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Acronyms

BEIS	UK Department for Business, Energy and Industrial Strategy
CHP	Combined heat and power
CSE	Centre for Sustainable Energy
DNO	Distribution network operator
EV	Electric vehicle
FiT	Feed-in tariffs
PFER	Prospering from the Energy Revolution
RO	Renewables Obligation
SLES	Smart local energy systems
UKERC	UK Energy Research Centre
WWEA	World Wind Energy Association

Contents

Summary

This report provides the full methodology and findings from an analysis of common types of local energy system project in the UK over the past decade. It accompanies a short policy briefing on the same topic. Local energy in general terms comprises place-based responses to a wide range of social, environmental or economic needs related to energy. The particular subset of local energy system projects analysed in this report emphasise integrated or 'systems' type solutions across supply, distribution and demand.

Using cluster analysis of 147 local energy system projects from an updated and extended 2018 UKERC study, we identified four common project types distinguished by their geographic, scale, technological and institutional characteristics.

The first type describes projects led by 3rd or public sector organisations and including demand-side technologies and sectors (n=41). An illustrative example is Active Homes Neath led by the Pobl Group in south Wales to integrate renewable technologies and reduced energy consumption in social housing.

The second type describes projects led by private firms (but not DNOs) with relatively small budgets and narrow scopes to cover supply-side electricity technologies in a single sector (n=24). An illustrative example is Bus2Grid led by SSE in London bus depots to demonstrate electric vehicle-to-grid technologies and business models.

The third type describes projects led by private firms (but not DNOs) with relatively large budgets and broad scopes to cover multiple energy vectors integrating across demand, network, and supply-side technologies (n=34). Three of the four PFER demonstrators fall within this type. An illustrative example is ReFLEX Orkney led by the European Marine Energy Centre to inter-link local electricity, transport and heat networks into a single controllable system including demand-side and storage resources.

The fourth type describes projects led by DNOs or similar firms focusing on electricity network improvements (n=47). Most of these projects were funded through dedicated funding programmes, such as the Low Carbon Network Fund. An illustrative example is Low Carbon Hub led by Western Power Distribution in East Lincolnshire to integrate significant amounts of low-carbon generation on to electricity distribution networks while avoiding network reinforcement costs.

These four common types of local energy system project are indicative of a wide range of project rationales, ranging from public policy objectives in housing to electricity-network management and integrating variable renewables to multi-sector multi-vector energy-system integration. These are common types of local energy system projects only; the wider community and local energy landscape in the UK is still more diverse.

By reducing the wide variety of local energy system projects to a smaller number of common types, this report is designed to help policymakers and funders better target support mechanisms and to help researchers parsimoniously capture project heterogeneity when modelling system impacts.

1 The changing landscape of local energy in the UK

1.1 What is the landscape of community and local energy in the UK?

Distributed generation, storage, and flexibility services are now a significant feature of the UK electricity system. Over 30GW of power generation capacity is connected to distribution networks, of which over 85% is renewables (including 13GW of solar PV, mainly on rooftops). An additional 3.3GW of storage and 320MW of flexibility services are operational. However, local energy activity is unevenly distributed across the country, as is leadership and involvement by local authorities (Tingey and Webb 2020).

In general terms, local energy projects are activities, initiatives or investments which are area- or place-based responses to local energy needs or opportunities. There are many different terms and definitions (see Box 1). Although dominated by electricity supply, distribution and end-use, local energy needs also relate to gas, heat, transport, and other energy carriers.

Box 1: **Different terms and definitions for community and local energy projects**

Community power (WWEA): projects majority owned and controlled by local stakeholders with the majority of social and economic benefits distributed locally ; see also (Walker and Devine-Wright 2008).

Community energy (UKERC): small civil society organisations or social enterprises running local projects that generate renewable electricity or encourage energy saving and efficiency (Braunholtz-Speight et al. 2020).

Local energy (BEIS): any collective action project led by local organisations (public, private, civil society) to reduce, purchase, manage and generate energy for local benefit.

Integrated local energy projects (CSE): place-based solutions combining elements of demand and supply, involving more than one technology or service (Bridgeman et al. 2019).

Energy system demonstrators (UKERC): deployment and testing of more than one technology type that could underpin the operation of a low-carbon energy infrastructure in the future (Flett et al. 2018).

Smart local energy systems (PFER, EnergyREV): defined not by what they are, but by what they do in delivering cleaner, cheaper and more resilient energy services.

Local energy system (DELTA-EE): seeking to match local (renewable) energy resources with local demand within a bounded, small energy system (Delta-ee 2019).

