engineered it to be in the region of about £40. I would say that you need to make some savings, and internally we're thinking £50-60 is something that's worthwhile, that's £5 per month, so we tried to get up to that level but I think it

	was actually closer to the £40 level when we were actually able to do the calculations and say we can take on this much cost. […] We present these options a lot to the customers but people even though they can make some cost saving it's just not interesting to them. Large electricity supplier (6 May 2022): Customers really needed to have a real sense of the saving that they were gonna make in their pocket and there might have been a £50 annually to do a lot of these things and they went like 'oh, I thought it would be more like hundreds of pounds and to be quite honest I'm not gonna do that for £50 and that was a lot of the sentiment we got from some of those pilots. Some customers seemed really engaged and really kind of embraced it, but I would say that they were probably in the minority in that group of customers that we did the pilot with. […] This magic £50 that people talk about in terms of saving, if that became £100 or even £80 would it actually encourage more customers to develop those behaviours? Large electricity supplier (15 Jul 2022): There's another point on the financial incentive which is the behavioural disconnect between the fact that this is actually the unit rate that you are paying, so there's a disconnect over what this means for individual daily or hourly consumption v. annual consumption because you are not saving a lot of money now, but imagine if you were doing it more throughout a year – needs a bit of mental gymnastics on how you portray that. […] Bill reduction must be in the £50-100 range to be worth it, or you could do a day of free electricity. Small electricity supplier (14 Oct 2022): I think the changes to infrastructure, just doing more rates, it's some change, but it's doable; but 'can you make that meaningful to the customer?' is the challenge there. Demand aggregator (13 Nov 2023): If you're trying to build at a national level that awareness and consumer participation and active engagement in the network […] then there's the need for the government to still subsidise [DR], similar to Contracts for Difference for solar, or feed-in-tariffs where there's quite a lot of support from the government to make it happen until it was mature enough to be profitable and cost efficient. Distribution network operator (13 Dec 2023): There's something about free electricity that gets people quite excited. Yes, people are interested in the price spikes and avoiding those, but the real excitement is negative pricing. So, I think there's another gateway into flexibility around demand turn up, as well as demand turndown. Consultant (24 Jun 2022): I think customer interest is never a problem. Every time we ask people, they are happy to save their energy cost, to create some positive impact to save our planet. But I think the key problem is to get them to pay for that. We tell them they have to pay an extra £100- 200 to add a system on top – you have already paid thousands for EVs, for heat pumps, you now have to pay the extra cost for that. People are not really prepared for that.

	Lifestyle tariffs Large electricity supplier (5 May 2022): We took our smart metering portfolio and looked at how they use their energy during the day and then did a bit of data science and came to 10 distinct clusters of consumption. […] There is a group that start their evening later (they came back at 7 or 8pm vs 5pm for most people) and they could benefit from a tariff that accounts for that because energy is most expensive between 5 and 8 […]. If you move your consumption out of those 3 hours you can benefit and they could benefit without doing anything, they just carry on with their normal life. We looked at that, but the savings were very small, we couldn't settle it and then there's a chicken and egg problem because that's their current lifestyle based on their current price. If I change their price, they will adapt their lifestyle so I actually don't know how much they can save because I don't know what they will do when I price the tariff different, so I can't quote them. How do I quote a TOU if I don't know how you're going to move your consumption? We didn't have to look at the hedging so I don't know what it would do for the hedging strategy. If they move their consumption my hedge is going to be wrong and until they move their consumption, I don't know what my hedge needs to be so the supplier will have to carry that risk. [In terms of quoting], I can't promise my customers a £100 saving and then they don't save £100 – the regulator would have a problem with that. And then how can I substantiate my claim that the customer would save £100 when I don't know anything about them. Large electricity supplier (6 May 2022): I know there's behavioural economics and nudge theory that would say you can nudge people to change their time of consumption, but we also appreciated that people are quite regimented in the way they consume electricity. So we wanted to create the ability to have a tariff that would meet the customer's behaviour, help them save a bit more money, hence have a warmer feeling towards our brand and hence they're more likely to stay with us and they continue to use TOU going forward. We were less down the nudge route whereby we wanted to get people to convert. We made it very clear you could, and opportunities were there, but it was more about how we can help people save money just by using the profile that they're on, that was the initiative we took. Large electricity supplier (6 May 2022): Our EV portfolio will be the lead in terms of TOU, I'd like to think we can then develop some lifestyle tariffs that work for customers. Large electricity supplier (18 Nov 2022): I think the more technology comes along, the more you can be very specific about it. You know, there's always been talk of like the baker's tariff, early morning cheap or maybe target nightshift workers, who have a different usage and so on. You know, let's be honest, people who work in late shifts are often some of the poorest people like cleaners, etc. So, you know, that could benefit them more, which is good news. Small electricity supplier (27 May 2022): I definitely do [see a future for TVTs] and I think it will probably be more lifestyle tariffs, and you can probably market more to individual types of consumer needs, like a professional couple that aren't

	using energy during the week or lower costs on the weekend. You might be if you're home during the day or you might have home working tariffs or whatever, things that spoke to the way that people were using energy and also whether they got electrified transport. I think all of that stuff will extend and it will probably help to make the marketing a bit less generic.
Value of DR to commercial actors	**Profitability of DR for the business** Large electricity supplier (26 May 2022): There's a wider point that creating more distributed generation and battery capacity in people's homes, in the retailer's space, moves that market power away from generators. So, there should be an incentive for us to offer some sort of these tariffs that benefit customers and disrupt that kind of market imbalance. In simple terms, batteries mean that rather than having to sell back our energy when we're a distressed seller and buy when we're distressed buyer, we can store that ourselves and then use it. For a retailer such as us having lots of customers who have batteries or EVs that are flexible that we can dispatch means that we can do that and manage our costs effectively and optimise that ourselves without being the distressed buyer and the distressed seller in the market. Large electricity supplier (20 May 2022): We're moving to a situation where actually the wind blows all the time, and the sun shines or it doesn't shine, and you need to change [the system]. Using energy can make or not make a supplier money, but actually making sure the customer uses the energy at the right time will be the most profitable. So, in the past, it would have been more profitable to make them use as much as possible because you can add a profit margin onto that. Now it will be much more profitable to say shift your usage. If we can convince customers to move consumption out of peak and into an off-peak time, we make more money than getting them to use more in the off-peak time. Large electricity supplier (24 Jun 2022): The trial went well; we managed to make it work even during Covid time. And after the end of the trial, we were reporting of course with our commercial team to present the results, the updates and all that. In this specific case, although it works and it's very interesting, pre-Covid the business case was not very strong because back then prices were still very small. I was assuming my wholesale price to be £50/MWh, it's probably now £200-300, so numbers need to be updated. Back then this didn't progress any further mainly because the business case was still not there with those prices. Large electricity supplier (20 May 2022): I don't see access to data as the main blocker in this space. I think it's good access to revenue streams. Large electricity supplier (6 May 2022): We really don't believe that in the long-term there was the full benefit of [TVTs] because I don't believe it makes much money if it ever does. Large electricity supplier (6 May 2022): I'll be honest, when we looked at what offers are out there, there must be a significant amount of subsidy in some of those products because we can't compete with some of the bottom-end market EV products at the moment, unless someone's procured energy some time ago that's at a much better position, so it's really hard for us to compete.

	<u>Small electricity supplier (27 May 2022)</u>: The benefits for suppliers of being able to compete in this market depend on their wholesale arrangements. So, how much exposure you have to the wholesale market determines the extent to which you might pass through wholesale price fluctuations. <u>Small electricity supplier (14 Oct 2022)</u>: I don't think that TOU tariffs in the future will play out much differently for prepayment customers as it will a standard customer. But […] there are great gains to be made here at some point in the future. The demand usage profile of prepayment customers compared to a credit demand usage profile is a little bit flatter, so it's not quite as pronounced. That's because many customers are at home all day and don't go to work. So, for many customers there's not that 6 o'clock / 7 o'clock spike in electricity demand. There is still a spike because many customers do go to work, but it's certainly not as many proportionally as credit customers. But nonetheless, even though the usage profile is flatter, there is still a spike. And there are still peaks and troughs all over the place. And for us as a business if we could encourage behaviour, if we could convince people to not do their washing at 7 o'clock at night, but to get a time and do it in the middle of the night or whatever, if we can encourage via TOU tariffs a different behaviour from our customers what it will mean to us is that our purchasing of the energy costs will be disproportionately lower because we'll be able to buy just blocks of energy which are cheaper. […] So, there's definitely a strong future in this in principle. <u>Small electricity supplier (30 Sep 2022)</u>: From an operational perspective, the challenge we have with TOU is being able to provide it in a really scalable way and looking at the EV tariff we've had so far, there's quite a bit of effort that goes into getting customers smart, getting them on the tariff, getting them billing well compared to someone who is just on a traditional tariff. We need to find a way to make it scalable and efficient. <u>Demand aggregator (13 Nov 2022)</u>: Raising private investment [during the pandemic] was so hard because obviously the investors were so risk averse to something that was so new, like 'what? are you telling me that you're going to switch fridges and freezers or EVs or heat pumps, and that's going to work? Consumers are never going to engage, consumers may be interested for a bit, but then they're not going to care anymore,' and all these kinds of things. It needed to be supported from the government at that time. […] We tried to approach energy suppliers at that point, but suppliers were not interested, they were like 'yes, we know that DSR is a thing, and it will be, but this is probably in 10 years' time or 5 years' time, not right now.' And at that point, energy suppliers were either not interested because that didn't align with their investors' plans around meeting revenue plans, and so on. Or they were just trying to survive, because they were just going bust and all they wanted to see was how they can cut their costs, basically, how to survive. Adding another layer like introducing DSR to customers was just not a solution. <u>Demand aggregator</u>: (25 Nov 2022) There is an assumption that Octopus Agile is a loss leader, some people say that because you can't settle it, it's so competitive, so they're probably not making any money on it. They're just proving technology. And Octopus is an interesting competitor because they are a software company,

	they are not an energy supplier, they want to sell their platform rather than supply customers. <u>Consultant (21 Sep 2022)</u>: Before [the price cap], the competition was all based on low prices from small suppliers who proved to have not very sensible business models, and Octopus was kind of doing its thing on the side that was only a novelty thing. Who knows whether they made any money out of it? <u>Consultant (11 Oct 2022)</u>: It's too much of a risk to the supplier if they can't control your demand. Because you as the supplier, you're exposed to the tariff, you can give incentives to your customer but ultimately, if they don't move, you know, yes, you can pass some of that through, I guess. But it depends on your proposition. Now, for a supplier, if I now have an asset like an EV, and I can control that asset, now I have control over the TOU over a large proportion of your energy demand. Now I'm not exposed as much to the risk if you're not doing what I expected you to. […] There's no need for TOU tariffs until consumers have got these big energy hungry assets. And there wouldn't have been much appetite for suppliers to be exposed to these risks until they had control of these assets in a flexible way. **<u>Impact of DR on customer retention and attraction</u>** <u>Large electricity supplier (18 Nov 2022)</u>: The [confidential TVT] was definitely seen as a [customer] acquisition tool. And EV tariffs we can also see as an acquisition tool. Because the number of EV tariffs out there is fewer than the number of standard tariffs. Especially in today's world where nobody is switching. […] At the moment, EV tariffs may be the only thing that people switch for. So, it could be very much an acquisition tool in today's market. <u>Large electricity supplier (15 Jul 2022)</u>: We have a pretty high customer lifetime value and a pretty low churn rate, especially in comparison to industry average. I think fundamentally though, the attraction strategies still come down to value for money. That doesn't mean being the cheapest, but it means that combination of incredibly great customer service, simplicity, but also value for money. And then I think it's important that value for money does not equate cheapest, but you feel like what you're getting is worth it. <u>Large electricity supplier (6 May 2022)</u>: It's more push [rather than customer pull for TVTs] at the moment. When customers have an EV, we're now getting that trigger when customers are saying what tariff have you got for me but other than that I don't think there's a massive awareness of what can be brought through TOU. Yes, you've got that really small number of super engaged customers that are probably all with Octopus. We do get some engagement but it's such a small percentage of the base, it's not mass demand by any stretch. <u>Small electricity supplier (27 May 2022)</u>: We started to see some demand [for TVTs], people acquire EVs and want more off-peak energy, but there's nothing that isn't catered for them from off-peak [i.e. Economy 7]. So, if they know that they've got 7 hours of off-peak energy, they'll use that to charge their car. That's enough.

