Article:

Gillham, E. orcid.org/0000-0001-8908-6178, Nolden, C. orcid.org/0000-0001-7058-445X, Banks, N. et al. (3 more authors) (2023) Facilitating application of the energy service concept: Development of an analytical framework. Energy Policy, 178. 113584. ISSN 0301-4215

https://doi.org/10.1016/j.enpol.2023.113584

Energy Policy 178 (2023) 113584

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Facilitating application of the energy service concept: Development of an analytical framework

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ARTICLE INFO

Keywords:
Energy services
Analytical framework
ESCOs
Private residential
Flexibility service contracting
Place-based energy system integration

ABSTRACT

It is widely acknowledged that the servitisation of energy retail has the potential to reduce costs and environmental impact. However, there persists a limited awareness of what market activities the energy service concept can translate into, especially in Smart Local Energy Systems (SLES). In this paper an analytical framework is developed, tested, and applied to help clarify the energy service concept, assess where its application is most appropriate in such systems, and facilitate a more strategic approach to value creation at both household and systems level to support the transition to net zero. First, we develop it through a content analysis of the energy service field's most cited papers. Second, we test its boundaries at household level through a round of interviews. Third, we demonstrate its relevance at the energy systems level by applying it in two SLES contexts. Its application revealed that focusing on value creation through material-centric energy services alone is unviable while their coordinated integration into SLES involving centralised data-centric activities creates a potential business case around network reinforcement savings and flexibility provision. For the energy service concept to succeed in the residential sector, contractual service offerings require place-based energy system integration to align with network characteristics.

1. Introduction

In recent years, service-based subscription models have revolutionised traditionally product-based industries including manufacturing, software, telecommunications, music, and film (Lozic, 2020). Servitisation of the energy sector is considered to have an equally transformative potential, with widespread environmental, economic, and social benefits (Nolden and Sorrell, 2016). The concept of an energy service arises from the recognition that people do not desire energy itself, but the services it provides. End-users do not have a direct motive to buy equipment (e.g., a boiler) and units of energy (e.g., kWh), but instead purchase them to achieve a more advanced objective (e.g., a warm home). Under an energy service approach these end-user needs are met directly (Sorrell, 2007; Nolden et al., 2016).

The potential benefits of the energy service concept are well recognised (Kalt et al., 2019; Brown et al., 2022). Energy service models focus on consumer outcomes, and thus incentivise the delivery of greatest value at least cost. Commonly cited benefits to consumers include lower energy consumption and costs, more consistent billing, greater access to energy efficient and low carbon technologies, and a better end-user experience. Potential advantages extend to energy suppliers, who can benefit from alternative revenue streams, competitive differentiation, access to demand side response assets, and the simplification of complex future energy markets. The energy service concept is considered to have the potential to not only accelerate decarbonisation, but also capitalise on the benefits of doing so (Hannon, 2012).

The body of academic work published to realise the potential of energy services has grown exponentially over the past decade (Fell, 2017). Many of these studies aim to reveal barriers and enablers of the concept in selected contexts, such as housing retrofits (Tingey et al., 2021; Fell, 2021; Brown et al., 2022) or energy management (Dobes, 2011). Despite this growing body of work, service approaches remain a niche activity across the energy sector, representing less than 1% by revenue (Clarke, 2018). At the same time, flagship energy service

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https://doi.org/10.1016/j.enpol.2023.113584
Received 30 June 2022; Received in revised form 29 March 2023; Accepted 16 April 2023
Available online 10 May 2023

policies such as the UK's Green Deal have failed to deliver, and business models struggle to find traction beyond he public sector (Nolden and Sorrell, 2016; Rosenow and Eyre, 2016; Boza-Kiss et al., 2019).

In this paper it is reasoned that the concept's low adoption rate has been exacerbated by a poor understanding of the conditions in which the energy service concept may prosper, despite best efforts in capturing the nature and scope of energy service markets, business models, and markets throughout the years (Bertoldi and Boza-Kiss, 2017; Boza-Kiss et al., 2019; Brown et al., 2019a, 2022; Hansen et al., 2020; Marino et al., 2011; Nolden and Sorrell, 2016; Sorrell, 2007). In particular, the focus on household benefits resulting from Energy Service Company (ESCO) control over energy supply and conversion assets needs to be accompanied by a systems perspective to take account of grid service provision, maximise societal benefits, and improve the business case (Banks and Darby, 2021; Ford et al., 2021; Walker et al., 2021; Banks, 2022). Both a better understanding of what market offerings the energy service concept can translate to, and a better strategy to determine which contractual offerings are the most promising, is therefore required to improve the prospects of the concept's adoption.

This paper develops a viability framework, tests it, and applies it to help clarify the energy service concept and facilitate its strategic application in the private residential sector by taking into account of household and systemic benefits, involving the following steps.

1. Framework development taking into account both the household level of domestic energy service provision between data, fabric, and value and an energy system perspective which takes account of the increasingly decentralised nature of assets towards the grid edge
2. Testing the role of data and fabric as value boundaries of the framework in domestic energy service provision at household level through an analysis of data from interviews with academics and sector experts
3. Demonstrating its relevance as a validation framework at the energy systems level by applying it in two SLES contexts, Project LEO and CommuniPower, which draw attention to value creation within these boundaries

The private residential sector was chosen due to its historically poor penetration of energy service initiatives, and acute need for guidance towards decarbonisation (OBR, 2021; Wade and Visscher, 2021). Meanwhile, the growing penetration of intermittent supply of electricity from renewable sources is coinciding with a diversification of demand as a result of heating and transport electrification. These require careful balancing to maximise benefits at the systems level, avoid the exacerbation of inequalities at household level, and accelerate decarbonisation.

Project LEO represents a top-down SLES which integrates the private residential sector into flexibility service markets by focusing on data capturing and management. This Distribution Network Operator-led approach encourages supply and demand balancing at a local level as an energy services to the electricity distribution network. CommuniPower seeks place-based energy system integration by combining such flexibility services with energy supply contracting and retrofitting among households. This community-led approach to SLES seeks to lower system costs and optimise energy service provision by harmonising investments in local supply and demand alterations.

The remainder of the paper is structured as follows: in Section 2 the methodology used to develop, test, and apply the energy service framework is detailed. In Section 3 the literature on the energy service concept and existing analytical frameworks is reviewed. The framework is introduced, tested, and applied in Section 4. Implications are discussed in Section 5 and Section 6 concludes, highlighting policy implications and future research avenues.

