Beyond the pilots

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EnergyREV

Beyond the pilots: Current local energy systems in the UK

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Contents

Summary

The smart local energy systems (SLES) approach to the energy transition often seems like a radical departure from the present day UK energy system. Much research activity examines experimental pilot and demonstration projects, whose focus on multi-vector energy systems at local scale contrasts with the national scale and separation of the heat, power and mobility energy vectors characteristic of the mainstream energy system. Nevertheless, outside of the world of time-limited and grant-funded pilots, there are local energy systems in operation all around the country on a 'business as usual' basis. An understanding of what they do, who runs them and who uses them and how, despite going somewhat against the grain, they manage to survive in the UK, can complement the learning from pilot and demonstration projects.

This report presents the findings from research with the operators of 29 local energy systems across the UK. We find that, whether we consider their spatial scale, or numbers of customers, the energy technologies used and range of activities they undertake or the numbers of people working on them, there is a great diversity of local energy systems up and running in the UK today.

However, some patterns are observable. For the most part they exhibit fewer 'smart' energy features than pilot projects, and operate on a smaller spatial scale, below the level of a whole town or city. Still, the word 'local' is used to cover a wide range of scales of operation: we found systems serving less than 10 customers to several thousands. We also noted that a range of customers value local sustainable energy. Sometimes this is where individuals play an active part in local system governance, often linked to some community or cooperative organisation. We also heard that business customers valued how a local renewable energy system enabled them to trace the source of the energy they used. In general, while climate change and decarbonisation of energy generation featured prominently in our interviews, issues around waste – especially future challenges of disposing of system components – appeared to have received less attention.

Many of our research participants were not primarily 'energy organisations'. Often they managed a physical estate of some sort – sometimes a contiguous estate, like a university campus, industrial estate or housing development; in other cases buildings scattered around a local area. We also spoke with energy specialists who managed systems on behalf of land and building owners. Some of these 'non-energy organisations' were local authorities; as a sector local government is already quite involved in the development of SLES, through e.g. participation in several of UKRI's Prospering From the Energy Revolution (PFER) demonstrators. However, we found many more, including housing associations, industrial and commercial estate owners and others.

What are the implications of these findings for the development of SLES in the UK? In brief, we suggest that energy policymakers and practitioners should:

- Better support the considerable demand for greater local energy integration that our research shows exists
- Recognise the range of things that customers value about local energy systems
- Support organisations outside of the energy sector to play a role in local energy systems
- Allow for the 'local' in local energy to be interpreted at a wide range of scales
- Support organisations to manage complex systems and maximise the economic resilience benefits from multiple revenue streams
- Help provide a wide range of SLES-relevant skills and training opportunities across the country
- Encourage life-cycle sustainability thinking, and use policy and regulation to help system operators address circular economy issues.

Finally, the level of ambition for the future displayed by local energy system operators was a striking feature of our results. Almost all of them planned to expand or replicate their current systems, and many were keen to increase the smartness and energy efficiency of their operations in the future. In the next stages of our research, we will be exploring business model innovations that might enable today's local energy systems to do this, and fulfil their potential in the transition to smart local energy systems.

1. Understanding local energy systems operating in the UK today

This report forms part of the EnergyREV research consortium's work on business and financial models for SLES. This work aims to broaden knowledge and understanding of the business structures and finances of existing local energy businesses in the UK, in order to understand how far they could act as pathfinders for the SLES of the future. The systems in our research are operating on an 'ongoing' basis at present;[1] they were not created as a time-limited demonstration or pilot project. Our research is increasing understanding of the number, type, operations, and aspirations of these businesses. We are examining the economic, social and environmental dimensions of their operations to get a fuller picture of how they contribute to a sustainable energy transition and considering what innovations, and policy support, would be critical to enabling them to play this pathfinding role.

This report presents the results of structured interviews with the operators of 29 local energy systems in the UK. For the purposes of this study, we define a local energy system as anything that integrates multiple energy system elements, which we take as "production, conversion, transmission, storage, distribution, and consumption" (Ford et al 2019: 8) at a scale greater than a single domestic dwelling, but smaller than a whole region or devolved nation (similar to the definition used by Rae et al 2021: 2). Examples could include a 'hard wired' 'end-to-end' islanded network, such as a biomass boiler (generation) feeding a heat network (distribution) supplying domestic households (use); or a 'soft' and open system, where a group of households supplement electricity from the national grid with electricity from rooftop solar PV and a battery at neighbourhood scale, rather than each household having its own battery. While there are various ways of defining 'local' energy systems, this approach allows us to examine cases where the Key Activities (see Section 1.1 below) of an energy system are taking place within a local area, and explore other characteristics of such systems – including how local other elements of the business model are.

In the next section, we explain the methods used to collect and analyse the data. We then present the results, and discuss our data in comparison with data on local energy demonstration projects. We conclude by reviewing patterns in the business models used to run local energy systems, noting some considerations for their future, and outlining the next stages of our research.

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[1] Two of the 29 are in fact under development at present, but both on an ongoing and commercial basis rather than as part of a research programme.

1.1. A triple-layered business model analysis

In our research, we used the concept of 'business model' to break down the operations and structure of the different local energy systems into a set of "critical components" (Massa et al 2017); fundamental elements that every system needs to have in some form or other. We then constructed a structured interview guide around this set of business model components as a basis for our interviews with system operators. (The full questionnaire is reproduced in Appendix 1.)

The Business Model Canvas (BMC) (Osterwalder and Pigneur, 2010) is a well-established tool for analysing business models, and is increasingly used to analyse smart or local energy systems (Braunholtz-Speight et al., 2020; Reis et al., 2021; Li and Song, 2019). It outlines the fundamental elements for a generic business: what resources are required, what goods and services are offered to whom, what partnerships are formed, and what the financial (cost and revenue) arrangements are.

However, the BMC is focussed on the conventional economic aspects of business models. As the development of SLES is motivated by their potential contribution to the broader energy transition (Ford et al 2021), we wanted to examine the environmental and social aspects of SLES, as well as the economic. We examined a number of alternative approaches (Pappas et al forthcoming) and chose the Triple-Layered Business Model Canvas (TLBMC) (Joyce and Paquin 2016) as a basis for this study. The TLBMC builds on the strengths of the original BMC, but adds layers of analysis that track the environmental and social impacts of each element of the business model alongside its economic aspects.

The original TLBMC was presented as a framework that could be used for a generic business that was supplying products to a retail customer. We made several adaptations to the framework, both to fit it better to the characteristics of SLES, and also to produce a shorter questionnaire structure that would be easier to complete with research participants.

The way in which our questionnaire, and the structure of this report, relates to the TLBMC is presented in Figure 1 below. The TLBMC is comprised of a total of 27 distinct topic areas made up of 3 layers of 9 areas each. We were able to reduce this to 11 topic areas in our interview schedule by identifying topic areas from different layers that overlapped each other. For example, questions on the number and type of customers served by the system could be used for the economic and social layers; questions about the energy technologies employed in the system for the economic and environmental layers.

1.2. Comparison with SLES pilot and demonstration projects

EnergyREV has previously published an analysis of 147 local energy system projects, which were largely grant-funded and intended to demonstrate or trial various sorts of technology and operation (Wilson et al 2020). We were interested in comparing these pilots and demonstration projects with local energy systems that were operating on an ongoing basis, without the special features that characterise many demonstration projects – like dedicated specific funding and regulatory exemptions.

Therefore, where possible and appropriate we used similar values for variables in our questionnaire. For example, we used a similar range of spatial scale values as possible answers to the question "what spatial scale does the system cover?", and many of the same categories of technology. This was for two reasons. Firstly, it facilitated a comparison between demonstration projects, and other local energy systems (see Section 3). Secondly, as the other EnergyREV study (Wilson et al 2020) was itself an extension of earlier research carried out by UKERC (Flett et al 2018), we felt that these typologies were well established in UK smart local energy research.

Further details of the methods used in this research can be found in Appendix 2 below.

Table 1: **How the SLES elements in this report relate to the Triple-Layered Business Model Canvas (TLBMC)**

Element in our research	TLBMC element	TLBMC layer
Value proposition	Value proposition	Economic
	Functional value	Environmental
	Social value	Social
Energy activities	Key activities	Economic
Energy technologies	Key activities	Economic
Smart energy aspects	Key activities	Economic
	Societal culture	Social
Geographical scale	Partners	Economic
	Scale of outreach	Social
Customers	Value proposition	Economic
	Customer segments	Economic
Customers Governance and ownership	Channels	Economic
	Customer relationship	Economic
	End-user	Social
	Scale of outreach	Social
	Societal culture	Social
	Governance	Social
	Communities	Social
Employment and skills	Employees	Social
Environmental impacts	Supplies and out-sourcing	Environment
	Materials	Environment
	Production	Environment
	Distribution	Environment
	Use Phase	Environment
	End-of-life	Environment
Revenue and finance	Costs	Economic
	Revenues	Economic

2. Results

Our results present a profile of the diversity of local energy systems currently operating in the UK on an ongoing basis. While the total number of systems (29) is relatively small, our in-depth approach, collecting data on social and environmental as well as economic layers of each system, reveals a great range and variety. They vary widely when it comes to energy activities and technologies, geography and scale, number and type of customers and lead organisations and governance.

Before we look in detail at the different elements of these systems' business models, it is useful to summarise the kinds of energy systems that we are analysing. Some of the systems in our data are campus based: in other words, they supply energy to a single physical site, owned or managed by a single entity. Sometimes this is actually a university campus, where there is effectively just one customer; in other cases there are industrial estates, social housing estates, or collective housing developments. Therefore, even within the category of campus-based systems, there is considerable diversity in the types and numbers of energy users and the part they play in the governance of the system. Further, one campus may be host to several separate physical systems, managed by one organisation.

Yet other systems coordinate energy activities across several different sites. They might all be owned by one organisation. For example, our data includes a local authority energy system operating across 100 separate buildings around a city. Or they might be private households who have individually signed up to an electricity tariff that varies according to the availability of locally-generated renewable electricity, with a third party providing data technology and management time to coordinate this virtual system.

Some of these systems are 'closed' or 'hard wired' where end users cannot readily connect to other sources of power or heat. These can include electric microgrids or private wire systems, or heat networks moving hot water from a central combustion-based boiler complex to end users of heat and water scattered around a town centre or neighbourhood (for more detailed examples see Box 2). Others are more 'open' or 'soft wired' systems, where different sources of supply and demand coordinate their activities but are also able to connect to third party sources of supply or demand. These include 'virtual power plants' where multiple households pool their solar generation, or time-of-use tariffs linking household's electricity prices to the availability of local renewable electricity generation (for more detailed examples see Box 3).

In the rest of this chapter, we analyse this data by business model element. In first section we will explore the different kinds of value created by the local energy systems in our study. Further sections of this chapter will look in more detail into who captures the value - who the customers are, and who receives revenue from the system. It will also examine the positive and negative environmental impacts of the systems in our study, the activities and technologies used to create value and the scale at which the systems operate.

Subsequent chapters compare these findings with SLES pilot projects and draw conclusions for the future development of SLES.

2.1. Value propositions

At the heart of a business model lies the "value proposition" (Joyce and Paquin 2016: 1476, Osterwalder and Pigneur 2013: 26): the value that the business creates. The rest of the business model is composed of the activities and resources that create this value, and the actors that capture the value – including the business itself, usually capturing value in the form of revenue.

While the conventional Business Model Canvas approach focusses on how businesses create value for their customers through offering them a product or service that directly benefits them, the Triple-Layered Business Model Canvas takes a broader perspective. It considers how a business model can create social and environmental value, which might be an element of the value captured directly by customers, but might also benefit different actors. Therefore, important questions arising for our analysis are: what value is created by local energy systems? Who captures this value? Is the value captured at 'local' scale or somewhere else? Is this value realised immediately or over a longer time frame?

It is clear that the chief value created for customers is access to energy. While energy can be used for many different purposes (Fell 2017), some of these such as heating and cooking are clearly essential to human wellbeing. Therefore local energy systems can be said to create value because they "satisfy a customer need" (Osterwalder and Pigneur 2013: 26). The price of energy – the cost of satisfying that need - is clearly also important for customers, and it is notable that lowering the cost of energy to customers was the most frequently mentioned value proposition across all the systems. Not just the level of the price of energy, but price security, and protection from energy market price volatility was also mentioned as valued. This was achieved through being directly connected to energy generation through a local system, and is a particularly pertinent consideration in the light of recent energy market turmoil.

Other value created directly for customers included: increased thermal comfort compared to previous systems; face-to-face customer service facilitated by having the system managed locally; and in three cases, increased control over their energy supply through the customers collectively owning the energy system (see Section 2.8 on governance below).

In some cases, the value created directly for customers had a wider social or environmental aspect. Thus, reducing the unit cost of energy in the form of electric power and/or heat to customers might be of particular value to people otherwise vulnerable to fuel poverty (see section 2.6 below on customer profiles). In other cases, it is clear that value is created for actors at a wider spatial scale. For example, local ownership of, or employment on, energy systems can have economic and social benefits at the scale of a whole town, city or region. Environmental value can be realised at a wider scale still: for example, low carbon energy generation has an environmental impact on the climate at global scale. The reduction in demand for landfill sites through using non-recyclable waste as a source of fuel for combined heat and power (CHP) energy generation has a more local impact, but is still of value to more people than the system's customers.