	Small electricity supplier (30 Sep 2022): I think TOUs are both [an acquisition and a retention tool]. I think as more and more customers get EVs they want to charge up at a cheaper rate, so I do think it's going to become more and more of a hygiene factor, where customers just come to expect it. Small electricity supplier (14 Oct 2022): If we had a customer on a bespoke TOU tariff that they thought was great, I don't think they would leave us regardless of really what the price was, for the most part. I think the price differential would need to be very significant. I think once the customers get settled in with a little bit of a technological bind, they become very, very sticky indeed. As for the attraction strategies, […] at the moment we're not actively selling, there's no sales forces out there driving sales [due to market conditions]. The only sales we're getting are just where people call us up or they go through our website. But under normal circumstances we had a really strong sales force out there selling the smart meter and how smart meter was going to change our customers' lives and specifically the fact that a prepayment customer with a smart meter can top up from the comfort of their own home, doesn't need to go to the shop when it's pouring with rain and of course our salesforce will paint that picture of the pouring with rain, hail and there's no credit on your meter and you've got to go to the shop but with a smart meter you don't need to, you just sit and press the button. So, it would be similar with any TOU tariffs if we can find a good one in there, whether it be cars and show a great saving and changing behaviour. It would be a very strong proposition for our salesforce. So, there would definitely be big wins for us as a company.
Market barriers	Large electricity supplier (15 Jul 2022): Currently National Grid Electricity System Operator (ESO) [now National Energy System Operator or NESO] have no tool in their tool kit to shape demand. The only tool they have is to turn up generation instead of turning down demand. [There is a trial] turning demand down and looking to understand how reliably this can be done – is this resource category reliable enough that it can be baselined and that you can then scale it up and industrialise it and then how do you settle it? Large electricity supplier (26 May 2022): I would argue that generators have a higher degree of market power than retailers do in the wholesale market. Two reasons: generators are relatively highly capitalised and can make decisions about hedging or not, they have choice over when to sell their energy, whereas arguably retailers are very low margin and have less choice as to when to buy their energy. Because as soon as you commit to a customer if you don't go and hedge that energy, you potentially are taking a loss. So, you're always the distressed buyer or the distressed seller. If you're a generator, you go 'well if I wait and see what the outcome is either the price goes up, and I sell it for more or the price goes down, and I just don't generate.' So, I work in the retail side now. I've worked on the generation side in the past; they don't give a shit because their assets are worth billions and billions of pounds. The shaping a little bit more here a little bit less is low millions in scale, they just don't think about it because they're worried, they've got bigger fish to fry. Demand aggregator (13 Nov 2022): It's really hard to cope with all the administrative burden and to deal with, for instance, even with the demand

	flexibility mechanism, dealing with the duplication, whether the people knew or not, and then go into your portfolios and trying to automate that, it's such an admin and cost intensive thing that maybe only big aggregators or big suppliers were going to be able to cope with because basically, they don't deal with it, they're like 'ok, we're just going to still pay those customers, and we're just not going to use them.' Whereas those customers for a smaller company mean quite a lot – even if you have to drop 1,000 users or 100 users, that's quite significant. […] Distribution network operator (13 Dec 2023): One of the things we realised was that a lot of types of flexibility found it quite difficult to commit any availability six months or a year ahead of time, particularly on the demand side where that's just much harder to predict. There was a lot of flexibility that was saying, 'Well, I don't know what other options I might have, I might be able to sell on the wholesale market, I may be able to sell to National Grid. I don't know that. So, if you're asking me to commit now, I'm gonna give you a price that's really high, because I don't know what I'm missing out on.' With day-ahead it's much clearer actually how people should use their flexibility for the greatest reward. […] I mentioned there being lots of silos and lots of small pots of money and I think it's a real challenge stacking those back together. And that lots of companies have talked a good game over the last few years, but the reality is that even the most sophisticated ones are only achieving part of the value that they ought to be able to. And for the most part, people are not that sophisticated and they're therefore providing maybe one or two services and in a relatively risk-averse way, because the rules on stacking aren't clear, because maybe the coordination between flex buyers hasn't been good enough. So that's an area where we've been trying to improve things and develop a deeper understanding of what National Grid is trying to do and work with them in product design to make sure that actually we have lots of different flex products that they can fit together in a neat way. […] There is a challenge around value, where for a lot of people the rewards just aren't that exciting financially. Particularly if you think there's going to be some complexity or some risk to your operation by participating. And that's challenging, I'm definitely not in the world of like, 'we should just chuck more money at flexibility.' But we are trying wherever we can to show a sharp, cost-reflective signal rather than average things out and therefore have it be unattractive to everyone. […] So, if you take the DFS example, National Grid wants to reduce demand, because they might not have enough supply at a given time. We want to reduce demand, normally, at very similar times, because we might not have enough network to move the electrons around. However, because of the rules of the services they kind of fight each other, and so National Grid's rules for DFS will say, 'actually you can't participate in other services. You need to decide at the start of the winter. Are you a DFS bit of flexibility? Or are you some other thing flexibility,' which is unhelpful, I think… forcing that binary choice and locking someone out of opportunities that they could participate in. So, there is an element of competition here. But also, we and the ESO have what's considered reasonably strong incentives for whole system optimization. They're perhaps not strong enough. So we tend to have our priorities, they tend to have their priorities which is understandable, but I think where sometimes things get

	lost is that we need to do things in a slightly suboptimal way, in order for the overall cost of the system to be less. Consultant (24 Jun 2022): It's easier to achieve some home level values like self-consumption and TOU tariff optimisation, but it's super hard to access some kind of grid services like the flexibility market, the ancillary services, etc. When we say flex, it is a really big market because there will be ancillary services, capacity market (CM), so different types of services depending on how fast the load you control can react to the signal. They can make money for themselves, but it's really difficult to share a small proportion with the homeowners. Most of the flex use cases are quite niche today. Most people are still trialling and experimenting how to explore that value stream. It's super difficult for residential assets because you have to have a certain scale of products connected by your system to achieve the threshold of the capacity limit for that solution. But this context is changing because we're seeing more and more large loads installed in the homes. So that's why demand side flexibility especially for residential is becoming a hot topic in the recent two or three years. Just an interesting movement of the trend.
Coordination and alignment between commercial actors	Large electricity supplier (5 May 2022): The price comparison websites aren't set up to do TOU – so you couldn't go on USwitch and get a quote for TOU, it's just impossible and that's one of the largest acquisition channels, so that whole thing is not set up either. They don't have the capability to do that yet outside of the Economy 7 and car charging space. Large electricity supplier (18 Nov 2022): I live in a block of flats, and I have a parking space assigned to me. And when I asked them If I were to switch to an EV what would I do, the service company had no idea. They were like 'get one installed', but like no, you need to know is there three-phase supply there, how do you bill it to me and not the rest of the flats, you know all these basic things, but they have no idea. Small electricity supplier (30 Sep 2022): The other [barrier] is some of the Data Communications Company (DCC) adapter services that suppliers use. You've got big players like [confidential company name]. If those adapter services are not set up correctly to be plugged into billing systems, you may actually lack the ability to send and receive signals to collect readings on a half-hourly level and then actually be able to bill them and settle them. So, Kraken is only one part of the equation. Small electricity supplier (30 Sep 2022): Suppliers have been looking at agile tariffs probably for a few years now, but I don't think distribution network operators (DNOs), it doesn't sound like they've been doing that. It sounds like they've tried to load shift without the suppliers' consent or buy-in, and they got limited traction or results from it, and now they're realising they have to get a supplier. [They load shifted without the supplier in the non-domestic space] by trying to engage with businesses in turn down events. But the manufacturer could be penalised from the supplier from load shifting. So, it all has to be joined up. Demand aggregator (13 Nov 2022): The other barrier I'm flagging is the variability of flexibility markets across the different DNOs and the fact that if you try to play into that market, you're going to have to have at least six different

	relationships, and probably at the moment at least six different ways of working. There isn't a one size fits all. And I know the ENA [Energy Networks Association] is looking at this and trying to standardise it and Ofgem are trying to standardise elements of data best practice, but it's not there yet, it feels like that's a long way away. Even if these platforms coexist, which they do at the moment, and even if DNOs or distribution system operators (DSOs) have their own market platforms, what needs to be standardised is the process of procurement such that no matter which platform it's done through, they can have the same process that flexibility providers can automate and adjust and adapt to their systems. Distribution network operator (13 Dec 2023): I think there's a complexity issue with flexibility that we've ended up with a lot of different silos, different products, some of which are supplying different network operators, but a lot supplying different parts of National Grid, which is quite daunting for people to understand the rules and where to start, how much they're really going to get paid etc. Technology company (13 Nov 2023): There is more conversation to be had on whose role it is to engage with the customer? Because the retailers see it very firmly as their role. There's actually three groups that would like to do this: the retailers want to do it, or some retailers want to do it, Octopus being the obvious one; the networks would want to access the flexibility, but then you have third parties as well, who have direct relationship with the consumer, you know to sell them kit-services, possibly behind the meter, and yet, I don't think it's clear at the moment, whose remit is this or how do you engage on that? Therefore, if an end consumer has engaged with party A for that flexibility service, can they also then engage with party B at the same time? And how do you resolve conflicts of interest? I don't think that's clear at the moment. […] It's still not clear how the role of FSO [Future System Operator, now NESO], DSO, the regional planner is going to play out, how much scope are FSO going to have in this. They've made noises that they're not comfortable with central platforms, but they haven't said what they *are* comfortable with. Consultant (25 Nov 2022): Sending the right data flows is reliant on an incredibly antiquated system (from meter operator to data aggregator etc, the codes you need for that – the whole process is very cumbersome. Consultant (17 Jun 2022): There's a question of, if you're automating your car for example, with the prices of EVs and then you're also automating your heat pump for the price of EV if it's not connected and talking to each other, they're both going to look at the price signal and go 'oh, the price is low here' and they're both going to go for that which is not something that can be done. Because it's just two big loads in the house. It's just not going to work. So, there definitely needs to be communication built for the various assets. At this point in time, I think just for the EV charge points, there's 100+ EV charging points (not just in GB) with each having various types of communication. So, there's a lot of bringing everything together that needs to be done. The best way to say that is we have a lot of asset optimization, but we don't have energy systems yet. It's more individual things. There's just a lot of different hardware manufacturers for EV charge points and each of them are kind of their own thing. So, some of them are going to be using

	APIs, some of them are going to use direct communication through internet or something. Consultant (24 Jun 2022): It's very difficult to achieve HEM systems which can control multiple loads, rather than appliance optimization because there is an issue of interoperability today. Most of the different loads have their own language to speak, and within that market every brand, every company has their own proprietary protocols to be used. […] People want to have a solution that controls most of their loads together. They don't want several apps; they want one app to control everything. So, if their EV charger app can also control their battery and to control their PV that will be definitely more appealing than those that are not able to interact with other solutions. Basically, if we want to create more value, so you have a TOU, but you only control your EV for arbitrage from that TOU, it's definitely less than the value we can create if you can control more assets together to get their value.

Annex 3: Policy and regulation theme and sub-themes

Sub-theme	Respondent quote
Incentives for firms to offer DR	**<u>Market-wide half-hourly settlement (MHHS)</u>** **The value and timing of MHHS** <u>Large electricity supplier (24 Jun 2022)</u>: This is the time to send real [price] signals to the customer [implicit DR], rather than just switch it on and off [explicit DR]. But it's not there [implicit DR] because we don't have HHS for residential customers. […] There is no point for suppliers to invest before HHS is mandatory. It is an investment because you know, at the moment it's blended, it's based on aggregation and averaging. <u>Large electricity supplier (18 Nov 2022)</u>: Nobody knows how [MHHS] will play out. The issue that you have is very chicken and egg. So, we as suppliers are saying, 'well, you know, there's no incentive on us until MHHS comes along' but then Ofgem is saying 'if we bring MHHS that will give you the incentive,' but it's no guarantee suppliers will do that [offer TVTs]. That also depends on customers being willing to take such products on. If we go, 'okay, we've got HHS, we can see what you're using, we want to give you a special tariff that gives you a discount, etc.' Will customers go through it? I don't know. […] My understanding is that there is a red-amber-green system [for using the distribution network]. Yeah, it's not that strong, but we're in a world where we can't really pass that cost through without HHS. It almost can't be too strong right now because the whole point is it incentivises suppliers to incentivise customers to shift load. Well, if we have no way to incentivise customers then charging us more isn't gonna make a difference. […] Let's say, HHS came in, and you had very peaky network pricing signals. Now, technically, as a supplier, you could choose to pass all of that through to customers to say, 'this is when it's expensive, this is when it's cheap, it's up to you to move your load,' right. But what will happen is all the customers who don't want to or can't, will just switch to someone else. They won't stay with you. Because they'll be like, well, what's the point? Unless everyone's doing it at the same time, I don't think it'll work. <u>Large electricity supplier (6 May 2022)</u>: It's not only just necessarily about increasing the money we make. What we are genuinely worried about is being left behind in terms of the shape and profile of customers that we retain. I think eventually HHS will redesign how we look at value of customers. So, a standard profile today where customers are using 6am to 8am and then 5pm to 7pm, that sort of model is a very standard profile, but we may need to look at how we target the right shape of customers to meet our settlement objectives and our solutions and innovations as well. […] Obviously, MHHS is expected to become mandated by 2025 if it will happen. I'm not convinced that will happen. <u>Large electricity supplier (20 May 2022)</u>: [Hedging] is the same as insurance companies who price-risk premiums to predict behaviour, that's what our job is as future retailers. And when MHHS comes in, that's what you're gonna have to do. Every customer is gonna be priced differently and you're going to have to figure out and forecast that.