2. Methodology

2.1. Framework development

The energy service framework was developed using a semi-iterative research strategy based on Straussian Grounded Theory (Corbin and Strauss, 1990; Bryant and Charmaz, 2019; Lambert, 2019). This enabled us to review a broad body of literature prior to undertaking research, thus helping to clarify its purpose, scope and impact; develop a conceptual framework; test the framework's suitability in the private residential sector; and apply it in SLES contexts to indicate its usefulness in analysing the viability of emergent energy service models.

Grounded Theory has been used in previous energy service research to investigate the influence of income on service adoption (Sovacool, 2011), the interactions between service and utility models (Hannon, 2012), and the human resources required for service offerings (Chitchyan and Bird, 2021). As in this paper, each of these studies aimed to discover new themes in an under-researched area of the energy service topic.

Terms used in reference to the energy service market were collected from literature as primary data. Through a process of constant comparative analysis, this data was used to develop insights into the energy service concept and guide the collection of new data. In a distinct final phase, developed insights were then translated into criteria which were used to guide the framework's construction.

2.1.1. Data collection

Definitions and concepts related to the energy service market were collected from academic papers using Scopus and Google Scholar. It should be noted that while academic search engines provided advanced search functionalities, they likely caused non-academic 'real world' interpretations of the energy service concept to be underrepresented. To gain an evolutionary understanding of the changing meaning associated with the delivery of energy services over time, data collection began with the search of the term 'energy services' every year from its first mention in 1955 (in the context of nuclear energy services, which according to Fell (2017) epitomises the ambiguity of the term) until 2021. For each year the three most cited papers were reviewed, and excerpts which provided new definitional insights collected.

This approach was taken because "the historic context from which definitions emerge is central to appreciating their ethos and maxims" (Suddaby, 2006). Only the three most cited papers were reviewed because they were considered to produce a less biased insight to the concept's interpretation than other methods of data reduction, such as the selection of a particular journal. As new terms relating to the energy service concept emerged during the initial phase of data collection, they were noted and their descriptions collected simultaneously. Terms which needed additional data by the end of the process were searched for individually in a second stage of iterative data collection and analysis.

2.1.2. Data analysis

The analysis of data began as soon as it was collected, as this allowed recurring terms to be identified quickly and subsequently included in the search. Each identified term was classified as a code that related excerpts could be stored under, as shown in Table 1. To generate greater insight from the data, categories were developed by grouping and comparing codes. The research process ceased when continued data collection and coding did not produce any new insights. A limitation of this method was that only concepts with identifiable terms could be assigned a code and thus investigated. Concepts which are either ancillary or are not attached to a particular term were therefore likely underrepresented.

An advanced stage of analysis in Straussian Grounded theory is the development of storylines (Chun Tie et al., 2019). In this research a storyline was developed by recording when new energy service terms surfaced, or older terms evolved, onto a timeline. This data

Table 1
Example codes and categories.

Analysis Element	Examples
Codes	'energy service'; 'energy services'; 'energy service company'; 'energy service provider'; 'energy performance contract'; 'energy supply contract'; 'chauffage'; 'energy as a service'
Category 1	Value proposition: Comfort; Efficiency; Convenience
Category 2	Actor: Construction Companies; Utilities; Technology Companies; Consultants
Category 3	Measures: Material; Non-material
Category 4	Definition grouped by decade

reconstruction helped to clarify how the concept of energy services had evolved, and highlight if any gaps in the research remained. The insights developed were used to create criteria that detail how to conceptualise the energy service market comprehensively with clarity, and thus how to design the energy service framework.

2.2. Testing the energy service framework in the private residential sector

The framework was tested using a fully iterative research strategy. Energy service experts were interviewed to refine the concept and understand how the concept may best be applied to the private residential sector. Through a process of constant comparative analysis, the energy service framework was used to deconstruct each interview and reveal the most promising areas of application. These insights were then analysed to identify key boundary characteristics with regards to data and fabric which could indicate an energy service's future prospects in the sector.

2.2.1. Data collection

Data relevant to the development of the framework was collected through interviews in 2021 with stakeholders in the energy service market. The first round of interviews involved academics who had conducted research related to the field, and were known to us. Remaining interviewees were selected by searching for experts in fields with complementary expertise. This search was either completed by recommendation from previous interviewees, or researching the sector and cold-calling. Interviewees represented all major energy service topics identified using the framework, which included a senior consultant specialising in XaaS (delivery of anything as a service), a utility company research director, the director of a retrofit company, and academics who specialise in energy market business models, the built environment, and demand side energy policy. Interviewees were selected using an iterative process to maximise the coverage of important issues highlighted by the framework and previous interviewees.

2.2.2. Data analysis

Interviews were transcribed and coded thematically by identifying recurring subjects and opinions, as shown in Table 2. The codes were then categorised to give insight to the connection between themes, and ultimately the prospects of different energy services in the residential environment. With the aid of the energy service framework the developed insights were deconstructed to identify key service characteristics that could indicate the potential of an energy service activity's success. It must however be recognised that the Grounded Theory research method limits the strength of broader conclusions, as the insights generated are only a reflection of the data they are based on.

Table 2
Example codes and categories.

Analysis Element	Examples
Codes	'Efficiency Barriers'; 'Efficiency Enablers'; 'Technology Barriers'; 'Technology Enabler'; 'Value Proposition'
Category 1	Service Archetypes: Flexibility, Retrofit
Category 2	Barriers: Technical, Social, Organisational, Innovation
Category 3	Service Prospect Indicators: Centralised, Decentralised, Material Flows, Information Flows

2.3. Applying the energy service framework

We applied the framework in two SLES contexts to demonstrate its relevance as a validation framework. This involved full immersion in the project teams during final project development and the secondary analysis of primary data gathered throughout the project development process. This data includes reports, funding bids, presentations, and supporting documents. In the case of LEO, it also includes interview data from four annual rounds (each following a simple topic guide with a total of 52 interviews which were all transcribed and coded using NVIVO and followed). We supplemented this project data with primary data collection in 2022–2023 including four interviews with stakeholders in the case of LEO and two workshops with stakeholders of CommuniPower.

2.3.1. Data collection

In both cases, guides were structured to focus on the benefits and shortfalls of domestic energy service provision both from a household and systems perspective.

Questions asked include.