Another important broader value proposition for some systems was the provision of wider community benefits. While these benefits took a variety of forms, a common one was community benefit funds: the setting aside of a proportion of revenue for spending on local charitable or environmental projects. Unsurprisingly, it was mainly third sector owned systems (see Section 2.8 on governance and ownership) that maintained these funds, but one local authority-owned system also had a mechanism for making small grants to local projects and funded the provision of energy saving advice to local residents out of system revenues. In another case, a local community development trust – with a broad social and environmental remit – saw energy system revenue as a means of funding its work in other areas.

Having established a distinction between value captured by individual customers, and value captured by broader groups, we should note that this distinction can be blurred when customers themselves place a value on this wider scale value creation. Thus, four participants felt that customers valued the wider local economic and social benefits created by the system. Half of all participants said that at least some of their customers valued using energy from low-carbon generation.

Valuing the environmental credentials of the system was mentioned slightly more often in relation to organisational customers than it was to residential customers. One participant, the operator of a system that supplied business customers with energy from an integrated solar farm (among other sources), said:

> “It helps them meet their green agendas… we supply 1/3 electricity from our own system, and 2/3 from an accredited [renewable electricity] supplier: that's a big tick for… companies.”
>
> Participant #6, private sector owned electricity only 'end-to-end' system

In contrast, operators often felt that only a minority of residential customers were particularly interested in the environmental benefits. However, we also found that in systems operated by community land trusts and other forms of collective housing, sustainable energy was definitely important to residents.

Indeed, customers appeared to place a value on the social and environmental aspects of the system even where that system was 'hard wired', such as district heat networks or electric microgrids. This is notable because one understanding of a value proposition is that it is "the reason why consumers choose one company over another" (Osterwalder and Pigneur 2013: 26): and yet, in one sense, 'hard wired' systems prevent customers choosing between energy suppliers. As one research participant put it:

> “If they don't buy electricity from us they don't have any!”
>
> Participant #16, third sector owned electricity-only 'end to end' system

Nevertheless, in these systems, customer choice might be seen in the decision to move a household or business to a particular location, and characteristics of the energy supply to that location might be a factor in that choice. Thus, for three of the systems in our study (see Box 4) that mainly supplied housing developments, the positive environmental credentials of those developments, including low carbon energy supply, were promoted as one reason to live there. On the other hand, there were other cases, e.g. where a local energy system had been retrofitted to a social housing estate, where it was harder to see any element of active choice by customers. And where the energy generated was not from renewable sources, environmental considerations seemed to factor less often as something valued by customers, even though a gas-fired CHP system might offer somewhat lower carbon energy than alternatives such as mains gas or grid electricity due to its efficiency.

As well as customers and a wide range of other beneficiaries, systems create value for their operators. It was clear from our interviews that operators felt that 'smart'[2] operation of their systems created value for them in the form of cost savings and efficient use of system resources. Many were keen to emphasise that cost savings were passed on to their customers or were realised by the organisation running a system on its own estate. We will discuss how system operators captured value further in Section 2.10 on Revenue and Finance below.

Finally, there is the question of the temporal scale in which value is realised. Much energy policy interest in SLES is driven by a search for cost-effective means of decarbonising the energy system so as to avert disastrous climate change in the future (e.g. UKRI 2022: 2, Energy Systems Catapult 2021). We will return to this point in the Conclusion, but it is notable that, while this perspective was certainly echoed by many of our research participants, they were also keen to pass on the benefits of smarter operation – especially in terms of cost savings – to their customers today.

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[2] See Section 2.4 for discussion of how our study participants interpreted the term 'smart'.

Box 1: Using ICT with storage heaters in social housing to create triple-layered value

Westminster City Council owns several tower blocks that provide much-needed affordable housing in central London. However, many blocks were fitted with inefficient and dated storage heaters, which meant tenants often relied on expensive supplementary heaters such as fan heaters to heat their homes. Faced with this unsatisfactory situation, rather than scrapping the storage heaters and installing an expensive new system, in 2015 the Council engaged energy firm Connected Response to install a twin-track ICT-based solution in eight blocks comprising a total of 900 flats. They used remote sensing technology to be able to register each tower block as a single meter point (MPAN), which allowed the Council to access a lower cost energy tariff. Then they fitted the storage heaters themselves with smart controls that optimised operation in relation to ambient temperature and the short-term local weather forecast. These two measures have allowed the Council to lower the energy charge to tenants, and allowed the tenants to stop using supplementary heaters. Further, by retrofitting digital technologies to the existing infrastructure, they have avoided producing a significant volume of waste in the form of 900 scrap storage heaters.

2.2. Energy activities

Underpinning each system's value creation is some combination of 'energy activities'. By this term we mean 'supply side' activities such as the generation of energy, management of energy distribution infrastructure, or the supply of energy to end users.; We also use it to cover a wide range of 'demand-side' activities, from the provision of electric transport or the use of software and pricing systems to maximise use of local renewable generation, to insulating houses and installing efficient appliances to reduce users' energy bills.

We asked participants in our research to select those energy activities that were carried out as part of their local energy system from a list of options.[3] Below we show how common different energy activities were among the systems we studied and analyse how different activities were combined into energy systems.

Figure 1 shows how many systems were undertaking different energy activities. Generating electricity was the most commonly reported activity, followed by generating heat and installing or maintaining energy technologies. More generally, we can divide these activities into those comprising a 'business as usual' model of a generate-distribute-retail energy system (Figure 1a); and 'new energy' activities (Figure 1b). These include (reading from left to right): installing technology in user homes and premises; work to increase the energy efficiency of homes and premises; using ICT to manage demand; using demand or generation to provide flexibility services to the electricity distribution network; storing energy, often by storing electric charge in batteries; other support services for users and providing transport as part of the energy system, for example, by providing electric vehicles (EVs) to users.

Looking at how these activities were combined into systems, we found that 18 out of 29 systems in our study were multi-vector systems, combining two or more of electric power, heating, cooling and transport. Of these, seven used CHP generation, but eight used other technologies to deliver both electric power and heating (see Section 2.3 below for more on specific technology types).

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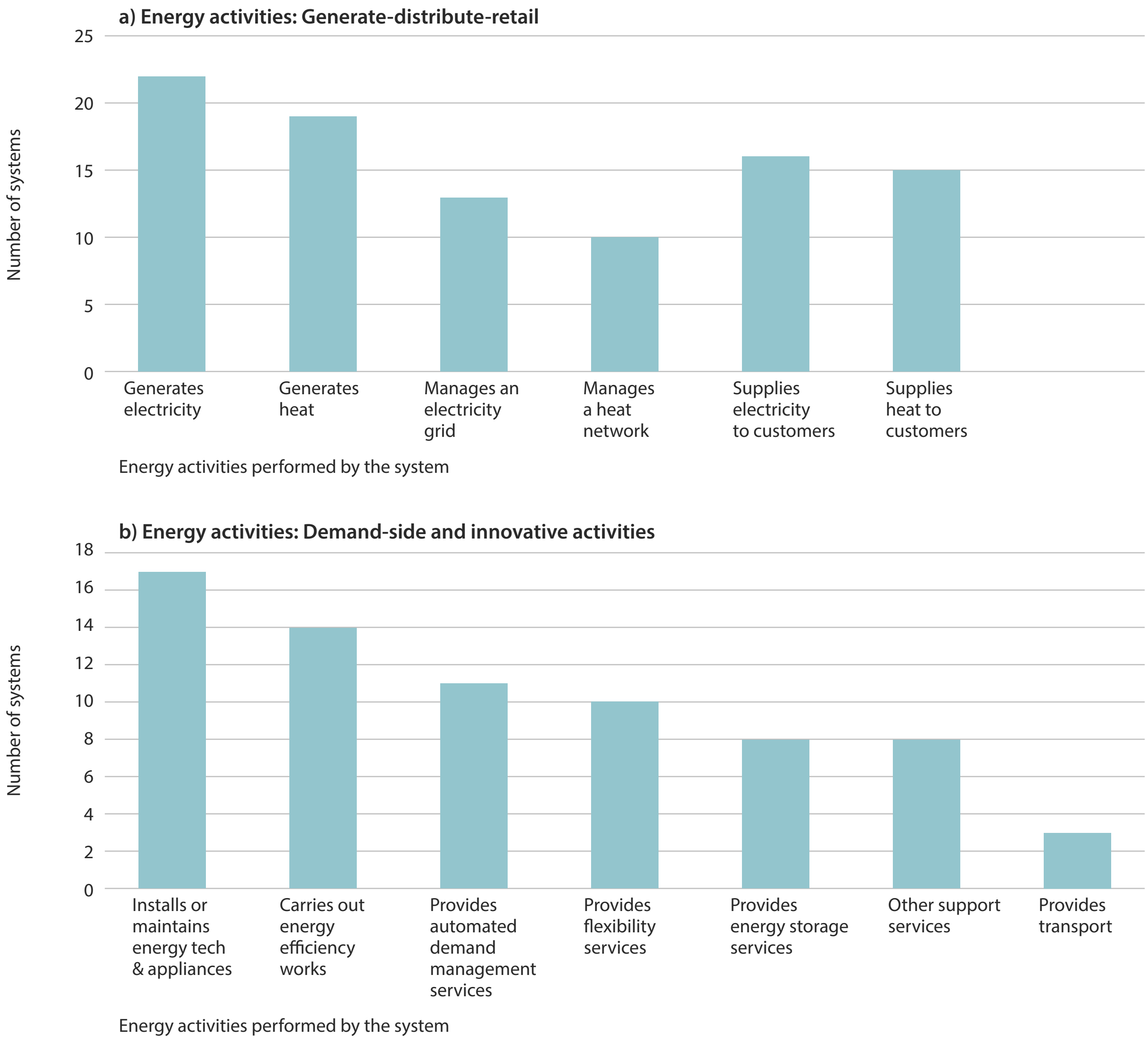
[3] Participants were able to select more than one option from the list.

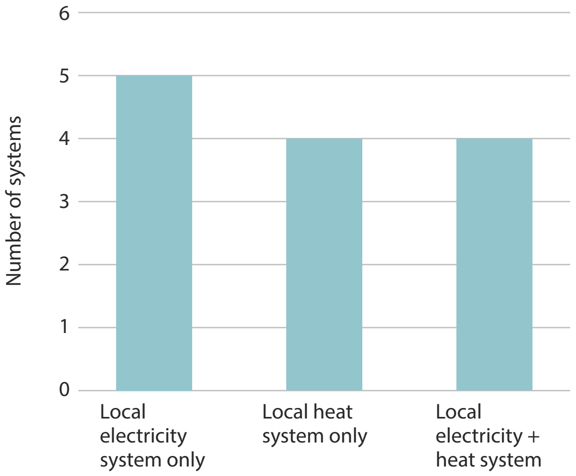
Figure 1: Number of local energy systems reporting different energy activities



Further, Figure 2 below shows that there are 13 local systems that have created what we term an 'end-to-end' local energy system. By 'end-to-end' we mean that they combine energy generation, energy distribution via wires or pipes, and the retail supply of energy to the end user, within one local system managed by a local operator . Four of these end-to-end systems supply heat and electric power; five are electricity only, and four heat only systems. The heat systems were generally 'standalone' systems, supplying all their customers' heating needs. In contrast, the electricity systems used a mixture of their own local electricity generation and power from the wider electricity distribution network.

The full picture is more complex than this, however: there are several other combinations among our participating local energy systems. In some cases, a system operator generates electricity and manages a microgrid, but does not have a retail relationship with the end user of that energy. In others, there may be an 'end-to-end' heat system coupled with some electricity generation that feeds the distribution network rather than the local energy system.

Figure 2: Types of 'end-to-end' local energy system



2.3. Energy technologies

The energy activities described in the previous section are performed using specific technologies. Typically, each system used several different technologies to perform its full range of energy activities. We drew on Wilson et al (2020) to produce a list of technology types, grouped into seven functional areas (full list of types and groupings in Table 2, opposite), and asked research participants which particular types of technology their systems used.