	Large electricity supplier (20 May 2022): I think [TVTs] will take off through MHHS. When that gets implemented, we'll be forced to do something. Suppliers will be exposed to their customers' individual profiles, and they'll have to reflect that in some way. Small electricity supplier (9 Sep 2022): MHHS will unlock TOUs for everyone. There are some companies who are already in this space who already have TOUs. We're learning from that, we'll come along once the systems are in place to do that. Demand aggregator (13 Nov 2023): Three years ago, there was even less of an incentive for energy suppliers to give incentives to users. Because it doesn't really matter the time of day when you use if you're going to be settled by profiles anyway. So even now, the incentives are not there. Consultant (17 Jun 2022): What's lacking at this point, and what needs to be changed is that currently, suppliers don't want to actually put customers on TOU tariffs, because they're still being billed on standard curves. And so, what's happening is that if their customers are billed on standard curves, and they're being billed on standard curve, then you don't really care when anybody consumes because you're just matching those two curves. But if you start to actually change the curve for the customer while not changing the curve that they're [the supplier] being billed on, then you're gonna get these kinds of differences which suppliers have to take on and it just cuts on their profits by doing that. And so, only when you actually change the market in a way where retailers can actually give correct actual consumption curves, and they get billed on those actual consumption curves of the customer, then it's more valuable to actually offer TOU. Until that happens, it's just not really too valuable. Consultant (11 Oct 2022): Nothing was possible until smart metering and then HHS is a barrier. Technology company (7 Jul 2022): I think [suppliers] are waiting for MHHS. [...] They haven't got the systems that support it at the moment, apart from, say Octopus, therefore [other suppliers] just say ok, rather than making changes now, we're going to have to do it when HHS has come in, so we'll just wait for that. So, beyond that whatever TOU tariffs they are offering will be a kind of gimmick where they're not actually settling based on them. […] There's again that question of how long they are going to wait. Is MHHS actually going to happen in the timescales that Ofgem are talking about because everything is always delayed. […]. When it's mandatory, then you're going to be in trouble as a supplier if you don't have knowledge of what the actual usage of your customers is, and the impact of people moving away and coming back to you i.e. the ability to shape it and reduce balancing costs. **Costs and benefits of elective HHS** Large electricity supplier (6 May 2022): We need HHS as a key piece and at the moment we haven't gone into the elective settlement process with any real volume. […] We're starting to turn that corner now and actually we've got [elective] HHS on our roadmap in the next 12 months. […] I think understanding a customer's energy profile and need and being able to then almost in the background match the right pricing to that and link it to the settlement and the value it will almost just be generically getting them the best deal; so, it might not be overly apparent that we're

	selling this TOU product but what the customer will benefit from is that value. […] So, I think it's going to help us because we will have to target and retain those types of customers. So, it doesn't always have to be all singing all dancing behavioural stuff or solutions. Yes, there's an element of that as well but some of it is just about driving the right value in terms of pricing and settlement. <u>Large electricity supplier (18 Nov 2022)</u>: There's a financial case for doing [elective HHS] and if our old [IT] systems had allowed for it, we probably would have done it too. Let's be honest. It makes sense, but at the same time, the question is…I don't know if Ofgem have a view on that, whether that's acceptable or not. To be fair, you're reflecting [customers'] costs. The only downside is you should be doing to all [the customers]. And then the question is, should you then be passing some of that savings back to the customer? And I don't think anyone is. […] A lot of the barriers to elective HHS have gone. But there's still some there. Obviously, there's a cost. So, for example, the people who take the data, the data collectors and aggregators in electricity who put that data in settlement, some of them are not qualified as half-hourly. So, they're technically not able to do that. So, you have to find a half-hourly data collector and data aggregator who charge more. So, there are costs attached to it. And there's different data flows and so on. So, the issue is, you have to decide: is the elective HHS cost worth it for the benefit that you're saving your customer? <u>Large electricity supplier (20 May 2022)</u>: Because of the way it works, half of customers are better off settled half-hourly, and half of the customers are better off profiled because the profile is set at the average. So, half customers are better than average, and half are worse than average. If we encourage someone to shift their load, but they were already in the bad half of that curve, we don't get any benefit from them shifting their load, because we still have to settle them based on the average profile. So, if they're super peak-y, and they then become average-ly peaky, we don't get a benefit from that because we still sell them to the average, but we might have to incentivise the customer to take that behaviour change, so that would cost us money. So, in the elective sense, that's a barrier at the moment. When we move to market wide, they will be the best customers, the peakiest and the most expensive, so we'll get the most benefit from making them go from extreme to average. <u>Small electricity supplier (27 May 2022)</u>: There's the option right now to put customers into elective HHS *if* you've got the capability to do it. <u>Small electricity supplier (14 Oct 2022)</u>: From a hedging strategy point of view, [elective HHS] could be significant and very beneficial; and the same for the risk. <u>Small electricity supplier (30 Sep 2022)</u>: If you have a demand forecasting system set up on industry settlement profile and then you move to a half-hourly profile, let's just take solar generation for example, you're likely to get a very different profile and potentially much bigger imbalance risk initially from switching from an industry settled process where it's predictable to a HHS profile where you have to do it on mass to actually smooth out that load and get more predictable load. <u>Technology company (7 Jul 2022)</u>: Until everyone is doing HHS, if there is an option to settle on a profile it's just easier because you know how many customers you have, you know what their usage is and you can work out what the half-hourly

	use is that you need to buy, you've probably been doing that for years and you know how to keep your balancing costs quite low, but if you then shift customers across to HHS then unless you've got a very good way of estimating day to day what the usage is going to be then you can open yourself up to balancing costs which can be quite high especially at the moment. So, I think that's what is preventing suppliers from doing it, it's just a risky thing to do and it can sum up to quite high balancing costs. […] There are some companies who are already running analysis on suppliers' customers to save money. Because at the moment if a supplier has half-hourly data for customers, they can segment them and settle them on a half-hourly basis. They pick the off-peaky customers and shift those to HHS and save money without telling the customer. There's a tool that allows suppliers to do that. Not sure how many suppliers are doing that, but it seems an easy first step. [What prevents suppliers from doing elective HHS is that] if you settle on profiles, it's really easy to predict what your customers' usage is going to be; but if you shift people to HHS and suddenly things change then you could be subject to quite high balancing charges. **Time reflectivity of electricity bill components** Large electricity supplier (15 Jul 2022): One of the big blockers to making TOU tariffs profitable is if you look at the cost stack, for any retailer, the only really variable element is the wholesale commodity product cost. All of the other elements of the cost stack, the levies, the grid fees, whether it's distribution or transmission, are just not dynamic enough so they don't reflect benefits clearly. […]. Large electricity supplier (20 May 2022): Distribution-use-of system (DUoS) has three separate rates at three different times: the green rate is low; the amber one is a bit higher than that and then the red rate is going to be 10 times that. So, that's one of the charges. The second one is transmission use-of-system (TNUoS) charges for transmission – for domestic non-half-hourly or all domestic between 4 and 7pm you get charged TNUoS and outside of that period you don't so that makes a spike in the signal and that's why we focus on 4 to 7pm. The third one is capacity mechanism charges, and they only apply between 4 and 7pm in the winter, I think. So, all of these charges stack up between 4 and 7. It's quite a blunt instrument to be honest, it's not great to measure dynamic-ness. Outside 4 and 7 the variation is due to changes to wholesale costs. It's a lot spiky-er on a day-by-day basis. Small electricity supplier (20 Sep 2022): [The price signal] has got better with the introduction of the red and green distribution pricing on DUoS. So, that has helped. Obviously, that's going to be subject to an Ofgem significant code review (SCR) soon on DUoS pricing, so we'll see what comes out of that SCR. The one they've just done, the little targeted charging review, has sort of moved costs away from unit base to standing charge base. So, that sort of goes against the TOU philosophy. Especially on the TNUoS side, on the transmission side. So, there's no incentive. […] If they want to encourage TOU, they need to put more into unit rate charges, but if they do that and people build generation and built batteries, then it reduces their exposure to those extra charges. Small electricity supplier (30 Sep 2022): [Network charges] only do effectively static time-of-use. […] There should be price signals on both sides, both from a

	distribution side and a commodity, a supplier side as well to really gain the best benefits for customers. Distribution network operator (13 Dec 2022): Suppliers are exposed to the red-amber-green DUoS costs. So, those are slightly imperfect, but they broadly will tell you 'don't use electricity between five and seven, or you'll pay more for it, if you do.' It varies to what extent these charges are passed on to customers, but for large customers, they typically would be, and so customer would avoid the red band of DUoS. MHHS should ramp this up, particularly domestic. I wouldn't expect households to be exposed to DUoS. I mean, there might be some that for the Agile tariff, but I think for the majority it will be for the supplier to manage their exposure and encourage customers to not use electricity at peak times. […] So, I think it's imperfect, but it does exist as a signal. I think it's one that Ofgem will look at over the next year or so and decide how to tweak it. Consultant (21 Sep 2022): Network charging is primarily a means of recovering the costs of running the network. It's not really intended, first and foremost, as a pricing signal to drive behaviour. It's just a way of recovering the necessary costs to pay for ongoing operation, like reinforcement and pay for legacy costs. That's kind of it. And that's been the mindset for setting those tariffs. I think there is an argument that those signals aren't strong enough to really drive behaviour. […] If there's lots of legacy costs that are being paid off, you could argue that that shouldn't be reflected in a short run price signal. Because in extreme, your short run price should go negative when there's too much renewable generation on the network. It should encourage more demand to turn up that otherwise wouldn't be there, but if you're trying to recover legacy costs of having done network reinforcement, you're just charging whatever it is, 20p/kWh over the overnight period. This dampens the dynamism of the network as a whole. […] In general, there is a question about whether the DNOs are incentivised to keep demand in check. And that's kind of a complicated regulatory question, really. I think Ofgem should be expecting them to because the world of building reinforcement to meet demand isn't long term sustainable, I think there's an expectation on DNOs that they facilitate [a] more balanced, smoother utilisation of their network, so get the overall utilisation up and not just say, 'Oh, here's another peak, let's reinforce it'. But in terms of the actual money that lands on the table, they get paid either way, and actually, arguably, they get paid more for reinforcement because that's the way the structure is. But things are definitely moving towards encouraging DNOs to take on more opex solutions, so finding ways to avoid the need for large capital expenditure for reinforcement. Now, sometimes that can be done through flexibility procurement, and obviously that's a simple cost/benefit analysis to work out to say 'Well, is it worth my paying this flexibility provider this much money per year to defer or avoid the need to reinforce?'. When you're talking about tariff changes [it] is a little bit harder to say what the cost implications are to a DNO, obviously there are some system and IT changes that have to happen, not so much for the flat tariffs but for any kind of dynamic pricing, that's a world away from where they are now and even things like capacity based charging, that's a whole complicated new way of settling and working out local capacity needs. I think all of that involves change and investment and there isn't really a strong case for it yet.

Policy and regulatory context	**<u>The supplier hub model</u>** <u>Small electricity supplier (27 May 2022)</u>: At the moment it's change upon change, enrolment, faster switching, HHS. You got to do all those things but then you also got to do some customer innovation on the top whilst not spending so much that you don't make any money. <u>Small electricity supplier (14 Oct 2022)</u>: The pressures on our company just to meet our regulatory obligations and show up profits each year are tremendous. And so, all of our main focus other than the obvious of being profitable, has been on delivering the smart rollout for two reasons. The first is that it is very much commercially in our interest to do so. And secondly, but perhaps equally as important we're obligated to do that. <u>Small electricity supplier (30 Sep 2022)</u>: We are a relatively small supplier in the grand scheme of things, so we've got to be very focused on what we're trying to do next and what we're trying to deliver. <u>Technology company (7 Jul 2022):</u> Suppliers need to prepare now if MHHS is coming on in 2 years, but as with everything, suppliers have so much to do that they don't invest any resource in future dates. **<u>Energy price cap</u>** <u>Large electricity supplier (18 Nov 2022)</u>: Nobody's really done the deep dive into this in Government or at Ofgem, but does the price cap work in the world of HHS? Because the price cap is a fixed cap on total usage but if your cost of your usage will depend on when you use it, it doesn't quite line up. […] [Hedging] is another thing that ties into price cap because the price cap assumes a certain hedging strategy. If you had TOU tariffs, you would have to hedge differently, but we've never had them at enough volume to make a difference. <u>Large electricity supplier (15 Jul 2022)</u>: I think there is some unique market construct in the current UK retail space which in the current wholesale market conditions make it a bit challenging to force TOU to really be fully exploited and that really fundamentally comes down to the price cap. Because of the six-month lag of the price adjustments, right now for example, even if I launched a TOU tariff (and TOU are generally fixed contracts, either 6-month contracts or a year, but with a defined price for the different periods), but even if I take a normal 2-band TOU to incentivise load shifting, whilst also kind of pricing, even if I just break even I'm going to be so much more above the price cap in terms of annual spend. I think TOU tariffs in and of itself will be very interesting to the current market conditions. Because you can really help people move load. And of course, even in high wholesale conditions there are cheaper periods, both seasonally and daily. But with the overlay of the price cap mechanism, it's a bit of a rate limiting factor. <u>Large electricity supplier (20 May 2022)</u>: One thing that hasn't been considered is the default tariff cap. How are they going to implement that? Are they going to come up with 70,520 different price caps per year? Or are they going to come up with one flat profile or are they gonna do something else? The risk is that if they do something flatter, then the benefits of HHS don't happen. You know, the idea is that we've got