- What contracts underpin spot-market transactions of domestic flexibility services? vs. What contracts translate long-term systemic benefits into household energy service benefit?
- What are the household benefits of enabling their energy service provision in flexibility markets? vs. What are the system benefits of enabling household and community coordination of energy service provision?
- Can data-focused business cases take account of difficult-to-measure features such as building fabric? vs. Can building-focused solutions harness data capturing innovations to improve the business case?

2.3.2. Data analysis

As the focus lay on value creation, which in turn depended on the commercial contractual arrangements which emerged from these proofs-of-concept projects which succeeded in improving technological and commercial readiness levels, this stage of data collection involved note taking rather than recording. Nevertheless, we occasionally use verbatim quotes where these were captured to exemplify a point. Data was transcribed using qualitative analysis software NVIVO. Applying the framework in these contexts helped draw attention to value creation opportunities at systems level alongside transaction barriers at household level. In this paper, we focus narrowly on the applicability of the framework to limit the word count.

3. A review of the energy service concept

In this section, we initially review literature on the definition of the energy service concept. Subsequently, we discuss existing frameworks which were developed to resolve this confusion surrounding what energy services encompass.

3.1. The definition of energy services

The underlying value of the energy service concept is well understood - energy is not consumed for its own sake, but for the services it provides (Kalt et al., 2019). Despite this established value, there are significant inconsistencies in the way the term 'energy service' is used and understood (Fell, 2017; Britton et al., 2021). Common illustrations range from boiler maintenance to heating, temperature control, or the provision of thermal comfort. The term is also used to refer to the active control of electricity supply, cooking food, and even the washing of clothes (Kalt et al., 2019). This broad application of 'energy service' has clouded its meaning, and as such there is no universally recognised definition for the concept (Morley, 2018).

In an extensive literature review of the journals Energy Policy and Energy Research and Social Science, Fell (2017) found 173 illustrative examples of the term, and 27 distinct definitions. Although no dominant interpretation of what is meant by an energy service was found, two broad themes emerged.

- 'Useful Energy/Work' - Energy services are the provision of useful energy or work in a form that is distinct from the energy itself.
- 'Benefit' - Energy services are the benefits to human well-being or society that are derived from the provision of energy.

These themes highlight a conceptual divide regarding how far down the value chain the term 'energy service' is thought to extend. While some consider an energy service to end with the delivery of useful energy or work, others believe it ends with the human experience. Although Fell's study was the first to reveal this divide in wider literature, it was not the first time the distinction had been considered in conceptual work. While some have argued that useful energy and its resulting benefits are discrete concepts (Nissing and Von Blottnitz, 2010; Sovacool, 2011), others believe that there would be no way to identify that work is useful if its use has not first been clarified (Day et al., 2016; Haas et al., 2008).

Similarly, the concept of 'energy services' suffers from an ill-defined market scope, with questions raised as to 'what is entailed', or what the market's 'boundaries' and 'borders' are as shown in Table 3. Explanations for this poor market identity commonly refer to the complexity of the market's offerings, the variation in terminology between countries, and the diversity of the market's players and contexts (Boza-Kiss et al., 2017; Hannon, 2012; Nolden and Sorrell, 2016).

In the entrepreneurial context, energy service activities are often described in terms of business models known as energy service contracts. These contracts are therefore central to how energy services are conceptualised in practice. There is a wealth of literature on energy service contracts, discussing their definitions (Sorrell, 2005; Wargert, 2011), respective strengths and weaknesses (Sorrell, 2007; Hannon, 2012), drivers and barriers (Boza-Kiss et al., 2017; Brown et al., 2019a; Marino et al., 2011; Nolden and Sorrell, 2016), and market performance (Larsen et al., 2012; Nolden et al., 2016). Recent studies have sought to shed light on the history (Fell, 2021) and the scope of residential energy service business models (Brown et al., 2022).

Table 3
Extracts highlighting the ambiguity surrounding the energy service market.

Sources	Extract
Boza-Kiss et al. (2017)	"The energy services market is still characterised by definitional confusion"
	"Differences in the interpretation of what is entailed by Energy Services Company (ESCO) still exist among experts and stakeholders in the field"
Kindström and Ottosson (2016)	"As a concept [industrial energy services] are still characterised by definitional confusion"
Nolden and Sorrell (2016)	"With such a diversity of companies and activities, the boundaries of the 'sector' are unclear and there is no single trade association"
	"Various definitions of energy service contracting have been proposed, but few satisfactority describe the diversity of contractual arrangements that are available or the range of activities involved"
Wargert (2011)	"Energy services are a very wide concept without any clear boundaries"

3.2. Energy service business models and frameworks

The ambiguity of energy service contracts nevertheless means that not only is the scope of the energy service market unclear, but so are the distinctions between its activities. To help clarify the concept, energy service frameworks have been developed to help "assess the feasibility of energy service contracting in different circumstances". Such frameworks aim to clarify the scope of an energy service contract by highlighting which energy streams are included (e.g., electricity, hot water, heating). The most cited one by Sorrell (2005, 2007; Fig. 1) enables the analysis of each stream using two checklists - one for contract depth and one for finance. Depth covers how each energy stream is controlled (e.g., asset ownership, maintenance, operation), and finance covers how the service is funded.

Sorrel's conceptual model clearly illustrates how energy streams and assets interact, and how value is delivered at each stage in the chain. However, the model was only ever intended to differentiate between supply and performance contracting models, and is therefore unlikely to be comprehensive. What it does cover is increasingly outdated – alone in twelve years after it was published, the body of literature on energy services had increased by a factor of 7 (Fell, 2017).

Another framework, the 'service ladder', was introduced by (Kindstrom and Ottosson, 2016) to help "visualise the various types of energy services". As seen in Fig. 2, the model shows how energy services can extend over different levels of complexity, from information analysis through to comfort-based performance contracts, and ranks each service based on the energy efficiency savings achieved. Although potentially comprehensive, the model assumes all activities lead to some level of efficiency savings, and gives a poor indication of what each activity involves. The use of unintuitive titles such as 'information', 'analysis', 'activities' and 'performance' exacerbates this, making it difficult to derive what energy services means from the diagram.