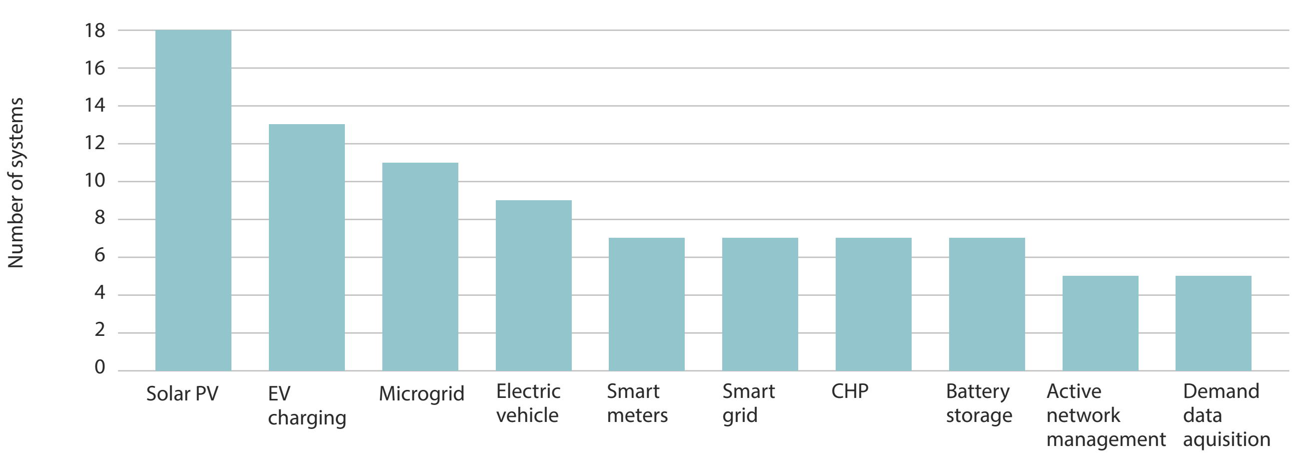
In Figure 3 we can see that solar PV is the energy technology that features most often , with 18 local energy systems using solar panels to generate electricity. After that, microgrids and EV charging points were the most common electricity technology types, and almost always found in systems with solar PV. Heat networks were the most common heating technology type, but we rarely found them operating on their own: 8 out of 10 heat networks in our study were either connected to CHP generation, or operating alongside a local electricity system. Other quite common technology types were battery storage (seven systems), CHP (seven systems) and biomass boilers (six systems). At the uncommon and more unusual end of the spectrum, there was a hydrogen fuel cell being used to power an electric heating system, a water-source heat pump connected to a heat network, and the use of electricity to make solid recovered fuel from household waste.

Table 2: Energy technology types included in each technology grouping

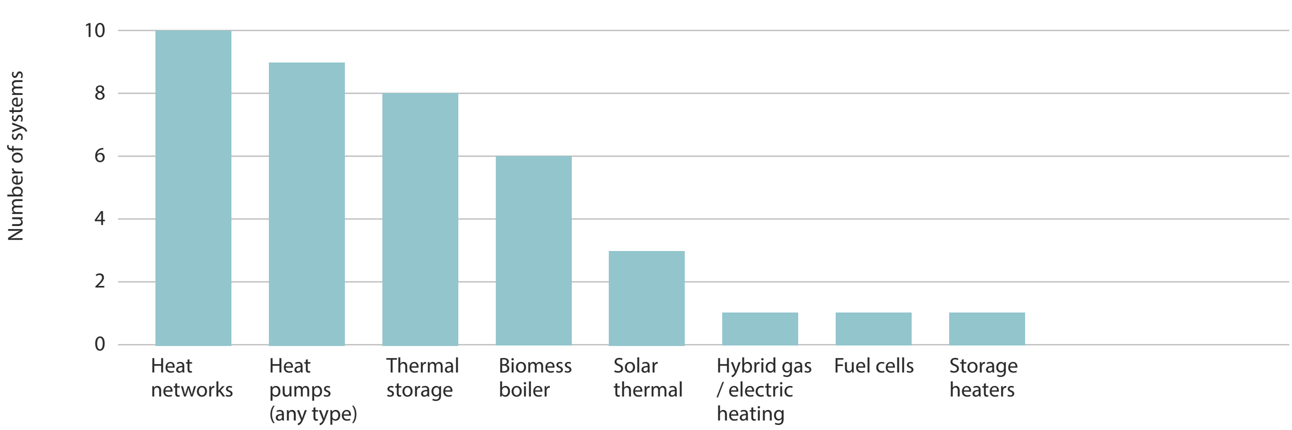
Technology grouping	Technology types included
Local electricity grid management	• Electric microgrid • DC network • Active electricity network management • Electricity network data acquisition • Smart meters • Electricity demand data acquisition
Electricity grid integration	• LV grid monitoring • Smart grid • Demand response • EV charging • Vehicle-to-grid • Wireless charging
Heating	• Biomass boiler • Heat pumps (any type) • Solar thermal • Heat network • Hybrid gas/electric heating
Hydrogen and alternative fuels	• Fuel cells • Hydrogen generation • Hydrogen storage • Alternative grid fuels • Biofuels
Electricity generation	• Solar PV • Wind • Hydro • Combined Heat and Power (CHP) • Tidal or other marine • Anaerobic digestion
Energy storage	• Battery storage • Thermal storage • Storage heating
Other end user technologies	• Building management system • Low energy building • Smart lighting • Hydrogen vehicle • Electric vehicle • Other (please provide details)

Figure 3: Most common technology types used in local energy systems, as reported by research participants

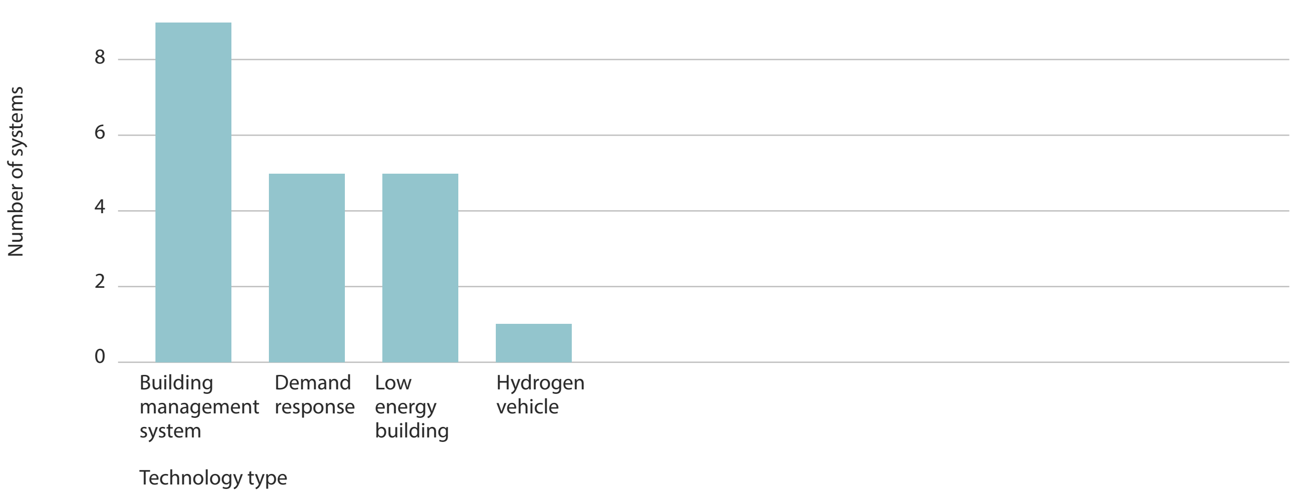
a) Electricity technology types



b) Heating technology types



c) Other technology types, including demand-side technologies



Box 2: 'Hard-Wired' local energy systems

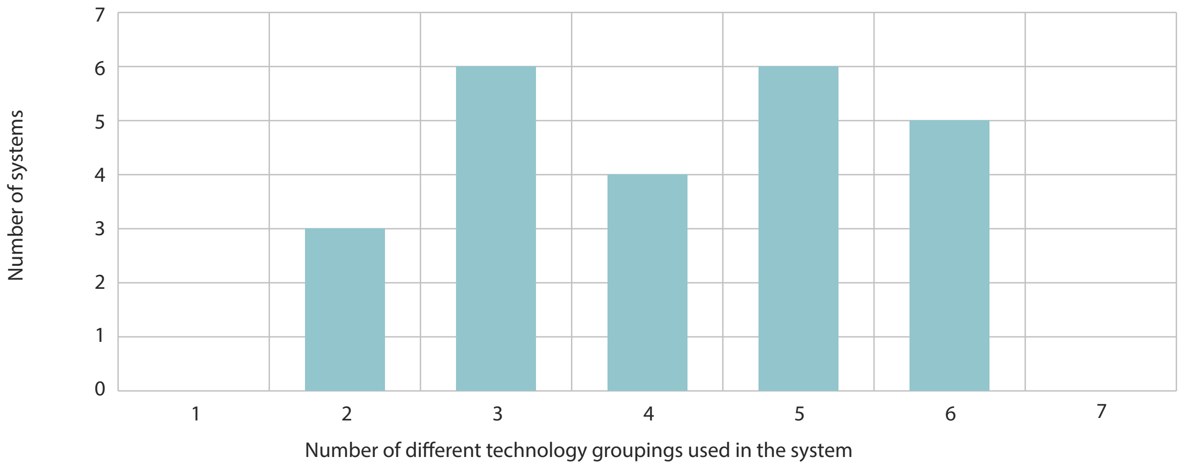
We found examples of hard-wired local energy systems that provide electricity, heat and both. Kingmoor Park in Carlisle operates four industrial estates. It supplies its tenants with electricity from a 1MW solar farm adjacent to the estates that it developed with help from estate tenants North Lakes Solar, and now owns. They have also installed EV charging stations, which – among other users - charge the park's own electric van. Further north still, the Perth Food and Drink Park is a commercial estate owned by Perth and Kinross Council, featuring a rooftop solar system that supplies tenants with electricity and that was developed and is now operated by iPower.

Heating networks are mostly associated with housing in our study. Both the St Mary's District Heat network in Oldham run by a housing association, and the local authority-run Ernest Dence Estate communal heating network in Greenwich, London, supply heat and hot water to social housing residents. While both also use gas-fired boilers, work is underway in Greenwich to convert to using Water Source Heat Pumps. In Oldham, First Choice Homes is exploring options for decarbonising the network, including heat pumps and a biomass boiler.

Two urban CHP systems are good examples of the larger, 'hard wired' multi-vector energy systems in our study. Thameswey Energy in Woking generates heat and electricity from a CHP plant, and renewable electricity from solar panels on 100 buildings, with a total of 1.8MW capacity. These supply customers with heat, cooling and power through its city centre heat network and private wire system, that also incorporates thermal and battery storage. Revenue comes from customers (residents and organisations from public, private and third sectors), and from export of surplus energy to the national grid. East London Energy (ELE) is a subsidiary of Engie that runs a large district energy network, generating, storing and supplying heat and hot water to 5000 residential customers and 60 organisations in Queen Elizabeth Olympic Park, the former Olympics site. Heat is generated from a combination of gas and biomass, the latter sourced from within 50 miles of the site despite its inner city location. ELE operates under a long term lease from the network owners, the London Legacy Development Corporation.

As an additional measure of the complexity of the different systems in our study, Figure 4 shows how many systems used technologies from multiple different technology groupings defined in Table 2. While it is conceivable that a heat-only end-to-end system could use technologies from just one grouping -the 'heating' group in practice we found that every system uses technologies from more than one group. Indeed, using technologies from five or six different groupings was quite common.

Figure 4: Local energy systems by number of technology groupings used in the system.



2.4. Smart energy aspects

The term 'smart energy' is widely used but does not have a very precise definition. In our research into SLES business models around the world (Pappas et al forthcoming), we found that, while 'smart' is often associated with the use of information technology and automation in energy systems, in some contexts it is associated with changing consumer behaviour and greater user awareness of how their energy choices impact on the wider energy system. In other words, sometimes the 'smartness' is seen as being located in the technology; sometimes in the way people use the technology.[4] Where the people using the technology are also the energy users or customers of the system, it seems that they are playing an active role in the creation of value by the system. Therefore, when we asked our research participants about the smartness of their energy system, we presented them with a wide range of features that might be called 'smart', relating both to technologies and to how they were used (see chart below for full list of features). We asked them to indicate which of these features were found in their system; we also included an open-ended question asking them to comment on smart energy in relation to their system more generally.

As can be seen from Figure 5, the most common feature reported from the list we provided was for customers to have to learn to use new technology. This could mean, for example, learning how to heat their home with a heat pump, or with Passivhaus[5]-style heat recovery technology, rather than conventional gas-fired central heating. Clearly, this is a case of smartness being located in the way people use the technology, rather than in the technology itself. However, it is not clear from our data how far new technology resulted in more active and energy-conscious behaviour from customers. It was only reported for around half of the systems in our study and many of the research participants who did not report this specifically commented that they tried to combine change 'behind the scenes' with a customer experience that was as close to 'business as usual' as possible.

Several systems also use ICT in real time, charge customers different prices for energy depending on when they are using it with time of use tariffs and expect or encourage customers to use energy in new ways: for example Passivhaus-style domestic heating systems, or electric transport. More complex types of smart operation, where consumers sell energy back to the system operator or energy utility as prosumers or to each other in peer-to-peer trading were much less common.

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[4] See also Ford et al 2021, esp sections 4.2.2 and 4.2.3

[5] Passivhaus is an approach to energy efficient building, originating in Germany.