	HHS, so people react to usage as it becomes more expensive. But if Ofgem who sets the prices for most customers says no, it's just flat because they want to protect customers, then they don't get the benefit. So, does that destroy the business case of HHS? <u>Small electricity supplier (9 Sep 2022)</u>: The cap makes it simple for customers. I mean, with prices so high, if there wasn't a cap, it probably would have driven innovation, we would have looked at ways to help our customers better. Because there's a cap, that sort of innovation disappears, we don't really need to look at ways we can do that. It does stifle innovation in that way in that we can only charge what the cap says. And the cap only works for standard [tariffs] and Economy 7. So, if we came up with a 4-rate tariff or a seasonal tariff how would we compare it to the cap and how would Ofgem judge it? Would we have to get a derogation for that tariff from the cap? I would guess the cap at the moment is limiting innovation. If it wasn't there, the market would innovate a lot faster because it would be driven by demands of the customers. <u>Consultant (21 Sep 2022)</u>: At the moment with everyone effectively on a single price, or you know, ever so slightly different fixed prices, I think that's probably going to be a bit of a barrier to innovation because the kind of products that Octopus is doing, say, may not even be the right answer for even a very flexible consumer. Maybe when all that lifts, then we'll return to the trajectory towards TOU, but I don't know for sure. <u>Technology company (7 Jul 2022)</u>: The price cap has messed up the market for TOUs because for example if you've been on the Agile tariff over the past 2 years it's just been a non-starter because the average price has been way above the price cap, so I think that's really damaged the market for TOU. […] I think even under the price cap you could see TOU tariffs, but they're a bit of a risk to do under the price cap because you're allowed TOU tariffs, but you have to show that the average user would be paying less than the price cap so it's just an extra step you would have to take to show that the tariff is compliant. **<u>Relationship with Ofgem and government</u>** <u>Large electricity supplier (6 May 2022)</u>: I don't see a lot of barriers in terms of external restrictions. […] It's more our ability to move our own systems. I've found in my experience the doors have been fairly open to doing these things, we've been involved in conversations on trials, and I think regulators would be very supportive of facilitating that stuff if we really wanted to, I've not found it to be restricted environment where we can't do things. I've found when we've had those open conversations with Ofgem they've been broadly supportive of these types of initiatives because ultimately part of the objective is to help the customer save money, be on the right energy plan for them and hopefully embrace some of that technology stuff that are gonna make it sustainable for the future. <u>Large electricity supplier (20 May 2022)</u>: I know I've been pessimistic about BEIS and Ofgem and DCC, I think there are some frictions in the system, but I don't think there's anything that makes it impossible to do this […]. There are things that can make it better in the sense of support mechanisms, I think we could be much more

	pragmatic about our digital and settlement systems to make life easier for people to innovate around but I think generally BEIS and Ofgem should get some credit for pushing HHS, for having smart metering in place, relative to the challenges we have. We do have smart meters, they do work so there's a layer built for us to build on top of. Large electricity supplier (5 May 2022): When I speak to people, [I find that] policy isn't a barrier [to DR]. Distribution network operator (1 Dec 2023): I think, from a support point of view, I couldn't know what else government or Ofgem would be expected to do to facilitate [DR]. They've set baseline expectations, saying 'We want flexibility.' We have to interpret that and deliver. But they've also incentivised us by being assessed by experts and the actual service providers themselves: 'Have you delivered flexibility markets?' So, I think, from that perspective, the path for us to deliver is very clear. Distribution network operator (13 Dec 2023): The other thing that's not to be underestimated is Octopus' ability to embarrass people. I mean this in a positive way. And I actually love the fact that they're very challenging of different actors in the energy system, which is good. It's like 99% good. So, I think there's an element to which the ESO and even us want to be able to agree with Octopus as someone who's seen as a step or two ahead of others in the industry. So, I think there's a reputational thing that's not to be underestimated. And Octopus are also very well respected, I think, within quite senior levels of government. They're not without their challenges, but I think generally have been over the last few years quite good at getting their messages into the prime minister etc.

Annex 4: Technology theme and sub-themes

Sub-theme	Respondent quote
Types of loads suitable for DR	**EVs and batteries** Large electricity supplier (20 May 2022): I think it's easier to start with EVs and then maybe the heat pumps, because EVs are the ultimate flexible load, they're just these huge blocks of load and cars generally aren't used as much as people think so they're on the lot a lot so that's why the majority of integration will be around that. […] I think people are particularly keen to capture the EV and heat market. Large electricity supplier (15 Jul 2022): TOU tariffs generally become more relevant once homes start getting their first low carbon technology and low carbon technologies is the holy trinity of EV, heat pump or solar and battery. That's when it becomes really relevant. Large electricity supplier (18 Nov 2022): What else is a barrier to time use? I think obviously, people didn't have the load, that's obviously going to change with EVs. Large electricity supplier (5 May 2022): For TOU there are really only two use cases. The first one is the EV market which is obviously growing fast and there's heat (storage heaters that work on Economy 7 or Economy 10). Those are the only two use cases and there's quite a bit going on in the EV space but to fully benefit from the EV tariff you need a smart meter and only half of our customers have a smart meter. […] If you have an EV, you already have a battery. And a battery for a home is c. £7,000, if I can get a little device that does the same with my car for £500 that would be a massive save for the customer and that space is huge, there's a small company looking at that in the UK – the guys who figure that out in the UK will have a great proposition. It's a bit unfair to people in flats but you can still make it work for them. You could say plug your car in, help us balance the grid and we give you some money for it. It doesn't matter where you live as long as the car is plugged in, and the system works you can use the car to balance. There's huge potential there for using the cars that are just standing around. Large electricity supplier (6 May 2022): In terms of EV development, that's going to be significant, and we see that as probably being the lead area where we'll absolutely grow in the next five to ten years. We're putting a lot of our focus and strategy around that, not only in terms of commodity but also the partnership work with the other players, putting those solutions for EVs into homes in terms of charge points and then having those relationships in terms of charging infrastructure networks across the UK. That's a really big piece for us. Large electricity supplier (20 May 2022): I think the two big shiftable loads you have in the household are EVs and heating. And I guess at some point, battery storage will come up. Small electricity supplier (27 May 2022): We started to see some demand, people acquire EVs and want more off-peak energy, but there's nothing that isn't catered for them from off-peak. So, if they know that they've got 7 hours of off-peak energy, they'll use that to charge their car. That's enough.

Small electricity supplier (14 Oct 2022): The one bit of automation that might help more than anything we've got at the moment, would be EVs charging and discharging back into the system potentially. Because when EVs are at scale, there's more electricity than the fridge uses, so you immediately go on to more benefit but also significantly more investment as well.

Consultant (11 Oct 2022): [Innovation in the market] is not really necessary until you've got a high demand item, like an EV, or a heat pump where your TOU then actually becomes appreciable in terms of annual cost. Which is why a lot of this stuff is starting to come out now alongside EV chargers.

Distribution network operator (13 Dec 2023): I think, now, it's very hard to ignore EV customers in particular.

Heat pumps

Large electricity supplier (20 May 2022): We took a system perspective, and we believe there was a need in the market for TOUs particularly if heat pumps are taking off.

Small electricity supplier (9 Sep 2022): It will be interesting with heat pumps because TOU doesn't really work for heat pumps because they tend to genuinely have to run constantly. […] We had some very innovative tariffs in northern Scotland, and we were thinking how can we adapt heat pumps into those sorts of tariffs. But they just don't work because heat pumps need to just run constantly to provide a low level of heat. It's not like you can switch it on and get a real boost of heat like with a central heating system. They just run constantly. There isn't really a tariff that works for that, other than one that runs 24 hours a day.

Technology company (7 Jul 2022): There’s a study out, I think they were saying it’s now about £200 cheaper to run a heat pump than it is to run a gas boiler so that’s really interesting. There’s a concern out there, or a myth, that heat pumps are more expensive to run than gas boilers. You have the smart control that can further decrease those electricity costs, but I think if you’re starting from a position where you say it is going to be more expensive but we can reduce it to get below gas by using these fancy smart control things that haven’t been proven, then it’s more difficult than if you can say, yes, we can put in a heat pump, we’ll give a you a fixed rate tariff for 2-3 years and we even guarantee that your price is going to be lower than what you pay currently for gas.

Other types of loads

Large electricity supplier (18 Nov 2022): What's really movable is wet appliances. I could do washing machine or dishwasher at a different time. But then the other thing you have to think about, and this is what bill payers think about, for example when you do things in off-peak, so when you do your washing at night, the official London Fire Brigade advice is never turn appliances on overnight because there's a fire risk. Or, let's say, I do it during the day, and my washing machine is next door, my washing machine is old, is quite loud. I'm working during the day, I might not

	want to have it on during the day, because it's disruptive. Same with the dishwasher when you need it because the cycle is quite long. Large electricity supplier (15 Jul 2022): The way I think about it is that white goods are noise, the real thing is the trifecta of electrifying heat, electrifying transport, and self-generation (primarily solar). Technology company (7 Jul 2022): [Our trial] showed that there were relatively significant savings from being able to control the heat pump combining the smart control with the TOU tariffs. We also found that the savings from controlling other appliances aren't really there. There were pretty minor savings available from controlling things like tumble dryers and washing machines. Consumers liked the experience and the fact that they could control the device, but the savings were really, really minimal.
Business systems	**Legacy business systems** Large electricity supplier (20 May 2022): They probably wouldn't admit it, but a lot of suppliers probably can't do HHS yet because their billing agents can't do it and they haven't got time or the tech people to do it and so they haven't developed the half-hourly infrastructure which means they can't turn the customer's behaviour into a genuine economic benefit. Large electricity supplier (15 Jul 2022): A lot of suppliers don't have the technical capability to actually settle customers half-hourly and so the next three years are going to be very interesting to see how many suppliers can actually get ready for the mandatory switch in 2025. Large electricity supplier (5 May 2022): We are moving to Kraken. If Octopus can do Agile on Kraken, then we can also do the same. [An older TVT project] stopped because it was too expensive to do it on our old platform and the negotiations were ongoing with Kraken so the project would have been sunk cost so it's on hold until we get Kraken. Large electricity supplier (24 Jun 2022): I think changing the [IT] system is very important. During our TOU trial, I could see the system has to manage all these residential customers, their bills, all this is very old, very clunky legacy system, very difficult to update. [Moving to Kraken] should maybe speed up this process because changing things inside [confidential enterprise resource management (ERM) platform] is, I've been told every time, very time consuming, expensive, and difficult. To give you an example, I was asking them if I can change something so that when customers log in online to see their bills, maybe they can see a line to say [confidential text]. It's just a line, but they would say it would take 3 months to do and £50,000. Large electricity supplier (6 May 2022): The technical issue is that DSR needs sophisticated software and obviously Octopus are positioning themselves as a software company rather than an energy supplier – they are professionals in that area. Whereas with our internal systems, although good at doing lots of different things aren't fantastically set up to support an Agile tariff approach. We use [confidential ERM platform]. We are not considering changes. The view internally is that we've spent a lot of time developing our [confidential ERM platform]

	platform to be fit for our purposes for the things that we needed it for our customer base. And if we want Kraken, we understand that there are some things that it will [do] but we don't think it does everything. We've got something that we've invested in and it's good for our purposes and we think it's good for the future so we're not moving. Large electricity supplier (18 Nov 2022): We are very tied into our new [confidential ERM platform]. And I think that's the reason we wanted it because if you choose such as [confidential energy supplier] have chosen Kraken, as much as it's a great system and I've heard fantastic things about it, you are still beholden to what Octopus wants to change to the platform. And if it isn't supporting what you want to support, then you're in trouble. [Our old ERM platform] which is a very well-regarded system, is not energy specific. Everyone is now moving towards energy specific platforms. Small electricity supplier (14 Oct 2022): A fair amount of change [would be needed to offer TVTs]. At the moment, the system that we use is [confidential ERM platform]. They do support or they say they support TOU but I'm fairly sure the TOU they support at the moment is fairly prescriptive. It certainly wouldn't give flexibility. So obviously at the moment, the whole industry, we're all set up to handle TOU tariffs with an Economy 7 and Economy 10. It's quite prescriptive and restrictive. So, it would be a fair amount of change needed. Small electricity supplier (9 Sep 2022): The new [confidential ERM platform] offers us much more flexibility in terms of products. The old [confidential ERM platform] didn't seem to be very… Well, since I've joined when I've sort of asked 'can I do this, and can I do this,' then the answer comes back that 'no, it can't do it.' So, I think that was probably part of the decision making that was taken before I joined the company as to the billing platform they would use. We haven't seen yet if the new [confidential ERM platform] can do TOU tariffs because we haven't made that request. It can do Economy 7 and Economy 10, that's fairly standard. But if we were to get into the more complex, not necessarily the half-hourly rates, but if we were to get into sort of three, four or five different rates, then, I'm being told it can. For me, from a pricing point of view, the sky is the limit on what I can do and play around with tariffs. But I then am limited […] probably like other suppliers […] in terms of what the actual billing engines can do. Small electricity supplier (30 Sep 2022): So many people use them now that soon the market will be split between Kraken and Kaluza. Distribution network operator (13 Dec 2023): I think where tech has been a bit of a barrier is probably on the supplier side. There's a lot of legacy systems quite hard to change and do more complicated stuff. But a lot of them seem to be shifting to Kraken or something which, in their view will give them more agility in the future. Consultant (17 Jun 2022): There's also an issue with billing platforms and Octopus is the one who managed to bring this in the UK through Kraken but it's the only one who has the capacity to bill half-hourly. A bunch of suppliers are migrating to Kraken so once that's done it might make an impact. Kaluza can also do that with Ovo. All major suppliers in GB are going to be moving on the Octopus Kraken platform. So once that happens, there could be a shift in the market itself, more