Business model frameworks (BMFs) are a third tool that has been used in literature to describe and understand energy service activities. First introduced by Osterwalder and Pigneur (2010), they are a collection of categories which can be used to classify and clarify the major aspects of a business model. In the energy service literature they are most often used to compare service models to alternative business models, such as prosumer business models (Brown et al., 2019b), utility models (Hannon, 2012), domestic energy service business models (Brown et al., 2022), or models for specific activities such as retrofit projects (Brown, 2018; Brown et al., 2019a).

In each application of the BMF found, a generic 'energy service model' has been compared to an alternative business model. This means all of the most general characteristics of an energy service offering have been bundled into one singular business model. Given the complexity of the energy service concept, and the variety of business models it inspires, the use of BMFs in this way is not a productive way to conceptualise the market. The use of a BMF to compare different energy service business models may however be more illustrative (see Brown et al., 2022).

Given this conceptual ambiguity, we develop a framework to clarify the energy service concept and assess its prospects in different context. To test its efficacy, we apply it to two cases of energy servitisation in the UK's private residential sector which has historically witnessed low penetration of energy service initiatives although they are potentially critical to lowering energy demand and mitigating climate change (Brown et al., 2022). In doing so, we demonstrate its usefulness and identify where the energy service concept has the greatest market potential in the private residential sector.

4. Development, testing, and application of the energy service framework

Insights derived from this analysis of the energy service literature were divided into two major themes. These themes cover the scope of

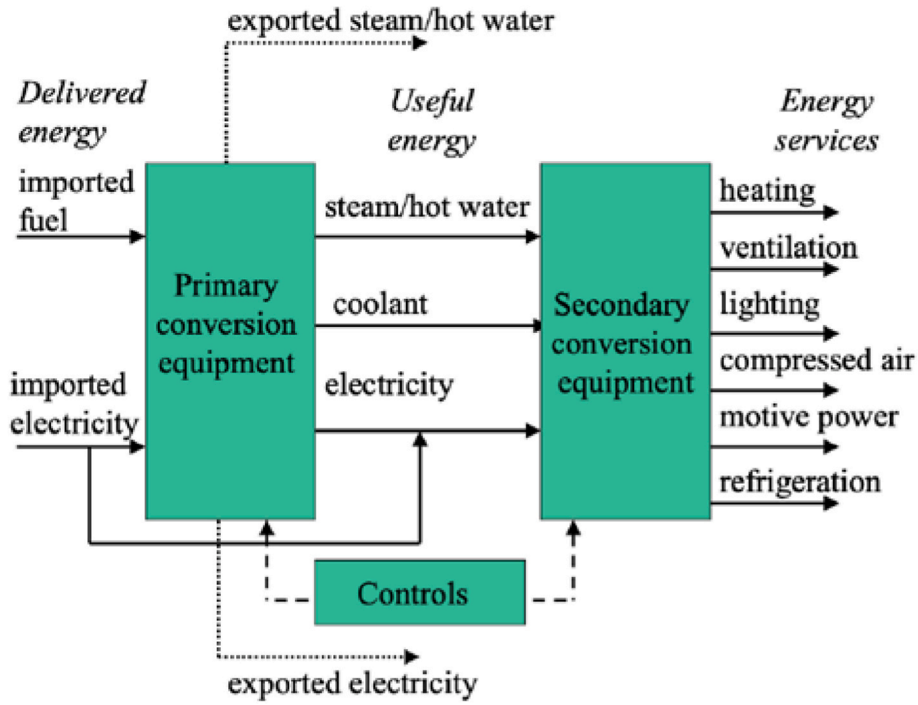

Fig. 1. Framework of the scope of an energy service contract (Sorrell, 2005).

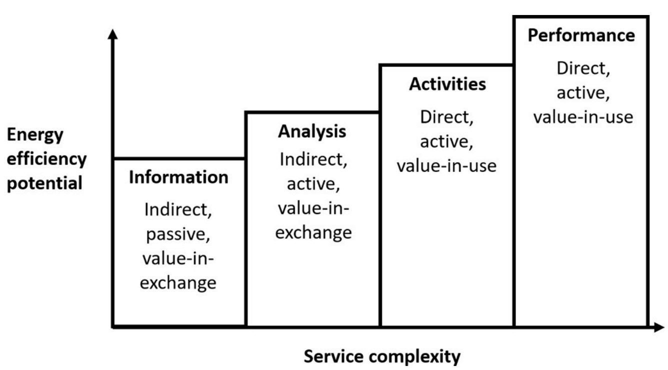

Fig. 2. Energy services ladder (Kindström and Ottosson, 2016).

the energy services concept, and the source of the concept's ambiguity. They therefore indicate which phenomena to include in an energy service framework, and how to do so with the greatest clarity. Next, the framework was tested through interviews. Finally, it was applied in two SLES contexts.

4.1. Developing the energy services framework

4.1.1. An energy system perspective

The scope of the energy service market was found to extended across the energy system's value chain from its popularisation in 1980 to the time of completing this paper in 2023. An energy system perspective was noted in the language that is used to describe market activities. Activities were often categorised by features of the energy system, such as whether they were centralised or decentralised, rather than technical demarcations like primary or secondary conversion equipment.

All stages of the energy value chain - primary energy, useful energy, and useful work - were found to be direct contributors to energy services and how they are conceptualised. Better windows or insulation can be installed to maximise the impact of primary energy (solar), heat networks can be installed to provide useful energy (hot water), and distributed equipment can be installed to deliver many varieties of useful work. All energy streams should therefore be recognisable in a conceptual model.

4.1.2. Energy, material, and information flows

An important aspect of the market's scope was found to be the inclusion of phenomena other than energy, especially fabric and data. It was found that these phenomena were often not just an accessory to activities in the energy service market, but often boundaries of service provision and increasingly central to their identity. For example, many energy services depend on a building for the delivery of useful work and some associated business and market models focus exclusively on building fabric retrofits (Brown, 2018; Brown et al., 2022).

Similarly, energy services can consist only of the flow of information, such as audits or smart system analytics, especially in the context of flexibility service provision through the temporary suspension of energy streams enabled through the flow of data (Banks and Darby, 2021; Banks, 2022). Between these extremes of purely fabric or information services, there is a whole spectrum of energy services that are at least partially defined by the involvement of data or fabric. Building fabric and data are therefore both core foci of specific models and boundaries of any conceptual model.