Figure 5: Number of systems exhibiting various 'smart' features

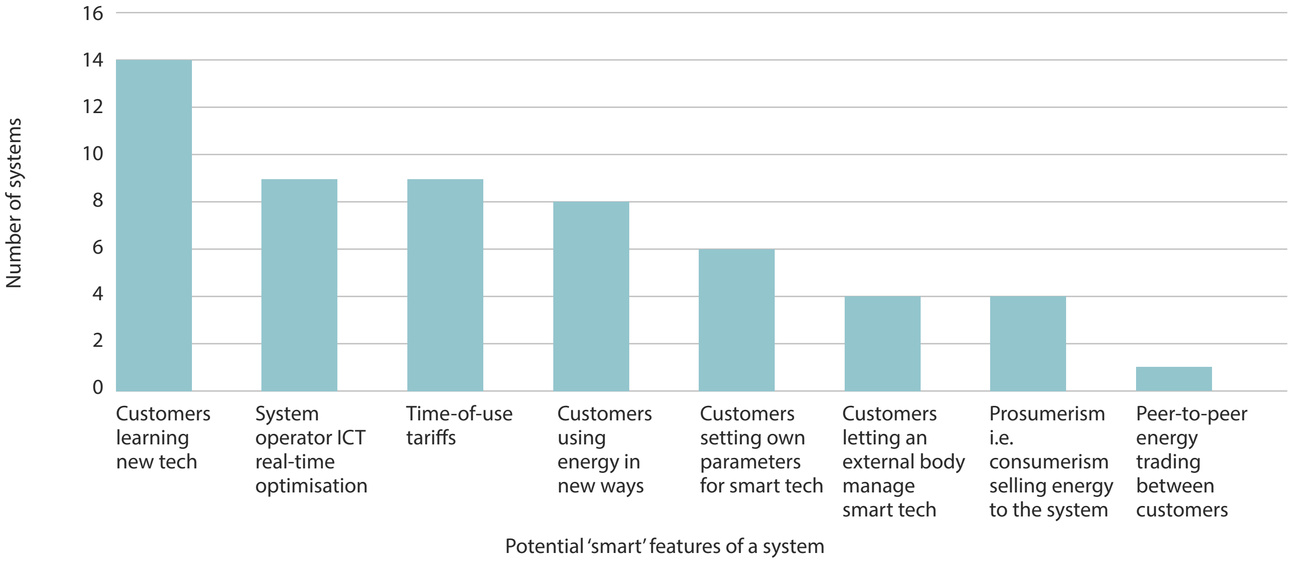
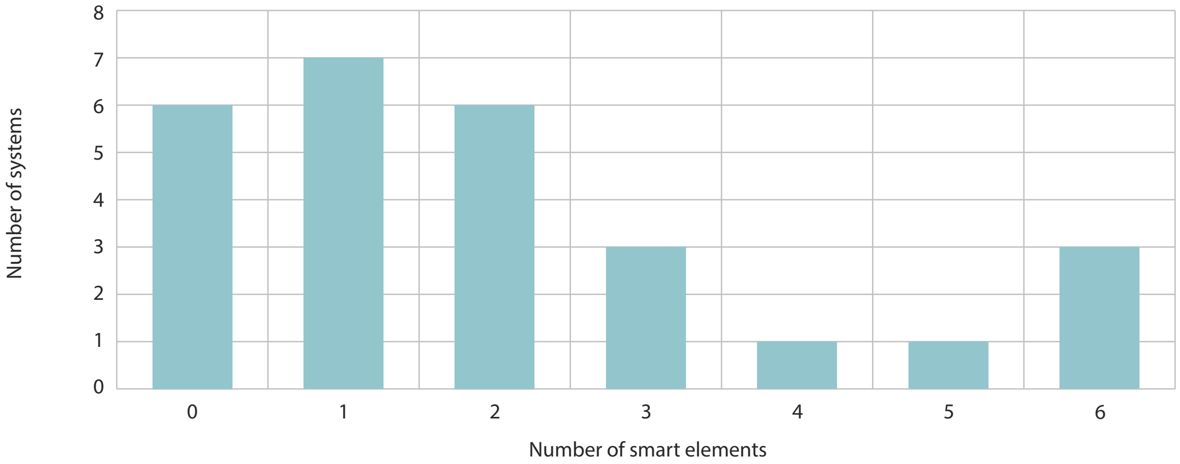


Figure 6: System smartness index



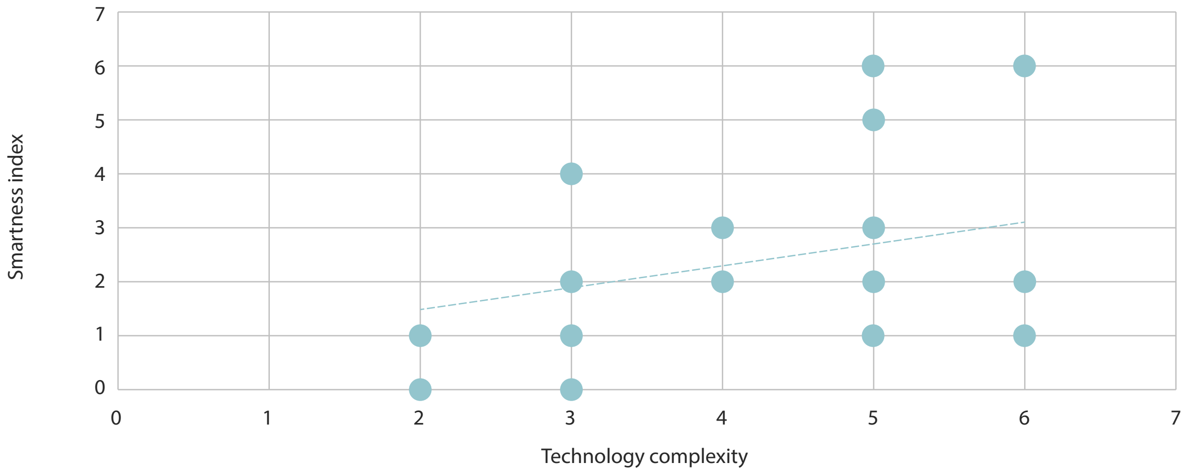
Very likely this is due to the regulatory complexity involved in these kinds of transactions in the current UK energy market, as well as, perhaps, to most of the systems we studied being relatively small and local.

What also emerged from interviews was a certain reluctance to describe their system as 'smart', even where we felt they could reasonably do so. In general it was seen as something positive; participants were not looking to distance themselves from the concept, but rather being modest and cautious about their use of it. Perhaps this is related to the lack of definition of the term; and also perhaps because it was seen as applicable only to cutting edge technology and levels of automated operation beyond those commonly employed today.

Notably, smarter operation was frequently mentioned as an aspiration for the development of the system, and we will explore this more in the 'Future Plans' section.

Figure 6 shows that most systems did exhibit a small number of the 'smart' features listed above. The three smartest systems (scoring 6 on our index) were all electricity-based. Figure 7 below shows that there is a slight tendency for more technologically complex systems to also have more smart features. However, this tendency is not very strong and, given the small numbers of systems involved, this result should be treated with caution.

Figure 7: Technological complexity vs smartness of local energy systems



Each point on the figure represents a local energy system. The X axis shows how many different technology groupings are used in the system (see also Figure 4); the Y axis shows how many smart features the system exhibits (see also Figure 6). The dotted line shows the trend of the relationship between technological complexity and smartness.

Box 3: **'Soft wired' or 'open' local energy systems**

Not all local energy systems operating today are hard-wired or campus based. Energy Local CIC has worked around the UK to found "Energy Local Clubs" which create virtual SLES. Households that join a Club are put on a time-of-use tariff for their electricity consumption, currently provided by Octopus Energy. This tariff offers cheap rates when local renewables are generating electricity and different prices for non-locally generated electricity depending on the time of day. Club members can use an online dashboard to check when local electricity is available, and monitor their consumption and bills.

2.5. Geographical scale

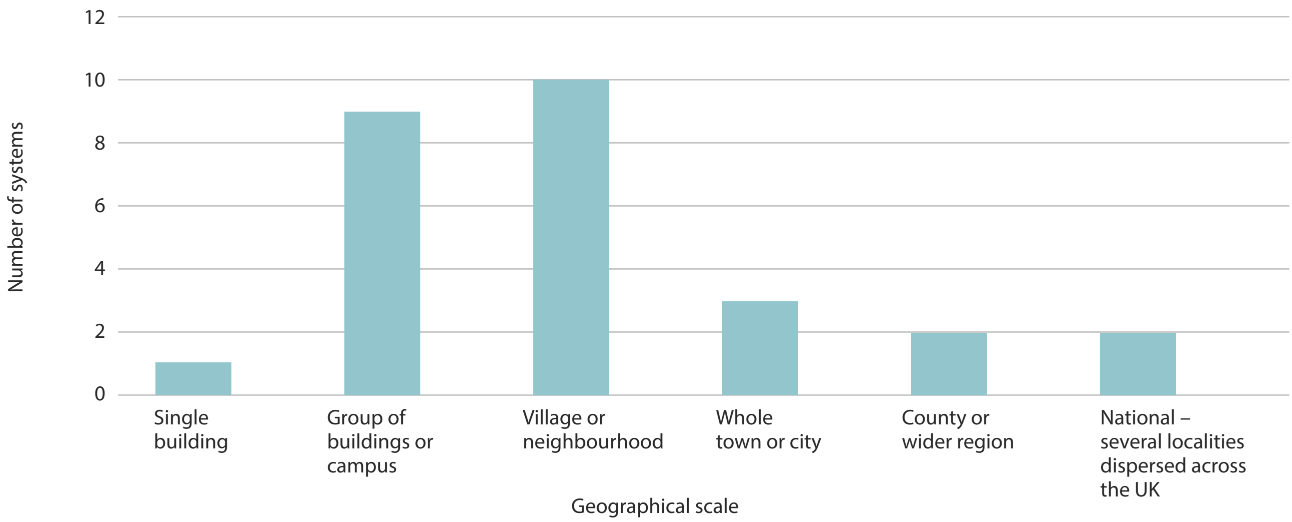
Finding the appropriate geographical/spatial scale for SLES is a key challenge for policymakers and system operators alike. We therefore asked participants to place their system in one of the categories shown in Figure 8 below. It is clear that the great majority of systems in our study operate at a scale smaller than a whole town or city. "Village, or neighbourhood in a city" was the most commonly reported scale of operation, with "group of buildings or campus" the second. This suggests that much of the expertise and experience in running local energy systems is based on these smaller scales of operation.

2.6. Customers

We asked our research participants what types of customers their system served, and how many. We defined two types: "organisational" customers which includes any organisation - private, public or third sector- and "residential" customers defined as domestic households.

As shown in Figure 9, we found diversity in customer types across our participants. Twenty-five system operators provided data on the types of customers served: of these, just over half (13) serve both residential and organisational customers. Then seven systems serve only organisations, and five serve only residential customers.

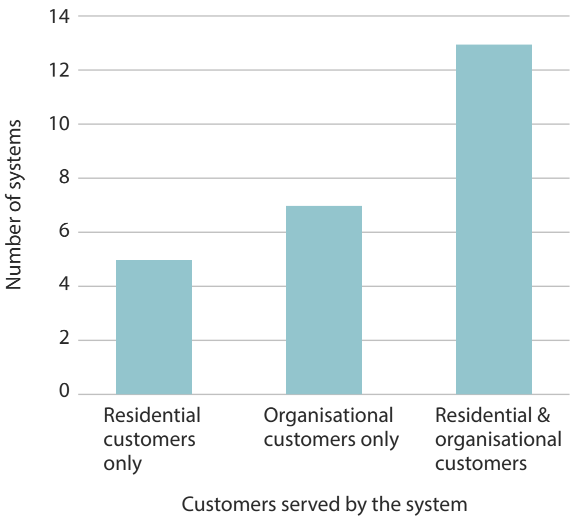
Figure 8: Geographical scale of current local energy systems



We found a wide range of size of systems - some with less than 10 customers, others with tens of thousands. We found that the 24 systems for which we had data on customer numbers could be conveniently organised into groups of 6 by size. There are 6 systems serving less than 10 customers each; 6 serving 10-49 customers each; 6 serving 50-249 customers each and a further 6 serving 250 or more customers.

We have broken this final group into 2 further categories: 4 systems serving 250-4999 customers, and the 2 largest systems that each serve over 5000 customers. Figure 10 shows how many customers are served by each different category of system, using a logarithmic scale to fit these very different sizes of system onto a chart. Thus, on the left hand side, there are the six organisations which served less than 10 customers each; and the chart shows that they served 11 customers in total, split fairly evenly between residential and organisational customers. Note that this chart uses a logarithmic scale, to allow very different system sizes to be displayed legibly on the same chart. Systems tended to serve much larger numbers of residential customers than organisational customers. Thus the largest systems with 5000 or more customers served almost entirely residential customers.