	capabilities to actually offer TOUs. […] There's a big problem around billing and it's not just in GB but everywhere. Every time we talk to a supplier, they pretty much say the number one problem in terms of why they can't offer TOUs is that they're working on engines to manage all the billing that are pretty archaic, and they just don't have the tools to actually build what they need. In general, [IT platforms used by suppliers] are usually very old, it's things that have not been updated in years. Consultant (25 Nov 2022): Sending the right data flows is reliant on an incredibly antiquated system, from meter operator to data aggregator etc, the codes you need for that – the whole process is very cumbersome. So, suppliers don't have the IT system to gather HHS data from domestic meters to go into settlement. Most billing systems are really antiquated; they just say how much power you've used and how much it has cost. It's difficult to change all that. **Migration to new platforms** Large electricity supplier (6 May 2022): Because of our transition to our new operating platform, we've lost about 18 months to where we might have been, so we prioritised getting customers onto our new platform and rightly the focus in the development has been about servicing experience and billing and accuracy and that sort of stuff so that we don't get things wrong for the customers in the basics. But what that's meant is some of our wants around development for innovation have just had to be put on the backburner a little bit. Large electricity supplier (20 May 2022): Migrations always go [off schedule]. I don't want to put a number on it and then it turns out not to be true.
Smart metering	Large electricity supplier (18 Nov 2022): I think that [maintaining and installing smart meters] is a genuine issue. I don't know if that's a failing of us as an industry that we haven't made it clear enough to people what the benefits of smart meters are. And I wonder whether as EVs start rolling out, people realise, oh, well, I can only get this tariff if I have a smart meter and then they'll get one. But for now, I think…because when smart meters first got rolled out, the only thing we told them was, you don't have to take a meter read and people don't see that as that much of a hassle, they can easily do that. So, I think that hasn't helped the rollout. But yes, the refusers are going to be an interesting one when we get to the last say, 10%. Because a lot of people are refusing smart meters. Large electricity supplier (5 May 2022): [Smart] meter health is a barrier. Large electricity supplier (6 May 2022): I would say that the reason why we're not rolling out [TVTs] to more people is because of the smart meter rollout as well: having smart meters that would get reasonable signal on a consistent basis. So, people who have a smart meter, when they have it, we get a reasonably high level who can give us that information but there are a significant chunk where we don't and then the other part is that some people just refuse smart meters. The DCC was slow and delayed everything else. I know it's better than it was. I think the data from DCC is much better. I would say the rollout, including the DCC, was done very differently than in other European countries whereby the network provider was required to put in the meter whereby everyone got more or less the same

	specification which was really simple. Because it's all piecemeal here in the UK, all the meter types are different and all the specifications despite SMETS 1 and 2 are not quite identical so there's all sorts of crazy things with it. And the signal across the UK is different depending on the geography. I think smart meters are the biggest barrier to having people on TOU apart from generally not caring about it [enough] to actively get involved. Large electricity supplier (20 May 2022): I don't think we're quite where we need to be in terms of that infrastructure to deliver. I believe people are relatively wedded to the smart metering infrastructure and the DCC which has not performed well. […] The other challenge is that in-home displays (IHDs) are quite unhelpful as devices, they tend not to work, we get so many customers calls about them. Most customers will use the app, but then because the meter isn't capable of doing real time stuff without a consumer access device, you're fully reliant on the IHD, but the IHD isn't sophisticated enough to take on products like TOU tariffs. The other thing is that settlement conditions on HHS are quite stringent, which is fine, I get why they'd want to do that. But then we get let down by the smart metering infrastructure because we're missing reads and also there are gaps where we can't get the reads from the meter for whatever reason and then that means we can't settle for that whole period and then we miss our settlement. Large electricity supplier (20 May 2022): There is a lot of historical innovation and in fact, some of the stuff we did in the '80s was very innovative and that's not compatible with smart. So ironically, the installation of smart is meaning that we're getting less than some of the innovative things we have done because they aren't compatible anymore. There are still some legacy radio-tele-switching (RTS) meters. As we move to smart, we need to take these RTS systems out and obviously the BBC who runs the radio don't want to support it anymore, they'd rather have the frequencies back so it's slowly coming down. As we instal smart meters, the way the smart infrastructure is set up is not as a broadcast system, it's more one-to-one dial-up system, so you wouldn't be able to replicate the RTS system, which broadcasts a signal, and all the meters switch on or off at a time. Instead, it's a one-to-one so you can change and update the timings on a meter. It's more like a telephone, so you have to send out a million signals because the DCC wasn't designed for RTS so it would be hard to replicate. […] One of the challenges we've had is that a twin element smart meter hasn't been invented as in there are specifications for it and as suppliers we could go out and commission a smart meter manufacturer to create one, however, [for a small number of customers] they would charge a lot of money so that's one of the limitations we've got at the moment. I think it's being resolved, there are rumours that other suppliers have commissioned twin element smart meters, but we still aren't convinced that they work yet. We've never seen evidence saying that they work fully in the round, so the box with two terminals might exist but we don't believe the IT behind it works yet. […] We're using smart chargers and vehicles are getting smart enough now that they can report their usage. One of the blockers we have on that is that the Electricity Act says you have to charge people's usage based on a meter, which sounds reasonable, but the problem is that the smart charger and the car aren't meters so we have to find creative ways with those regulations that we can justify and give the customer cheaper energy for their EV without having to install a twin element smart meter

	which would record the two separate rates or without breaking the rules and charging the customers without using a meter. That’s one of the regulatory hurdles that we have. […] I think one of the biggest barriers we have at the moment is for the installation of smart meters and what's stopping us on some of that is there's a regulation within the agreement between network companies and suppliers about load managed areas. A network company can declare an area a load managed area and that means that they can't change the switching times of any electric systems in there. So that means we can't change any of the TOU tariffs in the North of Scotland from their current timings. The fact that they're having this load managed network over the whole of Scotland is inhibiting our ability to roll out smart meters and then that's stopping us from doing more innovative tariffs, which would help with their network constraints. So, it's all a bit of a chicken and egg situation. […] Small electricity supplier (14 Oct 2022): Now for prepay, essentially, the billing is going on dynamically on the meter, and prepay meters SMETS1, SMETS2 meters are definitely not really configured for dynamic pricing. They don't have the command to support dynamic pricing, like I can change the price now for tomorrow. But in terms of having any hope of, of making the prepay meter operate dynamically, I'd say probably about zero without doing the SMETS3 rollout. […] The reliability of smart meters [has been a barrier to DR] because they're not 100% reliable, communication to them is not 100% reliable. Technology company (13 Nov 2022): I've got Utility Week trying to get a hold of me at the moment because the problem of the [smart meter] rollout really seems to have hit peak issues now. It was all of the focus of last week’s Future of Utilities conference with the retailers pushing back on how difficult it's going to be. And as I said, Utility Week was asking for comments today and the only thing I can keep coming up with is coordinated rollout.
Data access	Large electricity supplier (5 May 2022): The country is being asked to move from a system that takes one or two reads per year to a system that takes 48 reads every day, so data has exploded, and suppliers have struggled to make that work but that’s in place now. I need to use that data but the work to store it and access it has been done. Large electricity supplier (20 May 2022): I don’t see any [data related barriers], […] but you need to be careful with [having access to smart metering data] because it can be abused quite badly by bad actors. If you let price comparison websites (PCWs) in an unregulated environment to access smart meter data, I think you get a bunch of people creating PCWs but actually just reading people’s smart meter data and building Experian-like products on top of it. Experian as in credit scores and you can imagine …UK smart meter data and then go ‘ok, I know when all these people go to bed’ and you start to create head portraits of customers, and we don’t want that. That’s not what smart metering is for, so if we’re gonna go down more of a smart meter data sharing route then let’s do it in a way to protect customers and that means you have to be a serious licenced player in the market to get that data as opposed to being some cowboy price comparison websites. […] You know you have the smart meter which gives you half-hourly granularity, then you’ve got sub-metering of assets, so that’s a next layer of data which is useful and important and then you’ve got customer intent. So, what does the customer want and when? What

	schedules are they setting? And those are obviously important. All of those are personal data so none of it should be released without the customer's consent, so you can opt-in to have your data shared. Large electricity supplier (26 May 2022): Protection of customers, protection of privacy and data is not necessarily wrong, but clearly a blocker to be able to share data with companies and companies to be able to optimise demand on behalf of customers. Large electricity supplier (20 May 2022): I think where we are, we can choose to do elective HHS with the opt-in from the customer and that's all we need to do something innovative. And as part of any proposition, you can include in the terms and conditions – and the customer is always willing to sign up to the terms and conditions – that we get your half-hourly data if that's required of the tariff. Large electricity supplier (6 May 2022): The other thing is that in the past with people who are really price sensitive it's very difficult to sell a TOU tariff. It's easier to sell it to an existing customer because you already have the data and you know if the meter woks but if you're not a customer we don't know if you've got a smart meter, if we can connect it, if we can get data so the first tariff we sell you can't be TOU. Small electricity supplier (14 Oct 2022): We're not yet doing elective HHS. I need to look at the [consumer data] consent [regulations] because we need to do some research. And I think the consent [regulation] is changing, but because we haven't had the consent, we haven't done any [data analysis]. We can't. We're not allowed to. It's an impediment. […] I suspect what some suppliers have been doing is bundling up consents. So, if you sign on for x, you also sign on for research and settlements. So, you know, I thought I was going to look at the consent on the basis of that, you know, is it compliant to do that? Because it may not be. But I think the situation is already changing. So, consent is now probably already less of an issue. Demand aggregator (14 Dec 2022): Presumably when there will be more smart meters, you'll have a larger participant base: the barrier isn't just having a smart meter. When you sign up as a user, you have to give us consent to access your smart meter and validate that it's your house and that it belongs to you. So, you have to provide your meter point administration number (MPAN). Most people have no idea what an MPAN is. Then you have to do the validation with the MAC address. That process is not consumer friendly for mass market people. Most people don't know the difference between their IHD and the smart meter itself. They think it's the same thing. […] It's a lot of steps and barriers, whereas energy suppliers like Octopus have got that data already from the customers so they can skip all of that step. What we're looking at doing is how we can improve the Smart Energy Code, which, quite frankly, is overkill. It takes the General Data Protection Regulation, which is a really good piece of policy and legislation but then adds additional stuff on top. We need to make sure that we build trust with consumers, but at the same time balancing that with the additional barriers we put in front of them. […] We get through the sign-up journey with a lot of people, but you also get a large drop off rate. From 10,000 people, you get drop off every time you introduce a new barrier. We need to really focus on mass adoption – how do we make this the default option

	that everyone is on and work back from there, how we do that in a trusting way and address the issues that people are actually worried about. Demand aggregator (13 Nov 2023): I think [access to data] has been discussed [across industry] and there has even been this recent piece from Energy Systems Catapult that speaks about the DCC and accessibility. That's a pain for all of flexibility providers. It's not even only about the access, it's also about the quality of the data because, in many cases, it has gaps and then it becomes unusable.

Annex 5: Organisational capability theme and sub-themes

Sub-theme	Respondent quote
Perspectives on innovation	Large electricity supplier (6 May 2022): Traditionally we've only just competed in a price market, and we don't want to do that anymore. We want to offer a fair price to the customers, but we want to be able to stand behind other things. And I think that's where over the next 12 to 18 months we can develop that innovation roadmap. […] We want to be innovative, and we've got a real commitment towards sustainability and that's part of our brand pledge so anything that fits into that category is really important to us. There's a really clear view that doing nothing isn't standing still, it's going backwards in terms of value, so we've got to do that. […] As part of our core strategy, we want to be seen as being more than commodity, we want to be a solutions business. […] Internally, I think our leadership structure is very supportive of doing that, it's perhaps just picking the right thing and driving it forward. Small electricity supplier (27 May 2022): I'd say that it's the amount of change and the cost of it that's the principal barrier [to DR and innovation]. Small electricity supplier (14 Oct 2022): Our parent company has an interest in electricity charging points, and I think that they see a future of collaboration there, but none for us directly. Consultant (17 Jun 2022): There's a mindset within the supplier community especially visible in the UK that they can't do anything about [DR] and that they're scared anyways of what's happening in the market and there's no point to do anything. This came across from conversations we had. The good thing about Octopus is that they're not afraid to try things. They put 'beta' next to it and try it – this kind of thing will bring more innovation.
Resources and expertise	Large electricity supplier (24 Jun 2022): For us, innovation is very important, there is an internal budget allocated every year, so you have clear targets you need to develop your innovation ideas on different areas – it's a must, it's just your job to do that. Obviously once you have these ideas you need to have the back-up or the support of the business and on this, they were always very supportive and very interested. Small electricity supplier (9 Sep 2022): [Elective HHS] is available now, but with us being a small company, we're limited by resource. So, if we have resource focused on building MHHS, then I can't put in a request for resource to build elective HHS.

Annex 6: DFS diary sample

Available to download at: https://link.springer.com/article/10.1007/s12053-024-10268-z

Annex 7: DFS study – participant characteristics

Available to download at: https://link.springer.com/article/10.1007/s12053-024-10268-z

Annex 8: Paper 2 statement of co-authorship and contributions

This paper has been published in *Energy Efficiency* in October 2024 with the title *Domesticating energy flexibility. Learning from Great Britain's 2022–2023 demand flexibility service*. I am the lead author of the paper. I was responsible for the conception and design of the study, the collection of the empirical data, the analysis and interpretation of the data, and the writing of the manuscript.