4.1.3. Service benefits

The human experience, not technology, was found to be a common and clear way of distinguishing types of energy service, as the following quote from a participant in Project LEO suggests:

> *"We really need to drill down into, instead of working from a technology point of view to put something in place, identify what people actually want [...] we really need to look at the offering to the customer, and then figure out the technology side of things"*

While previous literature emphasises that the ultimate benefit of energy services is human well-being (Fell, 2017), this research has found that services are more likely to be described in terms of their value creation benefits, including value chains and revenues. Although financial benefits and value propositions are a key component both of the BMF (the interaction between 'Cost structure' and 'Revenue streams') and energy service benefits, value creation is rarely considered in the context of energy service (see Brown et al., 2022 for a notable exception).

4.1.4. Association of energy services with efficiency

The energy services concept was found to be fractured between 'traditional' literature on energy service contracting, and a more modern discipline called Energy as a Service (EaaS) which has evolved out of Heating as a Service (Fell, 2021; Brown et al., 2022). Until the 1980s, energy services were synonymous with energy efficiency (Hansen et al., 2020). This changed when utility companies entered the market in the 1990s (Dayton et al., 1998), as their control over electricity supply allowed for new services like load management as well as commodity sales and delivery (Kennedy and Simpson, 1999; Ng, 2000; Rufo, 2001; Vine et al., 1998).

However, as a consequence of the (2006/32 EC) EU Energy Services Directive, which states that energy services must lead to "efficiency improvements and/or energy savings" from a "combination of energy with energy efficient technology" (Boza-Kiss et al., 2017), the conceptual understanding of energy service contracts regressed back to a focus on energy efficiency in the 2000s. The conceptual regression is such that over 4/5ths of contemporary energy service contracting papers reviewed still refer to an efficiency-centric definition, and focus on traditional service models funded by efficiency savings (Boza-Kiss et al., 2017; Irrek et al., 2013; Nolden and Sorrell, 2016).

In the early 2010s, EaaS emerged as a new term to describe load management services and 'improving user experience' (Weil, 2018, 2019) enabled by advancements in communications technology (Altamimi et al., 2012; Cleary and Palmer, 2019), sometimes introducing energy services as if they were a novel idea (Weil, 2018). While the EaaS branch of energy services shares many features with traditional energy service contracting, an identity dependant on efficiency is not one of them. It has remained distinct from energy service contracting, which has largely failed to move beyond a focus on energy efficiency and well established technologies (Britton et al., 2021; Acuner et al., 2021). We thus find the energy services concept to be fractured between the 'traditional' literature on energy service contracting and the more modern discipline of EaaS.

4.1.5. Consistency of business model terminology

An inconsistency was found between how countries refer to energy service business models and activities. For example, for the same period of time Contract Energy Management in the UK (Nolden and Sorrell, 2016) and Chauffage in Europe (Duplessis et al., 2012) both referred to the supply of useful energy, such as hot water in heat networks (see also Heat as a Service; Fell, 2021). Similarly, at the same time Integrated Service Contracts in the UK (Bertoldi et al., 2006) and Retail ESCos in the USA (Dayton et al., 1998) both referred to the combination of energy supply and control of secondary conversion equipment. This inconsistency has likely exacerbated the ambiguity of what the term energy services means in application. A confusion over the definition of business models was also found to arise because of their evolution over time.

4.1.6. The energy service framework

Insights from literature were used to devise the energy service framework shown in Fig. 3. The framework takes a systems perspective, showing the flow of energy from primary resources through centralised and decentralised (household) assets to a final energy service benefit. It illustrates the key energy service market assets, how they interact with data flows, and how they may be used to convert primary energy into useful energy or work. These assets are grouped using a criterion of centralised or decentralised instead of asset function to make the human dimension, especially around household buildings, more tangible. All energy flows are shown to have the potential to contribute to a final energy service, and the benefits of these services highlighted using criteria that distinguishes indirect, direct, and financial components. All research insights, summarised in Table 4, were therefore used to develop the model.

Table 4
Tools to conceptualise the energy service market.

Key Conclusions	Extract
Scope: Take an energy system perspective	1 Market activities are categorised by features of the energy system, such as centralisation or decentralisation, rather than technical demarcations like primary or secondary equipment. 2 The flow of phenomena other than energy are defining characteristics of the energy service market, with activities being wholly or partially defined by the involvement of information or materials. 3 The benefits of energy services are a key part of the market's identity, and an important way to distinguish between different energy services. 4 All stages of the energy value chain provide service benefits, from primary energy, to useful energy or work.
Clarity: Avoid divisive or exclusive terminology	1 Terms and definitions used to describe energy services or business models evolve frequently, are used inconsistently, and are often disputed. Their omission makes a conceptual model more approachable, and more relevant over time. 2 Efficiency is a key and often defining part of energy service activities, but it should not be defined as an essential characteristic.

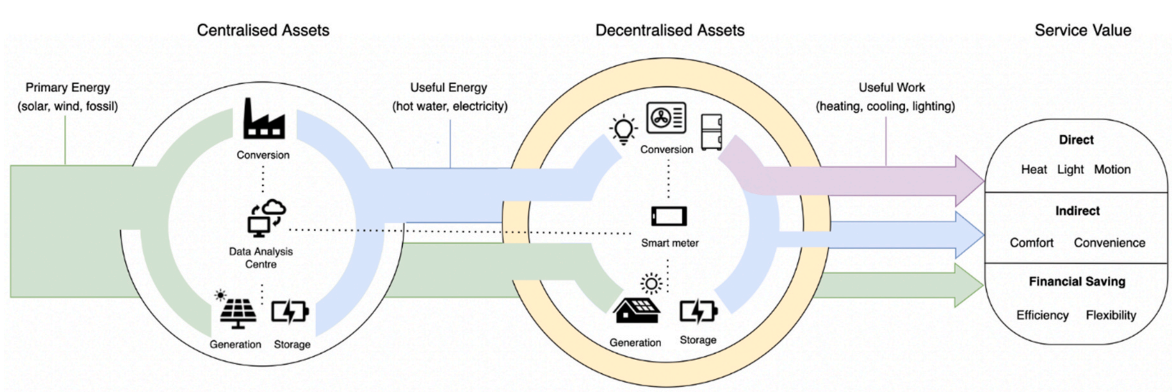

Fig. 3. The energy service framework.

4.2. Testing the energy service framework in the private residential sector

The purpose of the energy service framework is to support a more strategic application of the energy service concept. In this paper the UK's private residential sector was chosen to test the framework's efficacy due to its poor penetration of energy service initiatives (Hannon, 2012), and need for directional guidance in reducing carbon emissions (CCC, 2021; OBR, 2021; Wade and Visscher, 2021).