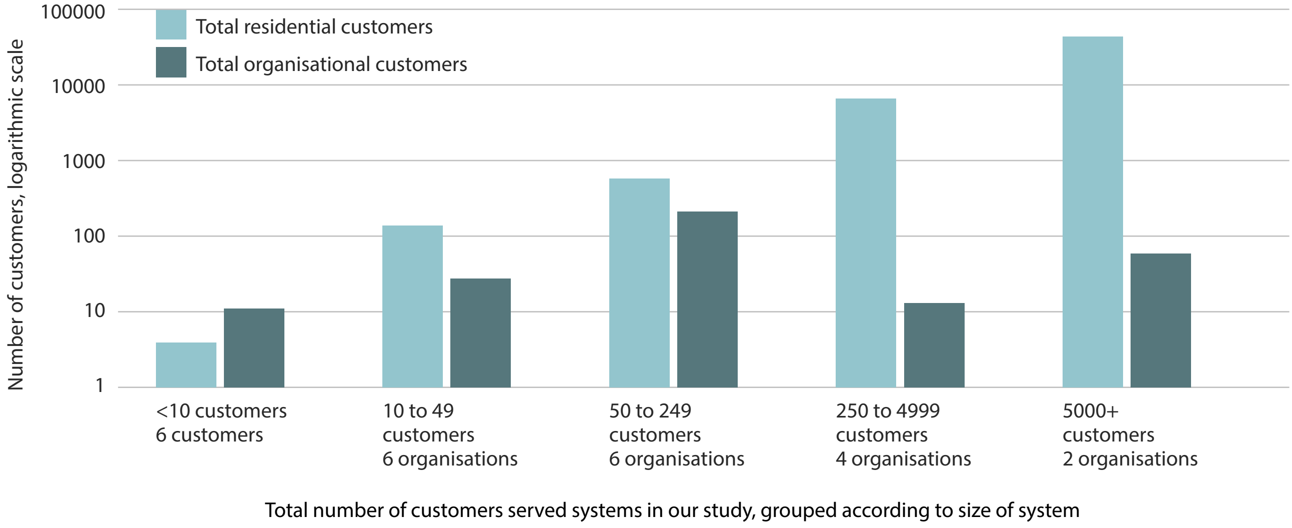
Figure 9: Number of systems serving different types of customer



We did not collect data on total volume of energy demand in each system, but each organisational customer is likely to have higher energy demand than each individual residential customer. On this basis, we might hypothesise that focussing on organisational customers allows for higher volume of energy sales for less customer relations input. However, we did not investigate this, and it is not clear if or how the customer relations workload varies systematically with type of customer and volume of energy sales. Filling these gaps in knowledge might be important for constructing viable SLES business models in the future.

Looking in more detail at residential customers, we collected data on the housing tenures of customers served by our systems. We find that systems of all sizes serve residential customers in a range of housing tenures. The majority of systems are serving people in two or more forms of housing tenure, e.g. private renters and owner occupiers. However, normally one type of tenure dominates. Figure 11 shows how many systems served a majority of customers of particular housing types. Across all our systems there is a slight tendency towards serving people living in social rented housing, particularly in comparison with the proportion of households in the UK who live in this form of housing.[6] But overall, diversity is the main conclusion.

Figure 10: System sizes by number and type of customer



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[6] We estimate around 18% of households in the UK live in social housing, defined as housing rented from a local authority or housing association.

Box 4: Local control: energy systems where customers are managers

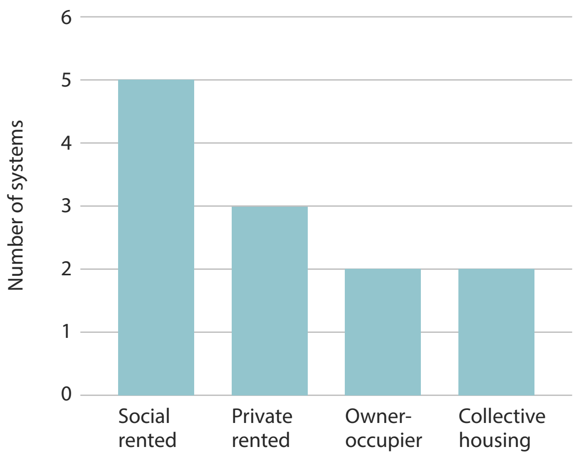
While a more active role for individual customers is a core feature of SLES, some of the cases in our study include customers in the formal processes for making strategic decisions about the system. The mechanisms for doing this vary, however, and are rarely simple.

Lancaster Cohousing is a community of 80 people which, constituted as a Company Limited by Guarantee, collectively owns and manages an eco-housing development on the banks of the River Lune in rural Lancashire. It runs a multi-vector renewable energy system that consists of a biomass boiler powering a district heat network for space heating and hot water owned by Lancaster Cohousing and rooftop solar panels and a run-of-river hydro plant providing electricity. The solar and hydro are owned by independent community energy cooperatives (MORE Renewables and Halton Lune Hydro respectively), who supply electricity under a long-term contract with the Cohousing company.

Across the Pennines in Leeds, the Climate Action District is being built by eco-housing specialists Citu, who use Passivhaus-standard construction and rooftop solar PV connected to a microgrid to minimise the carbon emissions from the District's energy consumptions. The solar microgrid is owned and managed by the District's residents through a community land trust set up by Citu.

A longer standing eco-community is the Findhorn Foundation in Morayshire, Scotland. Here, Findhorn Wind Park is a coop that meets around half the eco-village's power demand from its 675kW wind farm, distributed via a microgrid to 150 residents and 25 organisations. Local residents have a seat on the Board of Directors through their coop Ekopia, alongside the Foundation's trading subsidiary New Findhorn Directions (which owns the low voltage elements of the microgrid) and national energy "coop of coops" Energy4All.

Figure 11: Number of systems serving mostly one type of housing tenure



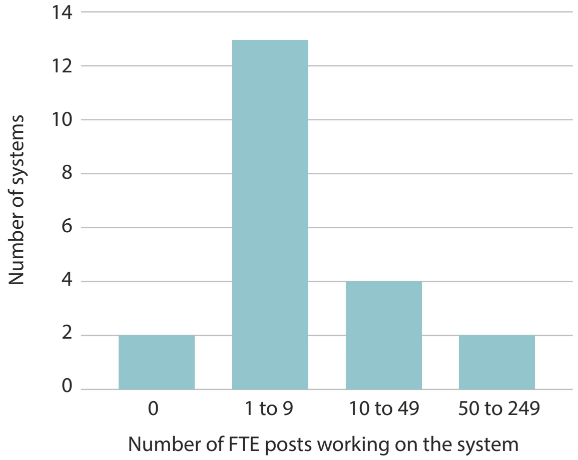
This chart showed how many systems reported that "more than half" or "all" of their residential customers were of a particular housing tenure. There were an additional four systems serving residential customers where no single type of housing tenure dominated.

2.7. Employment and skills

It is anticipated that the transition to SLES will require both retraining for the existing energy system workforce and the introduction of new people into that workforce (Chitchayan and Bird 2021). As well being a critical factor for SLES, it is also an opportunity for social impact through the creation of new employment opportunities. Therefore, we asked our participating system operators about the numbers of people employed in running their systems, and any points about the availability, or lack, of sufficiently skilled people to do this work.

Figure 12 shows us that most local energy systems in our survey are effectively micro enterprises, with less than 10 full-time employees (FTE). In fact, participants who selected the "1-9 FTE" category often said that their system supported less than one FTE: in other words, running and maintaining it was only a part-time job. However, there are also a few small (10-49 FTE) and medium (50-249 FTE) enterprises in our survey. While the largest system employed the most people, there was no clear and straightforward correlation between number of customers and number of employees, or other measures of scale or complexity of operation. There was a slight tendency for systems that included heat networks to employ more people, but more data would be needed to establish this link with confidence.

Figure 12: Employment in local energy systems



Of the two systems that reported zero FTE, one was run by volunteers; the other took "maybe one hour a month" to manage.

Energy is already seen as a "high skill… highly regulated industry" (Participant #6) with qualifications, permits and quality monitoring a routine feature of running a local energy system. Nevertheless, many system operators reported arranging additional training for their staff, for example to operate microgrids or use and maintain an electronic multi-building energy management system. Some also reported that the lack of locally available skilled people was a constant problem, constraining their uptake of new technologies such as heat pumps:

> "We struggle to get competent and trained staff in the areas of data, telemetry, controls. The mechanicals – gas and electric, plumbing – are no problem. The small wires are the problem!"
>
> Participant #3 – public sector owned end-to-end electricity and heat system

It was apparent that while many systems did work with local partners, and employ local contractors, they were not always able to do so. In several cases, national specialist contractors were used for particular aspects of system maintenance or operation. Not only did this limit employment opportunities in the locality, while, of course, increasing them elsewhere, but it could present an operational challenge if things went wrong. Having staff based nearby to fix problems would be an advantage, particularly for an essential service like supplying heat and power.

Finally, it should be noted that skills needs were not always in energy engineering. One system manager noted that their focus for skills development at present was in learning to work with more complex financial and commercial models, rather than in the physical operation of the system.

2.8. Governance, ownership and partnerships

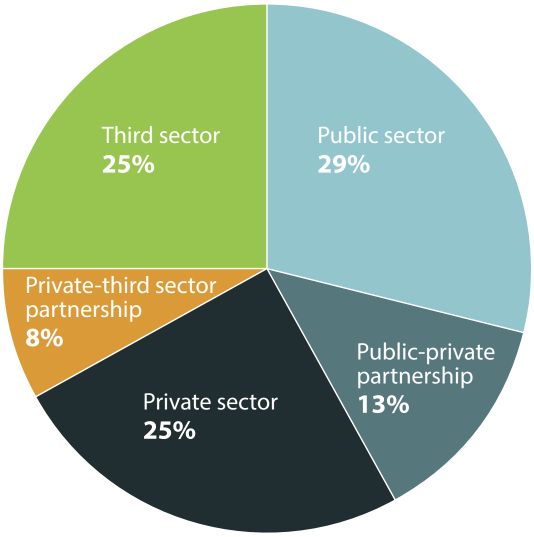
The identity of the actors and institutions that will manage and own SLES could make a significant difference to the distribution of costs and benefits from the energy transition. We collected data on the governance and ownership of local energy systems, asking who owned the system and who the key decision-makers were. We obtained this data for 24 systems.

Figure 13 shows that most systems (79%) were managed by a single sector, and often by a single organisation. When we include cross-sectoral partnerships, we see that private sector companies were owners or co-owners of 46% of systems, public sector organisations of 42% of systems, and third sector organisations of 33% of systems.

While public sector organisations were mostly local authorities, private sector companies included both small and large energy companies, an industrial estate operator, and two housing associations. The third sector groups in our study were all locality-orientated community organisations, including housing, energy and sports-focussed groups. Perhaps surprisingly, while we found two third sector-private sector partnerships (between a community energy group and a private school, and between a housing developer and a residents' community land trust), we found no partnerships between the public and third sectors in our study.[7]

There was frequently a single organisation that was largely responsible for 'strategic decisions' regarding the system, as the preponderance of 'single sector' ownership suggests.[8] While this can make for relatively straightforward governance procedures, when the controlling organisation is large, such as a a local authority, decision-making can become complex, as different operational departments and elected councillors might all have some leverage. In general, system operators also referred to the importance of working with other stakeholders who did not hold a formal governance position, often including customers and local authorities (where they were not formal partners). Finally, a few systems were part- or wholly-owned by their customers, who had the option to exercise decision-making power as members of an energy cooperative that owned the system.

Figure 13: System ownership by institutional sector



2.9. Environmental impacts

The environmental value that SLES can create is clearly key to their importance to policymakers. SLES are seen as tools to enable the integration of low carbon renewable energy into the energy system in a resource-efficient way. However, in our review of SLES projects around the world (Pappas et al forthcoming), we found that project documentation and independent studies often lacked the data required to complete the environmental layer of the Triple-Layer Business Model Canvas. In particular, waste and end-of-life issues received very little attention.

We were interested to learn how system operators and managers considered and monitored the environmental impacts of their systems. Mindful that, as well as creating value, it was possible that system operations could also result in environmental problems, we asked about both positive and negative impacts and about waste and technology end-of-life/decommissioning.

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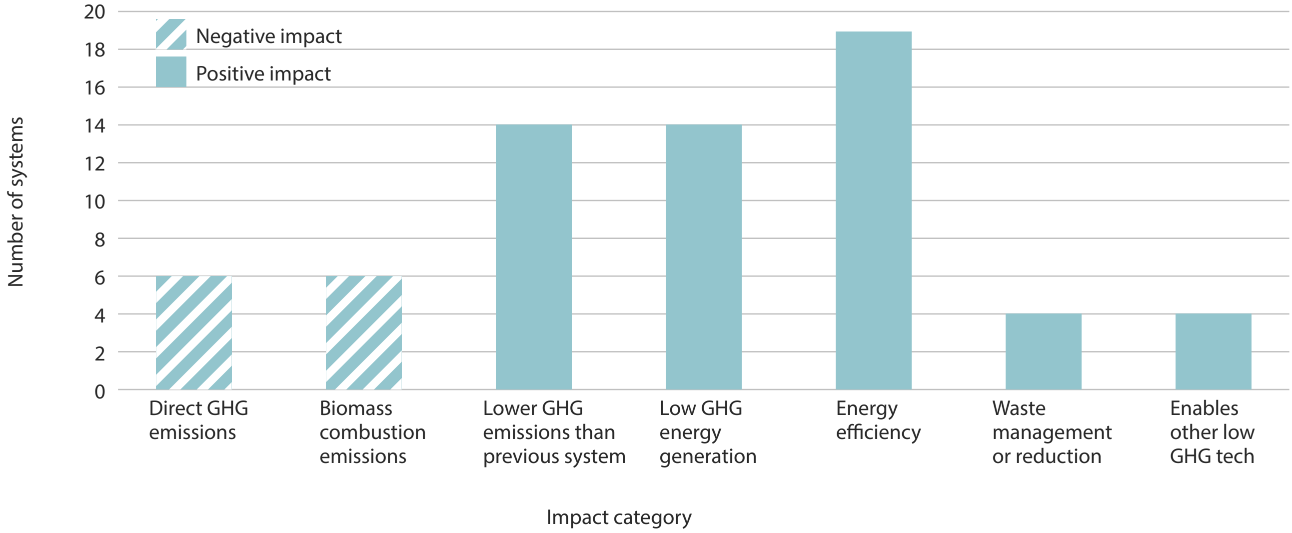
[7] There are many varieties of public-third sector partnerships in the wider local energy world – for example, Plymouth Energy Community, or Edinburgh Community Solar Cooperative. However, most of these would not qualify as an integrated local energy 'system' under our criteria. A notable exception is the demonstration project Project LEO, in which both Oxford City Council and the Low Carbon Hub (a community energy coop) are partners.