The Introduction was written alongside Sarah Darby, who is my co-supervisor. Her contribution focused on developing the contextual framing of the study and positioning it within the relevant academic literature. Otherwise, her involvement was advisory in nature and consistent with her supervisory role.

Sam Hampton contributed editorial input across the manuscript, improving clarity, coherence, and narrative flow. He also suggested revised names for the pathways identified in the analysis to make them more intuitive and memorable.

I retained responsibility for the analytical framework, the interpretation of findings, and the final structure and content of the paper. The research presented in this paper is my own work, and I take primary responsibility for the research design, analysis, and conclusions.

Annex 9: Summary of domestication pathways

Successful Domestication → Rejection

Domestication pathway	Description	Dimensions of Domestication		
		Symbolic	Practical	Cognitive
MOTIVATION DRIVEN SUCCESS	Successful domestication of the DFS thanks to participant's commitment to CO_2 reductions and energy security	• Motivated by environmental or security of supply objectives • Perceived shifting demand away from peak as normal • Framed DFS in positive terms • Secured support from initially reluctant household members • Became warm experts and persuaded others to join in demand-reduction efforts • Continued with DFS sessions despite being disheartened with rewards	• Planned activities around DFS sessions • Creatively adjusted routines to accommodate sessions • Knew from experience what actions to take during DFS sessions (had previously established routines) • Sense of resilience tested by short notice sessions and technical glitches	• Curious and eager to learn about DR • Disappointed with de in feedback and inabi to predict outcomes despite having established ways of monitoring usage and above-average understanding of DR
TECH-ENABLED SUCCESS	Successful domestication of the DFS using previously domesticated technology	• Motivated by environmental and financial objectives • Framed DFS in positive terms • Showed enthusiasm for using technology in new ways • Little awareness amongst family • Became warm experts	• Created new routines to re-domesticate existing technology • Planned some electricity usage around sessions • Made minimal change to household routines • Made little effort to accommodate short notice sessions	• Enthusiastic to learn f each DFS session hov improve outcomes • Disappointed with inability to predict outcomes and learn fr the data despite havin established ways of monitoring usage and above average understanding of DR
GAMING	Successful domestication of the DFS with unintended system consequences	• Motivated by environmental and financial objectives • Persuaded household members to join in • Disappointed and frustrated with the DFS methodology • Discussed DFS outcomes with friends and warm experts and became warm experts themselves	• Created new routines to domesticate existing technology • Planned electricity usage around sessions	• Enthusiastic and thorough in learning about DFS and DR • Disappointed with inability to predict outcomes
NOT WORTH THE EFFORT	Precarious domestication of the DFS due to perceived effort-reward imbalance	• Motivated mostly by financial rewards • Disheartened by perceived effort-reward imbalance • Concluded life-style not conducive to effective participation in DFS • Motivated by January sessions and streak framing • Little appetite to engage family or discuss DFS	• Did not form routines beyond minimal switching off of devices	• Made little effort to le how to improve savin
DISILLUSIONED	Rejection of the DFS because of wider negative perceptions	• Motivated by financial rewards only • Reflected wider negative perceptions of energy sector into DFS experience	• Did not form any routines	• No effort to learn or t own assumptions

Icon source: thenounproject.

Annex 10: Fulfilment of TIS functions in the first period of the DR TIS

Functions	DR foundations under a competition-led paradigm (2009-2013)
Influence on the direction of search	Policy sends signals towards decarbonisation and competition • Electricity Market Reform, aimed at attracting investment in low-carbon power and ensuring supply security, sets up the CM from 2014 • Ofgem launches Retail Market Review, leading to new rules to simplify tariffs and improve transparency for consumers • The Competition and Markets Authority investigates the energy market, highlighting issues related to competition and customer engagement DR potential is discussed in the context of the smart meter rollout, with DR understood mostly as a peak demand reduction mechanism • Government publishes Smart Metering Implementation Programme Rollout Strategy (2009a) and final cost-benefit assessment (CBA) with an assumption of 20% TVT uptake by 2030 (2009b) • Ofgem launches Promoting Smarter Energy Markets work programme (Ofgem, 2012) looking at how markets need to evolve to accommodate changes arising from the smart meter rollout, especially to accommodate DR • An Electricity Networks Strategy Group report (2012) emphasises the strategic importance of DR and its benefits for grid stability and cost efficiency
Knowledge development and diffusion	Academic literature is dominated by economic modelling to inform smart meter rollout policy decisions, interpreting results from early innovation trials • Hamidi et al. (2009) create load profiles of different appliances owned by a group of domestic customers to model total load profile • Roscoe and Ault (2010) model the impact of real-time pricing (RTP) on the United Kingdom (UK) system estimating potential 8-11GW peak demand reduction • Wang and Li (2011) model what critical peak pricing could like in GB • Darby et al. (2013) provide modelling which accounts for socio-economic factors to demonstrate smart grids' untaped potential for emissions reductions Early work begins to emerge towards the end of the period focusing on social aspects of DR • Darby and McKenna (2012) focus on social aspects of residential DR to conclude that households will be able to contribute to grid flexibility in the next decade
Entrepreneurial experimentation	DR only available to households through Economy 7 tariffs which have existed since the 1970s, mostly associated with overnight storage heaters Early signs of entrepreneurial experimentation through trials investigating the impact of low-carbon technologies like EVs, heat pumps, batteries, and solar panels on electricity networks

	• Low Carbon London investigates impact of low-carbon technologies on London's electricity network (Jan 2010- Dec 2014) • Customer-Led Network Revolution investigates how networks can better integrate low-carbon technologies (Jan 2011 - Dec 2014) • My Electric Avenue tests impact of EVs on electricity networks (Jan 2013 - Dec 2015)
Market formation	Decision is taken to create a CM from 2014, triggering early discussions between industry and government around the terms on which DR will participate in the CM (Lockwood et al., 2020)
Legitimation	Collaborations begin to emerge, mostly focused on how smart grids could support electricity networks cope with increased numbers of low-carbon technologies • Smart Grids Forum is established as a collaborative initiative involving the government, the energy regulator, industry stakeholders, and consumer groups to support the development and implementation of smart grid technologies • The Electricity Networks Strategy Group brings together representatives from government, regulators, industry, and other stakeholders to address the challenges and opportunities in the electricity network sector, including those arising from DR • UK Demand Response Association (UKDRA) is established in 2012 to represent industry players participating in DR • Interview UKDRA founder (Dec 2023): '*I was part of a Working Group between Ofgem, the Department for Energy and Climate Change and industry that included a number of DNOs that was looking specifically at barriers to DSR in the market. So that was the theme of the working group. There wasn't the focus on residential at that time. It really was more about looking broadly. It was more the DNO programmes and how DNOs were incentivised and the RIIO framework'* [RIIO is the name of GB's network price control framework, standing for Revenues = Incentives + Innovation + Outputs] Discussions take place around the reliability of DR in the context of its future participation in the CM • Lockwood et al. (2020) provide details of incumbent influence on the terms and conditions upon which DR entered the CM • Interview UKDRA founder (Dec 2023): *'I felt many times like I was on the defence having to explain that actually, DSR is a very reliable resource. […] And there were so many studies and the fact that we had such great partners like EnerNOC and Flexitricity* [two of the first DR providers in GB] *who could bring the data and bring the expertise – that really helped. It didn't end while I was still living in the UK. […] This is actually very similar to the conversations that still happen in the US* [United States of America]. *I don't know that we're ever going to convince the generators because from their standpoint, the DSR industry is eating their lunch, it's forcing their margins down. So, there's a natural tension that I think will always exist.'*

Resource mobilisation	Several organisations are created, and supply chains and commercial relationships start to emerge to enable the smart meter rollout • Smart Energy GB is set up as the independent, government-backed organization responsible for promoting the rollout of smart meters across GB • The DCC is set up for managing the secure communication infrastructure that connects smart meters with energy suppliers, network operators, and other authorised parties Ofgem's Low Carbon Networks Fund provides up to £500m of innovation funding to support projects sponsored by DNOs to understand how they can provide security of supply at value for money as GB moves to a low carbon economy Approx 15 market entries focused on energy supply (e.g. Bulb, Ovo) and some smart assets optimising solutions (EnerNOC, PodPoint, Moixa, Tado)
Development of positive externalities	DR providers operating in the I&C space and existing Economy 7 tariffs show DR proof of concept, paving the way for residential DR in the next periods • Interview UKDRA founder (Dec 2023): *'So, at the time, there were not so many players in in the DR space. So, I would say Flexitricity was first. They really were the first and for a long time, the only game in town. And then EnerNOC came over from the US, C-Power came over from the US, and maybe a handful of others.* Economic modelling of smart meter rollout benefits brings out the value of DR for the system and for users • Government-commissioned report (Baringa and Element Energy, 2012) assumes that as a result of smart metering 8% of households will take up DR by 2020; up to 40% by 2025 and up to 64% in 2030. They forecast DR benefits approaching £500m in 2030 in the best-case scenario

Annex 11: Fulfilment of TIS functions in the second period of the DR TIS

Functions	Experimental diversification and early scaling barriers (2014-2019)
Influence on the direction of search	With the UK government committing to net zero carbon emissions by 2050, policy decisions either directly aimed at DR (HHS) or aimed at supporting wider decarbonisation efforts (electrification of transport) signal a future in which DR has a significant role to play in reducing emissions • Government and Ofgem publish the Smart Systems and Flexibility Plan (2017) outlining 29 actions to remove barriers to smart technologies, enable smart homes, and improve access to energy markets for new technologies and business models • Balancing and Settlement Code (BSC) modification P272 enables elective HHS starting in 2016. Ofgem launches a SCR in 2017 to enable market-wide HHS (MHHS). [Energy codes are the rules and regulations underpinning the functioning of the GB energy sector. These can be changed through 'code modifications' or 'SCR' processes] • Government sets an ambition for half of new cars to be ultra-low emissions by 2030 (HM Government, 2018) This is balanced out by mixed signals around the role of competition – which supported large numbers of new entrants – in delivering decarbonisation. After finding in 2015 that UK customers are overpaying by around £1.2bn annually due to a lack of competition and engagement, the CMA recommends in 2016 a series of reforms, including a temporary price cap for prepayment meter customers and measures to promote switching. The government introduces the Domestic Gas and Electricity (Tariff Cap) Bill, leading to a price cap on all default tariffs starting in 2019 Changes to the smart metering rollout from a decentralised to a centralised approach – i.e. instead of suppliers communicating with smart meters through individual third party communication companies, a single communication company, the DCC is established for all communications with smart meters –, two new CBAs which revise DR uptake assumptions, and challenges with installing or operating installed smart meters raise questions around DR's future • SMIP's 2010 CBA had assumed 20% TVT uptake by 2030. This was revised up in 2016 to 20% by 2020 and 30% by 2030, and then down in 2019 to 3% by 2020 and 25% by 2034. • Interview energy supplier (May 2022): *Our inability as an industry to get smart meters on people's walls creates an issue. […] We went on to do it while other suppliers aren't investing the time and effort. In an ideal world, if we would have designed what we put in the homes of customers [ourselves], from smart meters to commissioning them and the processes around that, what tech you're allowed to use, what firmware, we would not have done it like the DCC has so we're wrestling with this unwieldy beast which is the smart metering infrastructure. We're happy to do it because we know the benefits of having smart meters and we see that, but it makes it*

	harder for our tech and our metering teams, it's not easy, and that then reflects into customers saying 'I've got a smart meter but it doesn't work', or 'I can't get a smart meter because of the signal in my area.' The challenge is we had to go and buy a company that is an adapter to the DCC because none of the other adaptors were up to what they needed to do. We now have an unbelievable team of people who've managed to work out the intricacies of how to work with DCC and can do it, but they still hit [barriers] and if you want to speak to people about how frustrating it is to work with DCC tech systems these are the right people because they live it every day.
Knowledge development and diffusion	Grey literature, often commissioned by government, continues to focus on economic modelling and removing barriers to DR • Imperial College London & NERA report (Strbac et al., 2015) cited in the Committee for Climate Change's Fifth Carbon Budget calculates total gross benefits of flexibility between £3-£3.8bn per year, mainly associated with the deployment of energy storage and DR • Carbon Trust and Imperial College London (Sanders et al., 2016) estimate net benefits of DR, storage, interconnectors, and flexible combined-cycle gas turbine power plants between £1.4bn-2.4bn per year in 2030 • Citizens Advice-commissioned study (Hledik et al., 2017) on the value of TVTs estimates annual savings of opt-in TVT products at around £20 to £25m/year • Jacopo Torriti (2016) launches the first book published in the UK to present a comprehensive analysis of the impacts, costs, benefits, and risks associated with DR programmes and policies • University of Cambridge & Imperial College London report (Strbac et al., 2016) for the National Infrastructure Commission expects the smart meter rollout to remove barriers to residential DR which is viewed as being at trial level only Academic literature starts nuancing the DR costs-benefits debate with aspects of user acceptance of and appetite for DR, user archetypes, capabilities, and fitting DR into social practices • Grünewald et al. (2015) consider how to reconcile the system need for complex price signals such as RTP with consumer preference for simple messages • Darby (2018) and Gram-Hanssen and Darby (2018) explore the meaning of smart homes for their users • Nicolson et al. (2017a), Nicolson et al. (2017b) and Good (2019) employ behavioural science perspective to analyse preferences of DR users • Powells et al. (2014) and Ramírez-Mendiola et al. (2018) disentangle DR into 'social practices' and 'activities' respectively to understand user preferences • Strengers (2014) argues that smart energy technologies embody a rational, individual, masculine image of the energy consumer termed 'Resource Man'