Private housing accounts for over two thirds of the residential sector's emissions, and represents more fuel poor families than any other housing tenure (BEIS, 2021). In recognition of this, in 2015 the UK government rolled out the Green Deal; an energy service approach to retrofitting the domestic sector. However, this programme was delivered to less than 0.1\% of the 14 million houses anticipated to benefit, and is seen as a dramatic policy failure (Rosenow and Eyre, 2016). It therefore remains unclear if and how the energy service concept can be applied to the private residential market, making it an excellent use-case for the energy service framework.

4.2.1. Interview results

Through testing of the framework in the above described interview process, data-centric flexibility services and material-centric retrofitting services emerged as both core foci of specific models and boundaries of the domestic energy service model. Between these two 'viability boundaries', a range of energy supply, service, and performance business models have been identified (Brown et al., 2022).

4.2.2. Flexibility services

The term 'flexibility services' refers to any energy service model which uses data and IT to remotely control equipment and generate money through demand side flexibility (distributed generation, storage, and demand response). This equipment could include solar PV, batteries, heat pumps, and refrigeration units. The key characteristics of a flexibility service are highlighted in Fig. 4. Such service are most closely related to EaaS, which uses IT to provide an agreed level of comfort at the lowest cost, but also applies to performance and supply contracts. Only recently have such business models been successfully trialled in domestic settings as part of innovation projects such as Project LEO.

There was generally a lot of enthusiasm among the interviewees regarding the viability of this energy service business model in the private residential sector based on the belief that this business model provides "a way for service providers to monetise flexibility" while providing added consumer value such as bill stability and thermal comfort. Added consumer value arises from the vision of a flexibility service provider taking control of decentralised assets such as heat pumps and optimising agile tariffs to deliver useful work (ambient temperature) at the lowest possible cost.

Interviewees anticipated a healthy demand for flexibility services because "it's one of the key measures to be able to make that shift to the renewables-based system that we know we need". At the same time, they recognised that "flexibility is complex, and individuals are not always best placed to make decisions about that". Even if they could, they cautioned that "no one is going to put in the hours of effort to optimise when an asset runs" to make the most out of agile tariffs.

This depends on the value proposition and many interviewees suggested that you needed "to improve the status quo if you were to make people want something", and this could be achieved by delivering a superior level of comfort. However, another opinion was that "the culture of UK residents is to be comfortable with their discomfort". Interviewees recognised that many people's living conditions can improve, but that some simply see defects as an inconvenience that they have become accustomed to. An example of this behaviour discussed was always having the window open in a certain room when it is too hot in the summer. Interviewees believed that preventing such mild inconveniences would not be considered by the public to be worth such large upfront costs and potential disruption to their home to avail of minor benefits.

The level of control that service providers would have over technology in an end-user's home was highlighted as a potential area of concern. All interviewees stressed the importance of letting people retain the ability to switch the lights on or have a shower when they want to. As summarised by one interviewee:

> *"We need to be careful not to over-fit these things. We need to carve out a space where companies can make money through service contracts and demand side flexibility, but also where consumers can have flexibility in their lives to be spontaneous."*

A suggested solution to this issue was to put the focus of flexibility services on assets that are cycling in the background, such as a fridge or heat pump. This was because these assets "already have some control logic turning them on and off, if there was more information feeding into that logic then I wouldn't mind or know.".

Flexibility services rely on taking advantage of electricity markets, however there are several technical barriers to overcome before this can be realised. The most critical of these is the "need to normalise agile tariffs" and arbitration. These are explored in greater detail below where we apply the framework to household flexibility service provision in local energy service markets.

4.2.3. Retrofit services

Improving the building fabric represents the other 'viability boundary' of private residential energy service models. These are referred to as 'retrofit services' and involve any energy service model which installs fabric measures, such as insulation and better windows to achieve improved energy efficiency. The services key characteristics are highlighted in Fig. 5.

Almost all interviewees believed a retrofit service by itself is unlikely to progress beyond niche application, and none believed it would reach

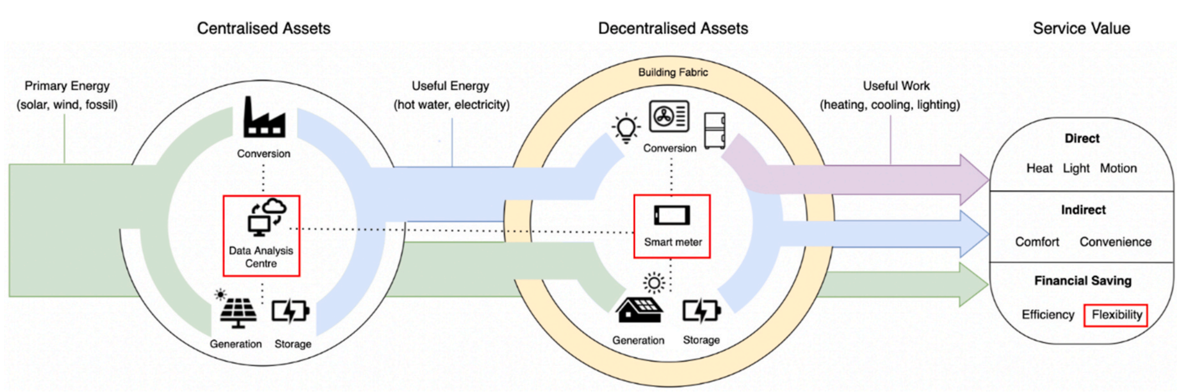

Fig. 4. The data-centric flexibility service 'viability boundary'.