[8] Note, however, that one of the single sector projects, Findhorn Wind Park, is jointly owned by a charity (Findhorn Foundation via a trading subsidiary), a residents' coop, and the energy developer coop Energy4All.

Figure 14: Environmental impacts reported by participants.



As Figure 14 suggests, the chief environmental benefits reported were those related to renewable energy generation, either as directly part of the system or enabled by it, and energy efficiency. Those that used heating technologies like hydrogen cells or heat pumps pointed out that these "run clean", avoiding the emissions of particulates and NOx that are associated with both gas and biomass boilers. In general, there was an emphasis on the efficient use of energy, notably the recycling of waste heat using various technologies, including for cooling. Many system operators were also keen to improve the energy efficiency of the fabric and operation of their own estate when the system served it, or encourage their external customers to save energy.

'GHG' is used as an abbreviation for 'greenhouse gases'. The impact categories presented here are derived from manually analysing interviews with research participants.

Participants were well aware of the complexities of their systems' environmental impacts, however, and also identified several negative impacts. These were mainly greenhouse gas emissions, for example from gas-fired heat networks, or other emissions from biomass boilers – the latter being positive for carbon emissions, but not particulates.

One system manager noted how their CHP system, which some years ago had been seen as 'green' because of its energy efficiency, was now looking less environmentally-friendly in comparison with newer, lower carbon technologies. This was driving them to consider restructuring their system to incorporate heat pumps.

2.9.1. Waste

Electronic waste management was mentioned as a priority by one interviewee; those using biomass of some form as fuel for their system noted that the resulting ash waste was recycled for use in agriculture. One anaerobic digester system in development was intended as a local 'closed loop', with waste spread back on the fields to be grazed by the cows that produced the slurry to be used in the system.

However, these cases were not the norm: in general we found little information on system waste. Only three participants were confident that they had data on the waste generated by their system. Some others noted that waste data was collected at the level of a larger organisation, for example where the system was one part of a local authority's operations. Many felt that their system generated very little waste beyond occasional parts needing replacing as part of routine maintenance in renewable electricity generation systems.

Overall, it appeared that little consideration had been given to what happened to system components when they reached the end of their useful 'life'. This is not to suggest that participants did not care about this aspect of waste and environmental impact. Rather, most system operators expected their components to work for some years to come, and it was not felt to be a pressing matter at present. 'We will deal with that issue when the time comes' is perhaps a fair summary of the general sentiment. One exception was the system outlined in more detail in Box 1, which used communications technology to improve the efficiency and effectiveness of 900 storage heaters that might otherwise have been scrapped across eight blocks of flats.

2.10. Revenue and finance

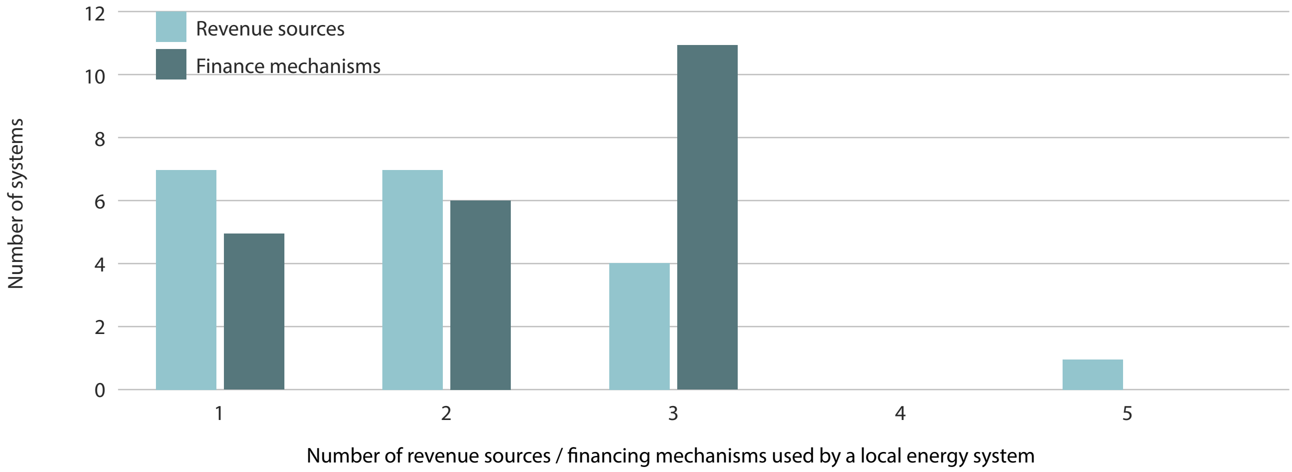
The economic value of SLES is also important. The ability of system operators to create and capture sufficient economic value in the form of revenue to meet the costs of operating the system will be critical in determining how the SLES sector develops, as will the availability of adequate finance to meet any investment needs that cannot be met from retained revenues. We therefore asked what kinds of financial instruments were used to pay for the establishment of the system and any ongoing operational costs not covered by revenues. We also asked what the main revenue streams for the system were.

Overall, we found that systems relied on a small number of revenue sources and financing mechanisms, as shown in Figure 15. The maximum number of sources of finance reported was three, and almost all systems also reported three or fewer revenue streams.

Looking into more detail at what these sources of finance and revenue were, we found that, regarding financing (Figure 16 below), it was very common for system operators to use some of their own reserves to establish and run the system. After that, grants were the most common form of external finance. System operators obtained grants from the public sector and from charitable organisations. The most common type of repayable finance was direct 'citizen finance' in the form of crowdfunding or community shares – used by six systems. Only a very few systems reported using loans or private equity investments; we found no cases of systems being financed by the issue of bonds, stock exchange listed share issues or the use of bank overdrafts.

Payments for energy from end users were the most common revenue stream (Figure 17). Most of these payments were on a 'pay per unit' basis, although some standing charge payments were also noted. Wholesale energy markets, whether through direct trading or through subsidised Feed-in Tariff or RHI contracts with a wholesaler, were also often reported as a source of revenue. (We found no mention of the new Smart Export Guarantee tariff.)

Figure 15: Complexity of local energy system financial flows



After that, several systems principally provided energy cost savings for their operators; and revenue from vehicle charging, which we separated out from general 'end users', was reported in four systems. Other ongoing revenue streams were sparsely reported, and no systems reported revenue from energy storage or operating peer-to-peer energy platforms. That is not to say that they don't engage in these activities, at least in the case of energy storage as Figure 1 shows, just that they don't monetise them separately from everything else they do.

Data on the size of system annual revenues was only available for ten systems so we have not analysed this in detail. However, even this limited sample shows a huge range: from just over £8,000 to well over £25m - a ratio of around 1:3000 from smallest to largest.

Most systems in our study were not the main source of revenue for their owner. In some cases, this was because the operator was an energy company involved in operating multiple local energy systems. For the most part, however, the owner was a local authority, a housing or commercial premises provider or another type of organisation that owns property that decided to take an innovative and sustainable approach to the energy needs of the building occupants.

Figure 16: How local energy systems are financed. The chart shows the most common sources of finance used to fund the establishment and/or ongoing operation of local energy systems.

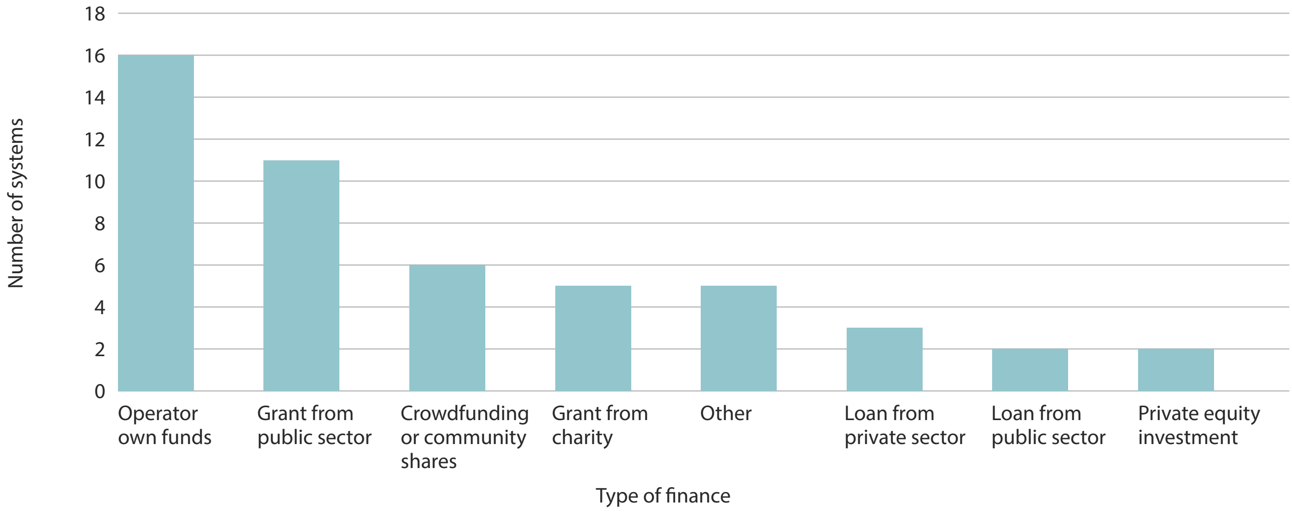
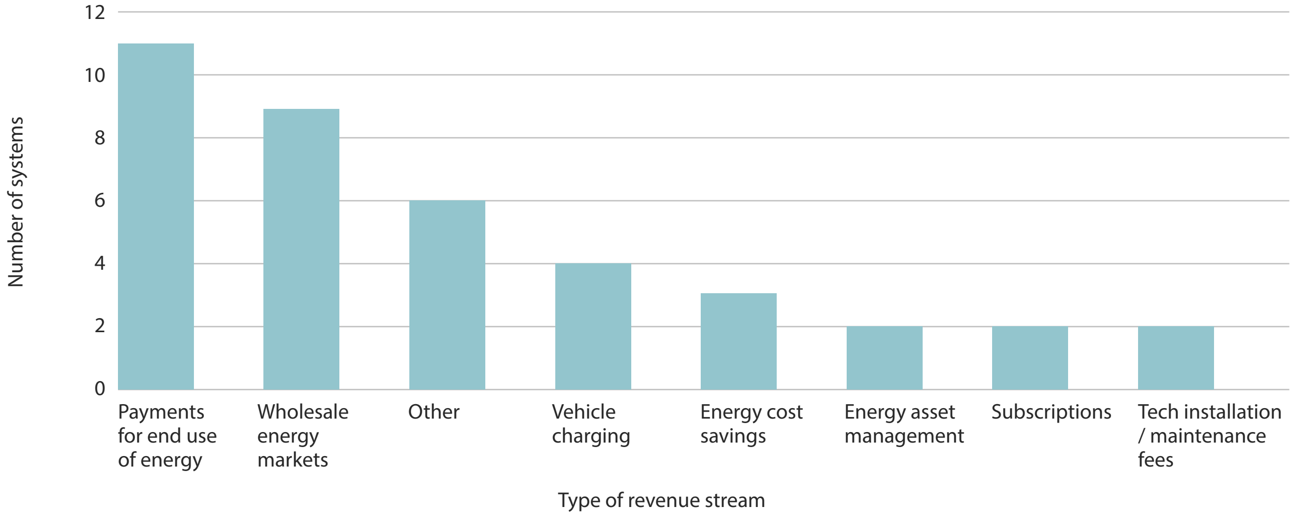


Figure 17: Types of revenue earned by local energy systems. The chart shows how many systems reported earning different kinds of revenue.



2.11. Future plans

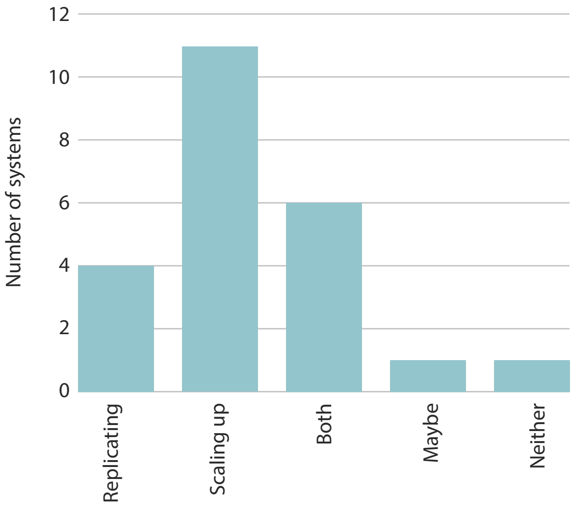
Since the aim of this research was to learn lessons from today's local energy system operators to inform the development and spread of SLES tomorrow, a key element of the study was to hear our participants' thoughts about the future of their systems and their organisations. Do they see themselves as part of an expansion of SLES in the future? What are their hopes for local energy, and what opportunities and obstacles do they see ahead? We asked whether they had plans to replicate their system in another setting, or to scale it up by adding more customers, more activities, or both, and to explain their answer in more detail.