<table>
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- Powells and Fell (2019) introduce the concept of 'flexibility justice' to warn against risk of injustices being locked into energy system design

Some early non-academic publications also focus on DR users, emphasising aspects of fairness and distributional impacts of DR

- Smart Energy GB-commissioned study (Fell et al., 2015a) concludes that successful DR implementation depends on addressing concerns of trust, privacy, and risk
- Ofgem-commissioned report (Cambridge Economic Policy Associates, 2017) assesses distributional impacts of TVTs

</td></tr>
<tr><td>Entrepreneurial experimentation</td><td>

Trials continue to investigate the impact of low-carbon technologies on electricity systems and networks with specific focus on integrating EVs

- Electric Nation tests impact of EVs on networks and smart charging benefits (Apr 2016 - Oct 2019)
- Recharge the Future looks to understand the impact of EVs on DNOs (Oct 2017 - Jan 2019)
- LV Engine tests how to manage electricity networks (Jan 2018 – Dec 2024)
- SmartCAR investigates smart charging approaches (Apr 2018 - Feb 2019)

Many trials also start looking at supporting diverse types of users in benefitting from DR (e.g. heat pump owners, fuel-poor households)

- Greater Manchester Smart Communities tests aggregation of heat pumps in social housing (2014-2017)
- Freedom Project tests how to integrate air source heat pumps with high-efficiency gas boilers in homes (2017-2018 heating season)
- Energywise (Tower Hamlets) explores how to increase participation of fuel poor households in DR (2014-2018)
- Get Smart investigates how to drive user engagement with DR (early 2017-2019)
- Project Shift explores and implements DR strategies (Jan 2019 - Oct 2021)

Some trials also explore complex propositions like local community energy, vehicle-to-everything and peer-to-peer electricity trading

- Project LEO explores smart local systems (Apr 2019 - Mar 2023)
- Cornwall Local Energy Markets trial tests local markets (Spring 2017 - Jun 2018)
- Project CommUNITY enables residents of a block of flats in Brixton (London) to trade solar electricity with each other (Oct 2019 - 2020)
- Powerloop looks to demonstrate viability of vehicle-to-grid (V2G) technology (2018-2021)

In terms of commercial products, Octopus Energy launches the Agile tariff, a capped RTP, the first of its kind in GB, to a select number of friendly customers. Social Energy, a British start-up, launches an ‘energy-as-a-service’ proposition whereby they install solar panels and batteries for households if they allow Social Energy to control those assets and enter them into various markets to decrease the household’s electricity bill. They later export their

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<tr><td></td><td>business model to Australia. However, DR products from most other providers replicate Economy 7 and mostly target EV drivers

Some incumbents consider or test DR products but do not find them worthwhile on a commercial scale
• Interview energy supplier (Nov 2022): We came up with these free Saturdays. Remember that? It wasn’t technically free Saturdays, you could use free Saturday or Sunday, it was up to you. And what it was, was that you’d get that free day, and, on that day, you can use as much electricity as you wanted, without getting charged for it. And the idea was that you'd shift load. And we did have some uptake to it. But it was more done as a trial because largely, we didn't reap any benefit from it […]. There were no financial benefits of doing it, it was more that some customers may want it because they can save money themselves. So, we did withdraw that trial after a while because it just didn't really benefit us.</td></tr>
<tr><td>Market formation</td><td>Slow progress is made towards the end of the period to level the playing field between DR and other technologies, or to remove barriers to entry in various markets
• Tempus Energy’s 2014 complaint to the European Commission about the CM’s bias in favour of traditional generation leads to the suspension of the CM until 2019 when participation thresholds are reduced from 2MW to 1MW and DR is allowed to bid for 15-year contracts on par with generation. Proven DR in CM increases from almost nothing in 2014 to almost 200MW in a 2019 auction as larger numbers of assets pass testing requirements. However, flexibility is significantly de-rated in the CM and clearing prices are low, so revenue for CM is limited
• The ESO launches the Firm Frequency Response Bridging Service removing barriers to small scale DR participation in frequency response in 2016
• The ESO runs the Residential Response programme to test innovative ways for residential flexibility assets to enter ESO balancing services in 2019
• The minimum unit size for participating in the ESO’s Fast Reserve Market decreases from 50MW to 25MW in 2019
• The ESO is legally separated from National Grid Electricity Transmission in 2019 to ensure impartiality of its operations

Work begins to develop local (DNO) markets
• In 2017, the Energy Networks Association, a trade body, launches the Open Networks programme to expand GB’s local energy flexibility markets and in 2018 DNOs sign the Flexibility Commitment facilitated by the ENA, agreeing to six common steps for flexibility procurement
• Electron and Piclo create flexibility trading platforms enabling efficient procurement of flexibility services by system operators
• UK Power Networks (UKPN) and Western Power Distribution start running DR auctions. In 2019, UKPN allocates £12m for DR procurement and reduces the minimum capacity threshold to 50kW to encourage greater participation</td></tr>
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Legitimation	Industry and academia come together under various associations, but no organisation dedicated solely to residential DR emerges • The Association for Decentralised Energy (ADE) is created 2015 to represent a wide range of technologies and services that contribute to decentralised energy, including DR, district heating, and energy efficiency. UKDRA dissolves and its functions and advocacy for DR are absorbed by ADE in 2017 • The ESO launches the Power Responsive Platform aimed at stimulating DR and storage participation in ESO markets with focus on I&C DR • The Centre for Research into Energy Demand Solutions is set up in 2018 with government funding, bringing together approx. 140 academics across 24 British academic institutions to understand the role of energy demand change in accelerating the transition to net zero Progress begins towards facilitating and legitimising data sharing in the energy sector. Government, Ofgem and Innovate UK launch the Modernising Energy Data programme aimed at creating data best practice guidance to help organisations understand government and regulator expectations around data management; set regulatory expectations for digitalisation and the use of data, and develop the right architecture that will allow efficient data sharing and enable interlinking of existing and new datasets across different sectors (like energy, transport, heat, land use etc), to support innovation and holistic decision making and outcomes
Resource mobilisation	Innovation funding • The 2017 Smart Systems and Flexibility Plan (HM Government, 2017) commits BEIS to spend up to £70m on smart energy systems innovation, including up to £20m for V2G products and services through the Energy Innovation Programme • UKRI launches Prospering from the Energy Revolution £104m fund to be spend between 2018 and 2023 for businesses and researchers to work with local organisations to accelerate innovation in smart local energy systems • Ofgem's Electricity Network Innovation Competition, part of RIIO ED1 [the price control framework for electricity distribution networks, applying between 2015 and 2023] allows up to £70m per year for DNOs to develop and demonstrate innovative technologies and operating and commercial arrangements to achieve environmental benefits, reduce costs, and maintain security of supply Approx. 30 new market entries bringing in a diversity of business models and resourcing from other fields e.g. digital flexibility platforms (Piclo, Electron, GridBeyonfd, Kraken, Kaluza), smart EV charging and storage solutions (Tesla, Powervault, ev.energy, GivEnergy, Ohme), virtual power plant operators (Equiwatt, Levelise, Lightsource Labs, Social Energy) Incumbents start investing in innovative business models: Enel X acquires EnerNOC, Centrica acquires aggregator Restore, Shell acquires LimeJump Energy suppliers begin investing in IT platforms to support flexibility

<table>
<tr><td></td><td>Octopus Energy creates Kraken in 2017, an advanced technology platform enabling Octopus Energy to manage customer accounts more effectively and expand their services globally
Ovo launches Kaluza in 2019, a technology platform providing advanced solutions for EV charging and HEM
E.ON and EDF purchase the Kraken platform in 2019</td></tr>
<tr><td>Development of positive externalities</td><td>The Tempus Energy case enables wide DR participation in the CM breaking some of the incumbent’s resistance and supporting legitimation of DR as a reliable alternative to traditional generation assets

Market entries bring innovative business models (Social Energy) or know-how from other fields (Octopus Energy), offering DR proof of concept which encourages resource mobilisation (e.g. investment in IT platforms)

Innovation trials help build relationships between various entities and help upskill local authorities, DNOs, and energy suppliers</td></tr>
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Annex 12: Fulfilment of TIS functions in the third period of the DR TIS

Functions	**Consolidation, disruption, and early transition signals (2020-2024)**
Influence on the direction of search	Signals towards decarbonisation firm up, with EV and heat pump rollout targets resolving some of the uncertainty over the speed and scale of electrification • Major policy publications (HM Government, 2022a, 2022b, 2021b, 2020a, 2020b) detail the government's approach to delivering a net-zero energy system whilst supporting economic growth across the UK. They present DR as one option to support decarbonisation and energy security, but fall short of linking DR and economic growth • Government publishes the Heat and Buildings Strategy (2021c) assuming 600,000 heat pump installs per year until 2028 and launches the Boiler Upgrade Scheme providing grants of up to £6,000 towards the installation and capital costs of heat-pumps. The grants are not conditional on participation in DR • Government creates the Zero Emissions Vehicles mandate in 2023, targeting 80% of new cars and 70% of new vans sold in GB to be zero emission by 2030, increasing to 100% by 2035 • The Clean Power Action Plan (HM Government, 2024a) commits government to delivering clean power by 2030, with an ambition of delivering 10-12 GW of DR by 2030. NESO modelling (National Energy System Operator, 2024c) underpinned the commitment. System governance evolves to accommodate climate ambitions and moves to a more centralised and coordinated approach • NESO takes over electricity system operation and wider energy system responsibilities in 2024 as a publicly owned company • NESO is appointed delivery body for Regional Energy Strategic Plans (National Energy System Operator, 2023) and the Strategic Spatial Energy Plan (HM Government, 2024d) as part of reforms to local governance arrangements • Ofgem receives a net zero mandate alongside its obligation to protect consumers (Ofgem, 2023a) • The Clean Flexibility Roadmap (HM Government, 2025a) published in Jul 2025 [out of scope for this research] announces the appointment of a Clean Flexibility Commissioner and a governance framework aimed at supporting Roadmap DR commitments Clearer plans begin to develop for the improving awareness of DR, ensuring interoperability, cybersecurity and user protection when engaging with DR, and digitalisation of the energy sector to support DR development • The Smart Systems and Flexibility Plan (2021a) and Digitalisation Strategy (2021) set out a list of actions needed to support DR • Building on its FlexAssure code of conduct and compliance scheme for I&C DR (2019), ADE launches HOMEFlex (2023) to improve user participation in energy flexibility services by ensuring transparency, inclusivity, and respect between service providers and customers

	• Government sets out interoperability standards between energy smart appliances (ESAs) and DR service providers, and cybersecurity requirements. Energy suppliers are required to make TVT data available in a standardised format, and Ofgem is designated the regulator for a new licensing regime for load controllers (HM Government, 2024e) • The Clean Flexibility Roadmap sets out 15 actions to support the delivery of 10-12 GW of DR by 2030. The publication refers to DR as 'consumer-led flexibility' and is accompanied by three publications aimed at: increasing consumer awareness of and engagement in flexibility (HM Government, 2025b); supporting market participation by improving system visibility of distributed energy assets (HM Government, 2025c); and exploring the benefits of secure data sharing to unlock innovation and create growth (HM Government, 2025d). Forward looking policies with potential impact on DR start to develop, raising questions about their interaction with DR • Review of Electricity Market Arrangements (REMA) (2022b) forecasts the need for 55GW of DR and batteries by 2035 as it considers introducing zonal pricing whereby electricity prices vary by location and time • Government and Ofgem seek views on the future of the retail market (HM Government, 2023a), retail market innovation (Ofgem, 2024b) and consumer engagement in domestic DR (Ofgem, 2023c) identifying key challenges across flexibility markets Existing policies are delayed or provide conflicting signals for DR • The MHHS delivery date changes in 2023 from Oct 2025 to Dec 2026, and then to 2027 in the next year • Ofgem consults on the next electricity distribution price control period beginning in Apr 2028 (Ofgem, 2024c) suggesting that networks consider system benefits holistically when choosing between network reinforcement and flexibility, rather than always prioritising flexibility • The smart meter rollout moves from an obligation on energy suppliers to take 'all reasonable steps' to install smart meters by 2020, to a framework in which energy suppliers have annual installation targets to achieve market-wide rollout of smart meters by 2025. [By the end of Q1 2025, approx. 67% of all meters (39 million) in homes and smart businesses were smart meters (HM Government, 2025e)] • Interview BEIS government official (Nov 2023): It's so frustrating…that kind of attitude [whereby energy suppliers assume government programmes will be delayed], isn't it? Because they know themselves how much they did to prevent meeting the 2020 target. It's self-fulfilling prophecies all around that just require them to invest less now, which is, from a business perspective, understandable because they don't have… they're operating on such tight margins in the supply market that you can understand why they take that approach. The government's approach to DR is depicted in Nov 2023 interviews as reliant on market actors to deliver DR, with government's role seen around removing barriers to DR. Siloed ways of working and an inability to model DR in