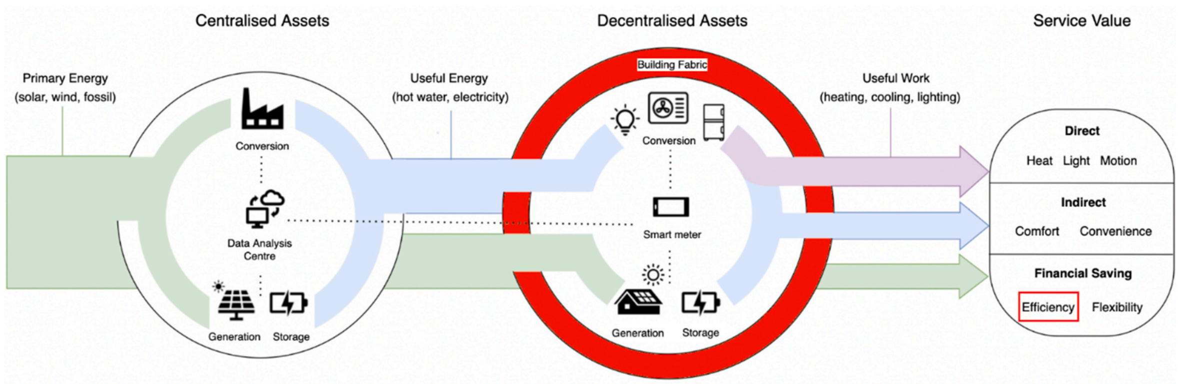

Fig. 5. The material-centric retrofit service 'viability boundary'.

mass market in the private residential sector.

> *"A retrofit, where there is a lot of energy efficiency measures put in through a performance contract on individual owner occupied households, that seems difficult"*

Providing retrofit services in isolation is unlikely to succeed because "the construction sector lacks innovation", and is unlikely to stray from its "well entrenched design and build model" (a topic discussed further in Killip, (2020). One of the main reasons for this is the lack of economies of scale in the retrofitting market. To make this energy service model work in the private residential sector, it requires collaboration among SMEs, financial institutions, government, and utility companies. Building SMEs and utility companies in particular are traditionally distinct enterprises that would need to have better cohesion. Some interviewees commented on this, however all suggested that there would be an organisational difficulty in mobilising the building sector's highly fragmented and small scale SMEs:

> *"It is too difficult to encompass SMEs providing insulation into a service model - there are lots of small players, different business models, a fragmented industry, and low visibility for the customer"*.

Interviewees also brought up many social barriers to service retrofits that are discussed in the literature (Satu and Kirsi, 2014). These include asset ownership disputes in multiple occupancy buildings, and the risk of consumers switching providers before capital intensive materials have been paid off. Solutions to these issues are not facile, as "forcing long term contracts can result in exploitation" as a result of opportunism (Nolden et al., 2016). Better regulation could lower opportunities for opportunities and exploitation:

> *"if you could introduce more certainty in the policy environment, then the efficiency models may be easier to execute. It would mean there is less risk about offsetting the upfront cost with the long term cost saving"*

A common concern not readily found in existing literature was consumer responsibility - "what does the householder have to agree in return?". This is the concern that an end-user's quality of life may be reduced. To ensure the energy bill drops by the amount expected in the service contract, would end-users have to promise that "3 more people won't move in, they won't have dinner parties, and they won't open the windows"? This issue is inherent in the proposition of a retrofit service, and emphasises the added complication and risk of decentralised ventures.

4.3. *Applying the framework in smart local energy system*

We applied the framework in two SLES contexts to verify the outcomes of the test which suggest that in the private residential market, flexibility services have greater prospects than retrofit services. For retrofit services to develop momentum, significant intervention is required to support capital costs, reduce operational risk, and improve stakeholder cohesion. By themselves, they are therefore better suited to regulatory than market approaches.

Flexibility services are thought to be promising because they can reduce the operational cost of low-carbon technology for consumers, while providing added benefits like thermal comfort. However, they rely on the popularisation of agile tariffs, and a regulatory drive for thermally efficient homes that can capitalise on such tariffs. The adoption of flexibility services was also found to require an improved understanding of how to integrate physical assets, and the value proposition to the consumer.

4.3.1. *Project LEO and household energy service integration in flexibility markets*

A complication of the flexibility service concept is how to integrate domestic assets into service contracts (Banks and Darby, 2021; Banks, 2022). As an innovation project, Project LEO received nearly £15m in government funding which was matched by nearly £30m of private sector funding. It sought to understand the role in local flexibility markets in deferring costly network reinforcements in light of increasing penetration of fluctuating electricity supply from renewable sources and increasing transport and heating electrification. As part of this proof-of-concept, it provided generous support to make domestic assets flex-ready, thereby overcoming the key barrier to commercialisation: upfront costs. In commercial market settings, external support is necessary as transaction revenues in such markets do not cover the investment costs:

> *"Just to be able to remote schedule the chillers, the amount we paid to automate that was quite high. I think we paid like 1600 pounds, which is quite significant and definitely not recovered through [revenues received during] Trial Period 2"*

> *"If you look at it just based on the actual costs just now for the system as it stands versus the offering that they get, the numbers don't add up."*

However, if flexibility was in-built and a contractual element of purchasing assets, any gain through flexibility provision would not stand in contrast to transaction costs incurred, especially if these assets were controlled remotely through data and IT.

4.3.2. *CommuniPower and community-led place-based energy system integration*

In isolation, it is "difficult to estimate the efficiency savings that can be attributed to installed measures" and due to the poor standard of retrofits there is "no way of knowing what the quality of an intervention will be, so it's very hard for firms to guarantee there will be a certain level of savings". All interviewees, even those who thought retrofit projects could be servitised, thought that other alternatives were more likely to create an impact on the residential retrofit market.

The centralised provision of useful energy, often known as supply contracting was briefly mentioned by interviewees, with unanimous agreement that these projects (e.g., heat networks) were better suited to social housing. All interviewees believed that centralised useful energy supply had a small potential market share of private housing, with one estimating that the "maximum possible market penetration is no more than 5%". The activity's potential was thought to be constrained by the need for densely packed housing, and the combined support of multiple tenants, the public sector, and the private sector.

Several interviewees mentioned Energiesprong as a business model to provide such retrofit services. It is "an innovative solution which has centralised the design and construction of its retrofits", thereby reducing the cost of installed measures and the risk of their under-performance. However, due to the need for a uniform housing stock and large contracts to reduce manufacturing costs, in its current form Energiesprong was considered to be more applicable to social housing.

CommuniPower seeks to combine aspects of centralised supply provision with Energiesprong's centralised design using a system's perspective. Through digital twin building using over 16 million data points accumulated in the 700 homes in and around the village of Barcombe in East Sussex, it gained a holistic understanding of both decentralised retrofit requirements and outcomes at a village level and centralised benefits from a coordinated approach at a systems level. It pursues a planned and integrated approach particularly suited to off-gas-grid villages where network reinforcement costs could derail decarbonisation efforts if each household pursued decarbonisation individually, which results in suboptimal decision-making.