It is clear that there are widespread hopes for more local energy activity in the future. As shown in Figure 18, of 23 participants who answered these questions, 17 hoped to scale up their systems, and 10 to build other similar systems. Six of these were hoping to do both. Of the remaining two, one was interested but uncertain and one answered "neither replicate or scale up" simply because they had recently sold the system to the building owner, and its future was therefore out of their hands. (On the other hand, their organisation was interested in developing new, separate energy projects.) While there may be an element of self-selection bias evident in these results– people less interested in SLES were perhaps less likely to participate in this research – nevertheless this level of future ambition is striking.

While the intention of doing more in the future was universal, the details of what system operators wanted to do varied widely. Most energy generators – of both heat and electric power - were hoping to generate more. Solar power generators seemed fairly confident that this would happen, although some felt that new projects were harder to establish without Feed-in Tariffs (FITs). On the other hand, those looking at future onshore wind developments seemed more cautious. They cited the absence of price support (e.g. FITs, the Renewables Obligation, or Contracts for Difference) coupled with the increasing size and therefore upfront cost of a 'typical' turbine, and wariness stemming from the recent history of frequent changes to wind farm planning guidelines.

Ambitions for heat provision ranged from those operating capital-intensive heat networks, for whom the broad economic outlook was key to the cost of investment capital, to housing developers building Passivhaus-standard houses that may use only heat-recycling ventilation and a small amount of electric solar-powered hot water heating. As noted previously in the discussion of environmental impacts, some operators of CHP and biomass-based heat networks were looking to change, feeling that these technologies no longer represented best practice in low carbon heat. Many were looking at heat pumps, but there was uncertainty around regulation, customer interest, and compatibility with other technologies on a network.

Figure 18: Are there plans for replicating or scaling up this system?



Encouragingly for advocates of SLES, there was a lot of interest in increasing use of smart technologies and smart operation, across many different energy activities and technologies. Increasing the level of local use of energy, more efficient operation, adding storage and electric transport, and greater customer engagement were all mentioned. Installing EV charging points was an ambition for several system operators; adopting vehicle-to-grid (V2G) technologies was very rarely spoken of, however, and it seems beyond the horizon of most actors at the moment. This is perhaps unsurprising, given that few of the UK's electricity Distribution Network Operators offer V2G capabilities at present.

Scaling up also meant different things to different system operators. Some who were principally concerned with supplying energy to a physical estate which they controlled saw future scaling up of the energy system as closely linked to increases in the size of the estate through new buildings. Others hoped to extend networks to reach new customers in the same geographical area; although one in a sparsely populated rural area felt that connecting to new customers would mean such a physical extension of the network that it could no longer be said to be 'local'. Others whose companies were less geographically rooted were keen to replicate work they had done in one area with clients and partners in other areas.

Finally, some challenges around scaling up were linked to policy and regulatory challenges. Many felt that they were operating at a scale below that which was catered for by most policy initiatives and regulatory offers, even those such as Independent Distribution Network Operator that are badged as being designed for local energy systems. It was suggested by one participant that policymaker visions for local energy are too driven by the geographical scale of existing institutions, such as local authorities, to accommodate the smaller scale systems that digital technologies enable. Others mentioned uncertainty over the future direction of government energy policy and timetable of regulatory change; the demands of regulatory compliance for electricity retail supply companies were also mentioned by several participants as an obstacle to expansion.

3. Comparing existing local energy systems with pilots & demonstration projects

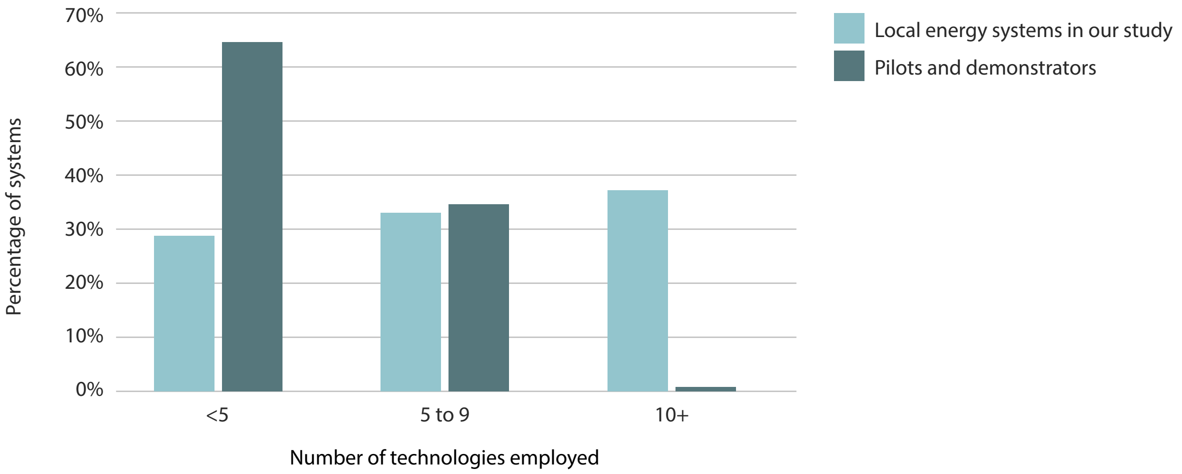
There is a long history of local energy system demonstration and pilot projects, largely funded by public grant schemes, aimed at contributing to knowledge on how to promote smart local energy systems. As we noted in the Introduction, EnergyREV colleagues have recently published an analysis of these projects (Wilson et al 2020). We worked with them to maximise the potential for comparison between the pilot projects that they studied, and the ongoing local energy systems that are the focus of our research. In this section we present the highlights of our comparison, and offer some suggestions as to what this tells us for the future development of SLES.

Pilot projects tended to be larger scale, in terms of geography and number of partners. A group of pilots operate at whole local authority area or larger regional scale, something we did not find among our existing systems. We also note that pilots tend to have much more complex governance than the existing systems that participated in our research. The great majority of pilot projects had four or more project partners, whereas the majority of systems in our study reported fewer than four organisations involved on a regular basis. Pilots are mostly led by private sector companies and by energy sector or other industrial sector organisations – whereas the existing systems we spoke with are mostly owned by organisations outside the energy sector such as local authorities, housing or other real estate providers etc.

The use of some innovative technological solutions for example the use of EVs to provide storage and flexibility to an energy system through V2G technology - was more common in pilot projects. We also see that there have been a small number of pilots of peer-to-peer energy trading, something we found no evidence of among current operational systems. However, we were slightly surprised to see that, in general, pilots did not use more complex combinations of energy technologies than existing systems. In fact, if anything, existing systems tend to use slightly more categories of energy technology than pilot projects do, as Figure 19 demonstrates.

While our study and the study of pilot projects used slightly different technology categorisations, our categorisation was adapted from that used by the pilot projects study, and in fact contained slightly fewer categories (we used 36 categories of technology, while the pilot projects study used 42). It may be that pilot projects were funded to look at specific technological possibilities, rather than to establish an entire local energy system. It should also be remembered that our 'sample' of existing local energy systems is relatively small.

Figure 19: Number of technologies employed: pilot projects vs local energy systems in our study



Overall, the comparison of SLES pilot projects with existing local energy systems highlights some significant similarities and differences. Pilot projects tend to be larger in geographical scale, more complex in terms of governance and slightly more likely to use the latest or untested technologies; yet they often don't use as many separate technologies as existing local energy systems. Some of this is unsurprising: for example, one would expect pilots and demonstration projects to often trial the use of new technology. It is also plausible that demonstrator's complex governance, involving many project partners, is in part driven by a funding process that requires a project developer to assemble a full group of partners in advance, rather than appoint sub-contractors as and when their services are needed. Nevertheless, our analysis serves as a reminder that the business models that are used to operate SLES in the future may be different from pilot projects in many ways – not just in the absence of grant funding.

4. Conclusion: key points

The overarching impression from this in-depth examination of existing local energy systems across the UK is their diversity. Whether looking at their spatial scale or numbers of customers, the energy technologies used and range of activities they undertake or the numbers of people working on them, there is a great range of systems.

This level of diversity precludes us from offering a menu of a small number of 'standard' business models to be taken forward. However, we believe that there are some points that can inform the next steps in SLES for energy policymakers and practitioners. They can:

4.1. Better support the considerable demand for greater local energy integration that our research shows exists

All the systems we studied have achieved some degree of local vertical integration of different parts of the energy value chain consisting of generation, distribution, retail and demand-side services. Many of them have also integrated horizontally, combining energy activities across multiple vectors and types of services, including the provision of power, heating and mobility.

This integration has been achieved, not only in the face of its inherent technical challenges (Rae et al 2021), but also against the grain of the UK energy system. The structure of the UK energy market, and energy regulation, tends to disaggregate these different functions and vectors and prioritise UK-scale operation rather than local systems.

This suggests that many actors find sufficient value in integration to make it desirable, despite the odds against it. Nevertheless, while we are not able to estimate the total size of the UK 'local energy system sector', we know that the great majority of energy customers are not served by local systems.

What is more, a striking feature of the research was that almost all participants had ambitions to expand and/or enhance their operations in the future. They were following developments in the latest clean technologies, and considering how their systems could become smarter, more efficient, reach more customers and provide more services.

We conclude: there may be considerable pent-up demand for more local energy systems. Such systems exist despite a difficult regulatory and market environment; there might be many more of them if the environment was more supportive. Previous EnergyREV research has highlighted the value that can be created through more and more integrated local energy action (Tingey and Webb 2020). Policy should support today's local energy system operators in their ambitions to improve and do more, and facilitate the creation of new local energy systems.

4.2. Recognise the range of things that customers value about local energy systems

All the system operators in this study valued both lowering the negative environmental impacts of their systems, and improving the affordability of energy for customers. However, there was variation in the relative weight attached to different types of value.

Residential customers: where the customers had a strong voice in system governance, the value proposition tended to be more focussed on sustainability and low carbon energy. Where residential customers had less direct say in strategic management, systems tended to be run to prioritise price and ease of use for customers. Our data do not allow us to say whether customers' increased voice led to greater environmental awareness, or whether more environmentally-minded people were motivated to increase their control over their energy supply. The systems with increased residential customer control were all community organisations, but of different forms and with different histories.

Organisational customers: several participants in our study reported that a wide range of businesses were keen to use low carbon energy. A local energy system that included low carbon energy generation was of value for them, not just because the energy was low carbon, but because of the traceability of the energy source. In the context of controversies over the 'greenwashing' of energy tariffs (BEIS 2021), they found that being able to physically point to the source of their low carbon energy gave customers confidence in being able to make their own 'green' claims to their stakeholders.

We conclude: these findings should encourage local energy system operators to pursue the decarbonisation of their systems and to be confident about promoting their green credentials to customers – whether business or residential. We further recommend that systems serving residential customers provide opportunities for customer involvement in running the system. These may allow those more environmentally-minded customers to come forward and get involved, other issues such as time, confidence etc. notwithstanding.

4.3. Support organisations outside of the energy sector to play a role in local energy systems

The local energy system they operated was not the main focus of business or revenue for many of the organisations we spoke with. Often, these were organisations that owned and managed some form of physical estate – housing, or industrial units. Supplying this estate with energy was in a sense a 'natural' extension to their main focus – managing the estate for its tenants/users; but it was not a core part of their overall business model.

Several of these were local authorities. We know that local authorities are already part of the world of SLES development, with several involved in SLES pilot schemes, and many more in sustainable energy schemes more broadly (UKRI 2022, Webb et al 2017). While welcoming this, our results suggest that the future of local energy systems is relevant to many other organisations: both those that currently operate such systems like our study participants, and others that might be interested in entering the energy sector. These include operators of physical estates in the private sector (e.g. industrial and commercial estates, rural estates, and many forms of multi-business complex), the public sector more widely than local authorities (e.g. the NHS), and third sector organisations (from national charities to local development or housing groups).

That is not to say that landowners or managers should occupy a privileged place in determining the future of local energy development. We found several examples of organisations operating energy systems serving physical premises that they did not own (examples in Box 3 in chapter 2); however, these were all organisations that specialised in energy already, and so perhaps do not need any extra outreach effort.

We conclude: a great range of organisations beyond the 'usual suspects' in the core energy sector, are running local energy systems today: in particular, organisations with responsibility for many kinds of physical premises or estates. This diversity of operators is a strength, as it brings different perspectives, customer bases, experience and skills into the local energy sector. We recommend that policymakers and practitioners should cast their nets wide when consulting, and when seeking partners to play a part in the future development of SLES.