	internal models are flagged. Work begins to coalesce around raising user awareness of and engagement with DR. • Interview BEIS government official (Nov 2023): We have the vision in these policy documents and the general approach to remove barriers across the piece, but then we're looking at the market to deliver. I don't think we would intervene to a greater extent, but there might be a necessity for us to be a bit more on the front foot on consumer engagement. That's not a nice-to-have, an add-on, it's essential, and we're coming to look at this properly now. DSR and flexibility is very widespread [across teams in government] so I can't speak for everybody, but I don't think we are in an interventionist mode, we're still identifying barriers, helping to remove them, and then expecting the market to deliver this wealth of smart tariffs and services. […] Consumer engagement though might be somewhere where we need to be a bit more on the front foot, more strategic and that's where we'll be looking at, whether that's some sort of information campaign or information service. • Interview BEIS government official (Nov 2023): I don't think you'll find anything that you don't know already from my take on DR barriers. It's the big three: it's the markets that don't provide signals; it's making technical standards and making sure that actually technology is able to do this in a convenient, secure way; and finally, […] it's consumer engagement, you know, the idea that people actually want to do this. […] Actually, the individual benefits [of DR] are quite low, relative to the benefit in aggregate to the energy system. So, actually, unless you've got an EV or electric heating, then it does start to make sense, you might see that shift, but otherwise, actually, you don't have much for saving. • Interview BEIS government official (Nov 2023): There's also a split in the department as to what, what sits where, which I think probably doesn't help with having a coherent view as to how this all comes together. So, one minister is responsible for smart metering, another is responsible for consumers, another one is responsible for generation and REMA, which is where some of these low carbon flexibility questions might come out, and then another is responsible for networks and within that, smart systems. I think they're broadly positive, there hasn't been anyone that's kind of like tried to stop us doing the work, which I think is good. But equally, the work hasn't necessarily got to the point where it got really… like the criticality of it to consumers has really come through. […] And then in terms of civil servants, um… I think that's a really interesting question because I think you're often in silos as to what it is you need to be focused on. I think there are a collection of people that recognise it is very important. I don't necessarily think that is as strong a collection of civil servants as it could be which means that it is always incorporated into advice where it should. • Interview BEIS government official (Nov 2023): The department's dynamic dispatch model is not able to model DSR or storage very well […] they've procured a new model, which the analysts are currently working on baselining, and it should be available by March [2024]. That should have a much better capability of assessing storage, DSR. So, the department is

	finally doing something about it, but it's taken.... I mean, I think we had the dynamic dispatch model like five or six years ago. They knew then that it wasn't very good. So, it's taken a long time to get to this point.
Knowledge development and diffusion	Academic research and grey literature converge with common focus on user engagement, user protection, and flexibility justice • CSE's Smart and Fair reports (Charlotte Johnson et al., 2024; Roberts et al., 2020) develop a capabilities lens approach on household types and emphasise the need for policies and technologies accessible to all, particularly vulnerable and low-income households. CSE also develops consumer archetypes to be used in policymaking and scenario modelling (Centre for Sustainable Energy, 2024) • Citizens Advice flags consumer risks arising from residential DR (Citizens Advice et al., 2021) and calls for a clear plan for inclusive DR solutions, better information, appropriate regulation, and inclusive innovation (Citizens Advice, 2023) • Blue et al. (2020) argue that efforts to promote flexibility in the energy sector need to focus on the social rhythms and timings of what people do and Lo Piano and Smith (2022) review options to act on the temporal profile of energy demand at residential level • Mihalache et al. (2024) analyse motivations for participating in DR and ways in which household incorporate DR into their daily lives • Torriti and Yunusov (2020) identify activities in the home for which people may either gain or lose following the introduction of TVT • Calver and Simcock (2021) evaluate the normative implications of DR in relation to energy justice and offer consumer protection recommendations • Crawley et al. (2021) apply the flexibility capital framework to two UK trials focusing on who controls the capital and for whom it delivers value • Gupta and Morey (2022) find general acceptability of automated DR in social housing if accompanied by thermal comfort limits and manual override Grey literature and some academic literature focus on removing barriers to DR • The Energy Digitalisation Taskforce publishes a report (Laura Sandys, 2022) making six overarching recommendations for government, Ofgem and industry to create a modern, decarbonised digital energy system • ADE (2024) highlights how the NESO can better harness electricity demand to support the UK's transition to net zero • Carmichael et al. (2021) focus on barriers, drivers, and opportunities for greater engagement with DR • Torriti (2024) considers the less explored aspect of DR governance i.e. which institutions are responsible for delivering DR Live labs begin to emerge increasing availability of electricity usage data for research • Smart Energy Research Lab (SERL) makes large-scale, high-resolution smart metering data accessible for research starting in 2020

	• Energy System Catapult's Live Lab project gathers a community of over 3,500 households ready to participate in trials of new clean energy innovations
Entrepreneurial experimentation	Trials aim to develop real-world solutions to address DR barriers like interoperability and supporting greater integration of EVs into electricity networks • Beyond Off Street demonstrates the potential of smart meters for smart charging (Mar-Aug 2020) • iDSR looks to facilitate interoperability between ESAs (May 2022 – 2024) • Kaluza installs and manages 320 V2G chargers, the largest project of its kind in the world Trials continue to test the potential of scaling up DR beyond early EV adopters • Project InvoLVe looks to identify barriers to low-income users' participation (2020 - Mar 2021) • Inclusive Smart Solutions looks to provide smart services to low income and vulnerable users (Feb 2023 - Mar 2025) • Clean Heat Streets tests neighbourhood installs of heat pumps (Mar 2023 – 2025) • Equinox looks to unlock DR potential of heat pumps (Mar 2022 - Jan 2026) • Crowdflex analyses the impact of enduring signals and one-off price signals (since Apr 2021) • Alternative Energy Markets tests innovative DR proposition (Nov 2022 - Mar 2025) Commercial products do not evolve very much compared to the previous period. Most TVTs target EV users, and some target heat pump owners. No commercial products exist tailored to pre-payment or vulnerable customers. However, some progress is made by incumbents participating in the DFS who package DR under different names and offer a diverse range of rewards as part of the winter programmes. British Gas re-launches weekend tariff offering electricity at half-price for a few hours on Sundays. [An overview of TVTs in the UK is available here, but it does not reflect the state of the market pre-2024 because it is being constantly updated. The database for this study was created manually from GB electricity suppliers' websites]
Market formation	Access to markets improves, including for non-incumbents • In 2021, Ofgem's RIIO-ED2 [the price control framework for electricity distribution networks, applying between 2023 and 2028] formalises a 'flexibility first' principle whereby DNOs need to prioritise DR, storage, and other flexibility sources over traditional infrastructure investments • Independent load aggregators without an electricity supply licence gain access to the Balancing Mechanism (BM) in 2020 under a new Virtual Lead Party (VLP) role within the BSC • The minimum asset size for participation in the BM is reduced from 100MW to 1 MW

	• From 2024, VLPs can also participate in the wholesale market as a result of an Enel X BSC code mod (P415) raised in 2020 Steps are taken to improve the revenue stack resulting from participating in various markets • In 2022, the ESO launches the DFS, a DR-only market, and from 2023 it allows revenue stacking between DFS and other ESO services • The ESO makes changes to the BM to increase participation of flexible assets (under the banner of Open Balancing Platform) • In 2024, Ofgem appoints Elexon as Market Facilitator for flexibility to align national and regional flexibility markets Some trials are geared towards market formation • The ESO and Octopus Energy run the Domestic Scarcity Reserve Trial, or the Turndown Trial, in Feb-Mar 2022 to determine if moving residential electricity demand out of peak times can support electricity system over the winter, leading to the creation of the DFS that winter • The Automatic Asset Registration trial (Apr 2022-2025) tests automatic registration of small-scale assets to support operation of local DNO market • The Flex Markets Unlocked innovation programme aims to design and develop innovative technical solutions to facilitate system-wide coordination, standardisation, and revenue stacking across multiple flexibility markets Despite progress, questions remain around the viability of DR products under current market arrangements • The DFS Guaranteed Acceptance Price (a subsidy) is removed in Jan 2024, lowering the number of DFS providers from 31 in the first year to 25 in the second • Coordination between markets, benchmarking methodologies to calculate revenue, and levelling the playing field with traditional technologies are flagged by industry as issues that still need to be addressed (Association for Decentralised Energy, 2024) Most bill stack elements do not reflect pricing at different times of the day sufficiently to incentivise energy suppliers to offer TVTs • Interview energy supplier (May 2022): Ultimately there's quite a strong signal in the UK, but where it's strong is around static TOU, driven a bit by transmission network use-of-system (TNUoS) and distribution use-of-system but both are being eroded by the TCR [Targeted Charging Review was a process to change electricity network charging arrangements]. Martin Lewis tweeted yesterday that all the cost in the price cap, the standing charge, and a lot of that is because of the TCR. We're going to a world where more stuff is being socialised through the standing charge and not in a TOU way and balancing services-use-of-system is going the same way of not TOU which means consumers will get the same regardless of how they behave, so there's no signal there or there's less of a signal to do something useful.

<table>
<tr><td>Legitimation</td><td>External developments like the Covid-19 pandemic and the gas price spike resulting from Russia's war on Ukraine highlight the importance of DR for energy security, not just decarbonisation
• The first lockdown reduces demand by up to 20% in periods of high wind, with record negative prices below -£50/MWh increasing system balancing costs by 39% and highlighting the need for flexibility (DR and storage) to balance the system (National Grid ESO, 2020)
• 2022 power prices are approx. 80% higher than in 2021, leading government to temporarily introduce an Energy Price Guarantee in Oct 2022

Against this background, the Turndown Trial legitimises the reliability of DR for security of supply with the ESO, leading to the creation of the DFS
• <u>Interview energy supplier (Jul 2022):</u> The goal of the Turndown Trial is to understand how to change the market. So, while the Turndown Trial is a very blunt tool, a simple concept, and actually a very poorly structured reward system, it is incredibly important because in two months it has convinced the ESO control room that the savings are real.[…] The active system benefit is that currently NG ESO have no tool in their tool kit to shape demand. The only tool they have is to turn up generation instead of turning down demand. So, the Turndown Trial is turning it down and looking to understand how reliably this can be done – is this resource category reliable enough that it can be baselined and that you can then scale it up and industrialise it and then how do you settle it?

Public messaging around the DFS legitimises DR with the wider public as a security of supply and decarbonisation instrument
• 1.6m and 2.5m households sign up to DFS in winter 2022-2023 and 2023-2024 respectively, despite small savings from participation. More than 80% of people surveyed after the first year of DFS said they would take part in the service again (Centre for Sustainable Energy, 2023)
• Smart Energy GB launches a new campaign in support of smart metering revolving around the slogan that 'it pays to be flexible'

In winter 2023, less than half of the respondents to a nationally representative study knew a lot or a fair amount about DR products, despite public messaging (HM Government, 2023b)

Networks from the previous phase continue, but still no association dedicated solely to residential DR. Government attempts to set up a Flexibility Forum around the 2021 Smart Systems and Flexibility Plan, but it only meets twice, and its scope is broader than DR</td></tr>
<tr><td>Resource mobilisation</td><td>Market shake-up determined by the gas price spike results in consolidation of incumbents and fewer market entries
• 29 energy suppliers go out of business between Jul 2021 and May 2022 due to the sharp rise in wholesale energy prices (National Audit Office, 2022). Incumbents inherit most of their customer portfolios under Ofgem's supplier-of-last resort process</td></tr>
</table>

	• Octopus acquires customer portfolios from Upside Energy (2020), Bulb (2022), and Shell Energy Retail (2023) and overtakes British Gas as the UK's largest electricity supplier in 2024 reaching a 22% market share and serving 6.8 million households The trend in the previous period of incumbents upgrading IT infrastructure to support innovative customer propositions continues with Centrica acquiring ENSEK in 2024, a provider of digital transformation services with an innovative customer account management platform Innovation funding continues • The government’s £1bn Net Zero Innovation Portfolio (NZIP) allocates £100m to the Flexibility Innovation Programme for energy storage and flexibility innovation • NZIP also allocates £60m to the Heat Pump Ready Programme to accelerate the commercialisation of new clean energy technologies and processes • The Government’s Office for Zero Emission Vehicles commits £1.3bn to accelerate the roll out of charging infrastructure across the UK • Ofgem’s Strategic Innovation Fund launches in 2021 to invest £450 million by 2028 to transform gas and electricity networks for a low-carbon future
Development of positive externalities	The Turndown Trial legitimises DR with the ESO as a security of supply instrument, leading to the creation of the DFS which in turn legitimises DR with incumbents and the public. The DFS also legitimises manual DR (Energy UK, 2024) The smart meter rollout workforce can be retrained as incumbents move towards installing ESAs • <u>Interview energy supplier (Nov 2022):</u> Because we have so much workforce in house, we'd rather use them than outsource. For technology, Centrica Hive is part of our portfolio. We're very conscious of the power of the brand. I always say that the thing that keeps Centrica Group going is our engineering workforce. I think they're so beloved by customers. Yeah, there was a survey done about who are the people who are the most likely to let into your house. And, interestingly enough, the top person was fireman, unsurprisingly, second was paramedic, and the third was a British Gas engineer, above a policeman. And it's all part of the process. So, for example, I visited our training centres for new engineers. There is absolutely no engineering requirements. In applying to be a British Gas engineer, the only thing that's important is your attitude to customer service. And once that's been checked in the interview, then all the training is done. And that's why there's so many people who are loyal to British Gas, especially elderly customers who know that they'll always get good treatment from these people.

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