In the case of Barcombe, an uncoordinated installation of just 340 heat pumps would entail grid reinforcement costs of around £5m. By building a digital twin, CommuniPower revealed that its community-led approach can deliver a 20-75% saving in network reinforcement costs by avoiding repeat work. Across the local distribution network, such a coordinated approach could save £40-70m in reinforcement costs. Such savings, however, are privatised while getting households heat-pump ready by investing in energy efficiency measures plus the cost and installation of heat pumps amount to around £35k per household. There is currently no effective mechanism to translate these privatised network reinforcement savings into service value for investment and financial savings among households.

5. Discussion

Developing and testing the energy service framework revealed the 'viability boundaries' of building fabric on the one hand, and information and data on the other. Building fabric, especially in the context of energy efficiency retrofits, are expensive and require advanced skills to install and long contracts to pay off. While such contracts exist, they are not known to have been successfully applied in the private residential sector as they are challenging to finance and are not reliable enough for long term performance contracts necessary to pay off investments. In comparison, services which are centred on information are far less capitally intensive, carry less risk, and can be used for a spectrum of applications, including generation, storage, and demand side response. This 'viability boundary' promises greater integration of domestic energy service integration into energy system solutions.

Applying the energy service framework suggests that the coordination of domestic energy services was found to be an important indicator of its ability to scale, and much of this coordination is enabled through better data capturing and exchange, as well as associated value attribution. While economies of scale are known to play a key role in the viability of energy service delivery (2007), by applying our framework we can reveal the disparities between benefits accruing to owners and managers of centralised energy system assets and costs concentrating among owners and users of decentralised assets. This is supported by earlier findings which suggest that energy supply contracts, which generate useful energy centrally, have proven more successful than decentralised performance contracts in the UK (Hannon, 2012).

Thanks to increasingly granular data flows, opportunities to coordinate residential energy service provision between centralised and decentralised assets increase. The provision of flexibility services by decentralised assets to the owners and managers of centralised assets, however, produces insufficient and unpredictable revenues to warrant their retrofitting to make them flexibility-ready, as Project LEO demonstrated. On the other hand, the coordinated installation and management of decentralised assets combined with centralised flexibility services integration at the distribution network level, as CommuniPower indicated, supports the emergence of integrated place-based energy service business models if centralised savings can be translated into decentralised investments.

6. Conclusion and policy implications

The widely acknowledged potential of the domestic energy services concept has so far failed to come to fruition. This is despite flagship policy commitments such as the UK's Green Deal in 2015, and an exponential rise in research publications over the last decade. In recent years there has been a notable increase in publications focusing specifically on emergent energy service models targeting households. It is pertinent to understand under which conditions the energy service model is most likely to succeed. A more strategic approach to the application of the energy service concept is needed.

The framework developed here has been tested and applied as a tool to understand the domestic energy service concept, and assess where its application is most appropriate. The framework is based on insights from the content analysis of 66 years of publications in the energy service discipline - each framework characteristic is a reflection of the insights generated. The key characteristics of the derived framework are a systems perspective, centralised-decentralised structure, inclusion of information (data), material (fabric), and energy flows, and illustration of energy service and system benefits.

An important insight found during the framework's development, testing, and application is that much of the conceptual confusion surrounding the energy service market derives from its association with efficiency. A traditional, more dominant view of energy services, often referred to as energy service contracting or energy performance contracting, is closely linked with improving efficiency. This traditional association has appeared to constrain how the scope of the market is understood, and causes forms of energy service that do not improve energy conversion efficiency to be overlooked. This source of ambiguity has not been directly addressed before, and it is hoped its recognition in this paper will help to clarify the concept's scope.

The UK's private residential sector was used to test and apply the energy service framework. The framework was guided by, and tested through, a series of interviews which asked where the energy service concept has the greatest future prospects in the sector. It revealed that centralised energy services based on the flow of data, such as demand side flexibility services, have the greatest market potential in the private residential sector. The value proposition of such a service, how to integrate assets into the business model, and how to best manipulate agile tariffs were therefore all identified as necessary and worthwhile future areas of research.

We applied the framework in two Smart Local Energy Systems (SLES) contexts, Project LEO and CommuniPower. These revealed promising EaaS innovations although current attempts to integrate households into both flexibility markets and place-based energy system integration are uneconomical at this proof-of-concept stage. However, coordinating the integration of decentralised household assets and capturing and apportioning the value of coordination in terms of deferred or avoided grid reinforcements costs as a result of avoided repeat works at the centralised asset level can create a business case for domestic energy service provision. In this context, our framework needs to be understood as one of many tendrils of the energy system with useful work and households to the right of Fig. 1.

Overall, the development, testing, and application of our framework suggests that the least appropriate applications of the energy service concept to private homes were found to be decentralised and material intensive, i.e., fabric improvements. These are lengthy, capital intensive ventures that are high risk and low return, and require collaboration between multiple otherwise unfamiliar stakeholders. These qualities are characteristic of housing retrofit services, which have been a long term focus of energy service policy and research. Those that provide energy services towards the centralised energy system, for example flexibility services, are emergent and promising, but by themselves do not provide sufficient revenues to warrant investment in decentralised assets to make them flexibility-ready.

A coordinated approach, on the other hand, suggests that domestic energy service provision can be aligned with decarbonisation targets if it is approached through an energy systems perspective. This requires a combination better data capturing approaches among decentralised household assets, which has been explored in the context of flexibility provision, with information on constraints among centralised assets in the context of increasing heating and transport electrification. However, further research is required to validate these findings and establish the usefulness of this framework in other contexts, both in relation to housing and areas such as the public sector, retail, and commercial office space.

CRediT authorship contribution statement

Euan Gillham: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft. **Colin Nolden:** Methodology, Validation, Formal analysis, Investigation, Writing – review & editing, Project administration, Funding acquisition. **Nicholas Banks:** Methodology, Validation, Formal analysis, Investigation, Funding acquisition. **Bryony Parish:** Methodology, Validation, Formal analysis, Investigation. **Tedd Moya Mose:** Methodology, Validation, Formal analysis, Investigation. **Katherine Sugar:** Methodology, Validation, Formal analysis, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

This work was supported by UK Research and Innovation through the UK Energy Research Centre's Phase 4 Programme (grant number EP/S029575/1) and UK Research and Innovation through the Industrial Strategy Challenge Fund, Prospering from the Energy Revolution Programme, Project LEO.

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