4.4. Allow for the 'local' in local energy to be interpreted at a wide range of scales

We found local energy systems running at a wide range of scales: from some serving the operator or just a handful of houses or businesses, to others supplying thousands of customers. Our findings therefore broadly support those of other EnergyREV researchers, who have noted the "wild" variation in scales of 'local' energy projects (Ford et al 2021) and the "elasticity" of the term 'local' in SLES demonstration projects (Walker et al 2021).

It is true that we found very few systems at the scale of a whole town or city. We note that colleagues in EnergyREV have suggested that any city-scale SLES will in practice be a "system of systems", joining up many smaller scale operational units and spheres of activity (Chitchayan and Bird 2021). Our research also suggests that the future development of SLES may need to focus on 'joining up' multiple 'sub-city' systems within a larger area. This could be done through a top-down approach, e.g. local authority led; or by a more bottom-up 'peer to peer' approach, with system operators initiating collaborations themselves; or by some mixture of these approaches. However, we found some quite large scale systems too – sometimes in city neighbourhoods that are almost the size of a small town.

We conclude: policy and practice should build on this diversity of scales, and avoid trying to impose any 'one size fits all' definition of the scale of a local energy system. After all, one of the purposes of decentralising decision-making, in any sector, is to enable people to devise solutions that fit their local contexts; another is to allow scope for experimentation and innovation. Our research finds that this is happening, and we suggest that it should be supported in the development of future SLES.

4.5. Support organisations to manage complex systems and maximise the economic resilience benefits from multiple revenue streams

Most system operators reported more than one source of revenue and more than one source of finance (see Figure 15 above). This is a contrast with the much wider sample of local energy businesses analysed in Fuentes-González et al (2021), that tended to rely on a single source of revenue. This may highlight the greater complexity of local energy systems compared to local energy businesses – the latter were mostly renewable electricity generators, for whom selling electricity to the grid was their one source of revenue. The local energy systems in the present study show more and more varied revenue streams (see Figure 17 above), which may give them greater resilience to specific shocks e.g. changes in policy support for renewable generation, or changes in the wholesale price of energy. Further, where an energy system is not the main source of revenue for the operating organisation, this might enable that organisation to draw on other sources of funds to support energy operations through temporary difficulties.

On the other hand, more complex business models bring challenges too. Managing complexity can be time-consuming and demand multiple specialist skills. The possibility of being temporarily subsidised from other areas of the operator's business can work in reverse too: it might mean that the energy system is sometimes under pressure to provide such resources to other areas of its operator's business.

We conclude: local energy systems have a lot to offer in terms of diversifying revenue and building economic resilience, particularly in today's volatile energy world. But they can be complex to run, and operating organisations - particularly smaller organisations - might need support in accessing or developing the necessary management skills. Providing such support could help realise the benefits of a diversity of operators and scales of operation noted above.

4.6. Recognise that the range of skills and training opportunities needs to be geographically widespread

As noted in section 2.7 above, many of the system operators we spoke to relied on national specialist contractors for key aspects of system maintenance, alongside local contractors for less specialist work. In addition to core energy engineering skills, our interviewees spoke of the need for specialist skills in ICT, data management, and financial and business planning; this supports the findings of other EnergyREV researchers on the wide range of skills needed for SLES operation (Chitchayan and Bird 2021).

We therefore suggest that more training and skills development opportunities relevant to SLES should be available across the UK, to improve the functioning of SLES and maximise the inclusive economic development benefits to localities. Key actors in achieving this would appear to be both FE and HE education providers, as well as larger companies offering apprenticeship schemes, with education, energy and economic development policymakers at local, devolved and UK levels.

4.7. Use policy and regulation to encourage life cycle sustainability thinking

Many existing system operators do collect some environmental impact data, and are aware of waste issues to an extent – particularly so in the case of power-from-waste systems. However, data available was patchy, sometimes because the proper disposal of waste was the responsibility of maintenance contractors, rather than the system operator itself.

More generally, there seemed to be a lack of attention to longer-term waste issues, especially what happened to system components when they reached the end of their useful life. This is perhaps not surprising – arguably the end-of-life destination of their components raises wider questions about the move to a more 'circular economy' that are beyond the scope of a single system operator today to fully answer.

We conclude: these are issues that policymakers and SLES development programmes may be best placed to tackle. While the energy sector is understandably focussed on the urgency of decarbonisation, the world faces multiple ecological and resource crises, and regulation and policy should encourage the adoption of circular economy approaches to sustainable resource use.

4.8. Pay attention to where, when and for whom local energy systems create value

In our earlier discussion of the value created by local energy systems, we noted that one of the principal value propositions that SLES offer is the possibility of integrating greater levels of renewable energy into the overall energy system at a lower cost than would otherwise be possible – through smarter operation reducing the need for extra generation capacity and network infrastructure upgrades. The attraction of this for many energy system actors, including public policymakers, is clear. Yet this value is, firstly, in the future; and secondly, most immediately accessible to system operators and network infrastructure companies. It is reassuring that the system operators we spoke to were keen to pass on their cost savings to their customers.

However, measures to ensure that future cost savings are shared with customers will be important; not only from an energy justice standpoint, but also to increase the political viability of developing SLES in the context of rising energy prices and concern about fuel poverty.

The question of the place where value is realised is another key one for local energy business models. Not all value created is captured directly by system customers or operators. Some may be realised for the local population in general (e.g. if the retention of spending on energy bills in the locality has a multiplier effect on the local economy). Some may be realised at wider spatial scales still, as when a lower carbon energy system contributes to reducing climate change. While any individual system's contribution is small, it is still a contribution to a global process, with global impacts. Yet it is important to remember that the places where local energy systems operate will also experience these impacts themselves: they do share in the value created by combating climate change.

We conclude: ensuring that energy consumers benefit from system efficiency gains is critical for the future of SLES – politically and ethically. More broadly, using a multifaceted analytical framework, such as the Triple-Layered Business Model Canvas, helps highlight the multiple sorts of value that can be created by SLES and the many different stakeholders whose interests should be considered when making energy system policy decisions.

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Appendix 1: Participating organisations

We would like to acknowledge the contribution of the following organisations, whose staff or volunteers kindly offered their time to be interviewed for this research. We are grateful for their insights and information provided, and willingness to share their experience and thoughts.

- Brampton and Beyond Community Trust
- Brighton and Hove Energy Services Co-op (BHESCo)
- Buckinghamshire Council
- Citu
- City of Bradford Metropolitan District Council
- Connected Response Ltd
- Emergent Energy
- Energy Local CIC
- Engie
- Evergreen Energy
- Findhorn Wind Park
- First Choice Homes Oldham
- Green Fox Community Energy
- iPower Energy Ltd
- Kingmoor Park Properties Ltd
- Lancaster CoHousing
- Public Power Solutions
- Royal Borough of Greenwich
- Stoke-on-Trent City Council
- Thameswey Energy
- UK Heating Matters
- University of Edinburgh
- University of St Andrews
- Upside Energy
- Wendron Cricket Club

Appendix 2: Data collection & analysis

Our data collection strategy was driven by our analytical framework (outlined in chapter 1) and the state of knowledge of local energy systems in the UK. Firstly, the analytical framework called for data on many aspects of a business model, but in a clearly structured way. Secondly, part of the task of the research was to explore the range of systems that existed, as there was not a well-defined "local energy system" sector, nor were there comprehensive lists available of every energy system that might fall within our remit,. Therefore, we decided to use a structured interview schedule divided into 11 topic areas (outlined in Chapter 1.1), which could also be used as an online questionnaire as our data collection tool to ensure comparability across potentially diverse responses .

The structured interview schedule based on our adapted Triple-Layered Business Model Canvas was designed over the autumn and winter of 2020-21. It comprised a mixture of highly structured questions with a range of predefined answer options (e.g. of technologies used in the system). Free comment sections were used to ensure that we captured the diversity of local energy system configurations, including possibilities that we hadn't anticipated in our predefined answers, and to capture qualitative insights about value propositions or aspirations for the future. The initial draft of the interview schedule was shortened and refined with input from UKRI; researchers from IPSOS Mori working with the Prospering from the Energy Revolution (PFER) SLES demonstrator projects; and the lead engineer for a PFER SLES Design Demonstrator project (Zero Carbon Rugeley).[9]

Interviews began in February 2021, and we continued collecting data until September the same year. Clearly energy companies were important contacts, but, given the uncertainty about the nature and number of existing local energy systems, we hypothesised that there might be other bodies operating relevant systems that we would want to interview. Therefore, researchers reached out to potential participants via several different approaches: the EnergyREV website and mailing list; UKRI's Knowledge Transfer Network; newsletters of the Association for Decentralised Energy, and Local Energy Scotland and through directly contacting potential operators of local energy systems, based on web searches and contacts in the energy sector.

The questions on the schedule were available for self-completion online, but the great majority of participants (23 out of 29) were interviewed using video call platforms such as Zoom and MS Teams. In these, the researchers completed the online questions on behalf of the interviewee participating in the study; the researchers shared their screen so that the participant could see the responses that were entered. In addition, one face-to-face interview was conducted – out of doors (for COVID safety) at the site of a housing development with a built-in integrated energy system.

Data collected was then downloaded into Excel and analysed both quantitatively and qualitatively by the lead author, with support from the wider team.

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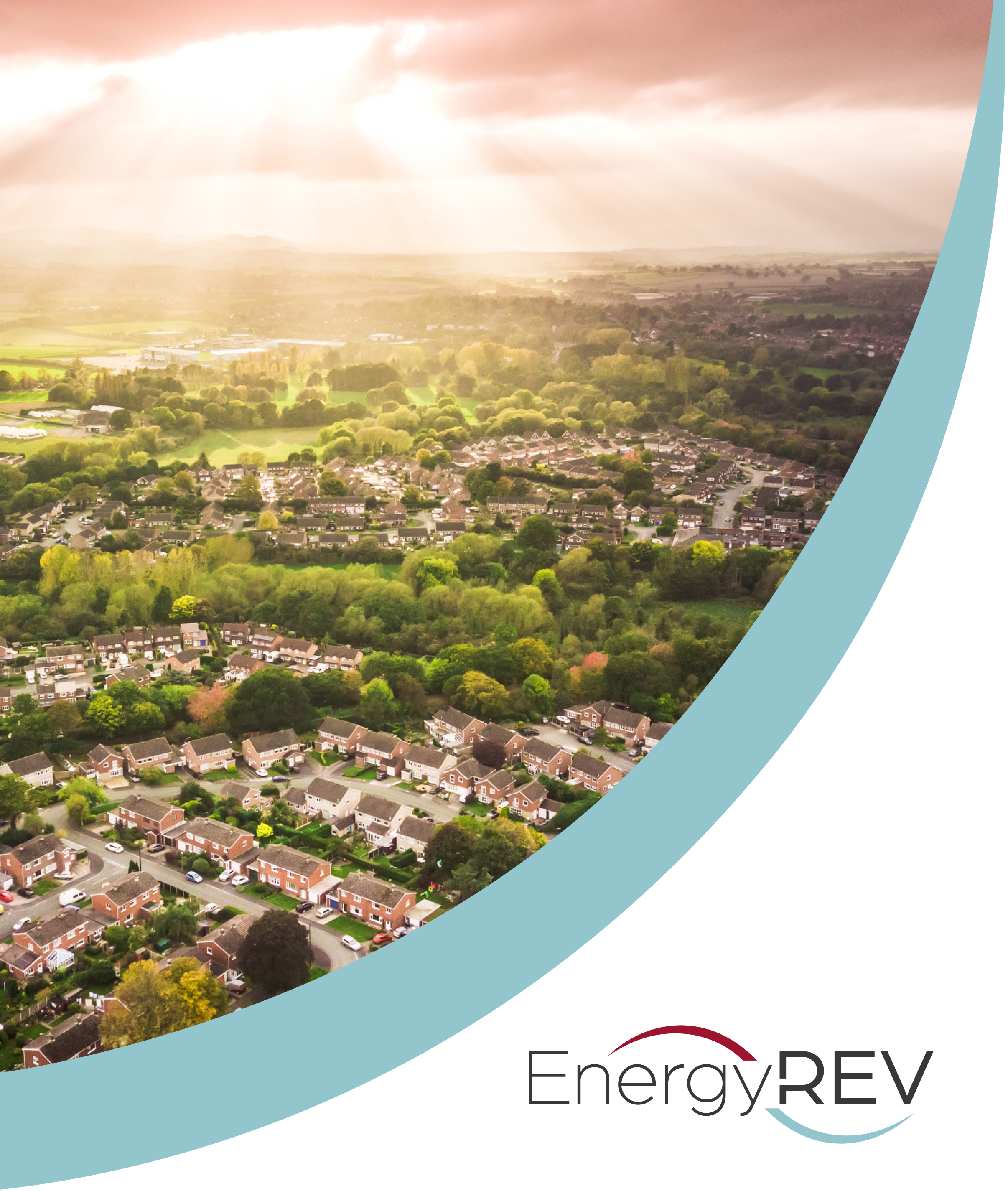
[9] The full interview schedule is available to download from the EnergyREV website.



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EnergyREV was established in 2018 (December) under the UK's Industrial Strategy Challenge Fund Prospering from the Energy Revolution programme. It brings together a team of over 50 people across 22 UK universities to help drive forward research and innovation in Smart Local Energy Systems.

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