Community energy describes collective citizen-led action motivated by a range of social, economic and environmental goals but focused on addressing specific local needs (Devine-Wright 2019). Community energy projects in the UK are diverse in form, scope and purpose (Seyfang et al. 2013). Urban energy projects have similarly been developed and led by a variety of community, private, local authority and partnership organisations (Rydin et al. 2013). Until recently, available financial incentives for renewables (e.g., feed-in tariffs) have seen site-specific electricity generation projects like rooftop solar PV become more common in the community energy sector (Braunholtz-Speight et al. 2020). Financial performance has tended to depend on revenues from the FIT and RO price-support schemes (which are now closed for new projects) in addition to energy sales to a mix of sectors. Demand-side projects are less common, but can generate revenues from service contracts or customer fees.

The community energy sector now has a clear vision to expand into other roles and services such as acting as aggregators and intermediaries (e.g., in local flexibility markets), addressing fuel poverty, providing low-carbon mobility and energy-saving services, and delivering heat networks (Braunholtz-Speight et al. 2019). This will require a broader range of skills and competences through alliances with other civil society organisations and energy SMEs, as well as local authorities as procurement entities (Braunholtz-Speight et al. 2019). Currently community energy projects raise capital from community share offers, loans and grants, and are commonly run by co-ops or other companies with volunteer or paid staff depending on their size (Braunholtz-Speight et al. 2020).

In contrast to community energy, **local energy** is increasingly used to describe multi-actor partnerships (potentially involving both public and private sectors) to promote local economic growth, job creation, and skills development, as well as to develop replicable, scalable business models (Bridgeman et al. 2019). The BEIS Local Energy Team was established to support local authorities and local enterprise partnerships (LEPs) in England to deliver low-carbon economic growth, supported by five new regional Local Energy Hubs.

Over the past 10 years, the UK landscape has shifted from community energy to local energy (Devine-Wright 2019). More recently, funding programmes have emphasised 'integrated' or 'systems'-type local energy projects (see next section). Local energy projects have also had to diversify and become more commercially-oriented as financial support mechanisms for renewable power production (e.g., feed-in tariffs) and area-based building retrofits (e.g., Green Deal) have been cut or withdrawn (Kuzemko and Britton 2020).

This changing landscape has seen projects moving from niche (e.g., remote island) to subsidy-driven (e.g., renewable power) to increasingly value-driven investments (Delta-ee 2019). New sources of value include flexibility services, self-consumption (connecting distributed resources with consumers), integrating across sectors and energy vectors, and low costs of capital from community ownership in exchange for resilience, autonomy, democratisation (Delta-ee 2019). Local energy projects may therefore be motivated by revenue generation, export opportunities, and network congestion, as well as fuel poverty, clean energy, and carbon targets..

Local energy projects can be led by private, public or civil society organisations, but do not tend to emphasise strong civic engagement. Three common institutional configurations for local energy projects are: (1) projects led by community groups, often supported by local authorities or private service providers; (2) projects led by distribution network operators, often with technical support from universities for project delivery; (3) projects led by local authorities acting as intermediaries to contract out services (Bridgeman et al. 2019; Rydin et al. 2013). Whereas DNO-led projects may be narrowly motivated by network management in the context of renewable power or electric vehicle (EV) integration, community or local authority-led projects tend to have a wider range of motivations.

1.2 How have local authorities engaged with local energy?

Local authorities are important actors and intermediaries in local energy projects (Kuzemko and Britton 2020). Local government in the UK is a mix of unitary, metropolitan and two-tier (county + district) authorities. Around three quarters of the UK's 408 local authorities have declared climate emergencies, and around one quarter have 100% clean energy pledges.

There are a range of political, economic, and social drivers for local authority engagement with local energy. Representative examples include: addressing fuel poverty and exploiting local resources or comparative advantage (e.g., Aberdeen); developing local skills, capacities, and leadership (e.g., Birmingham); (3) reducing carbon emissions and progressing towards clean energy targets (e.g., Leicester) (Webb et al. 2017a).

However devolved powers are limited so local authorities have to find innovative ways to develop necessary capacity and implement projects in competitive market environments (Wurzel et al. 2019). Local authority budgets from central government have fallen by almost 50% due to austerity cuts following the 2007-8 financial crisis (Kuzemko and Britton 2020).

Limited budgets and remits mean local authority-led action has been uneven, relatively small-scale, and focused on key competences in building stock management (e.g., site-specific CHP, and domestic energy-efficiency improvements) (Tingey and Webb 2020; Webb et al. 2017a). More supportive legal frameworks and financial settlements mean Scottish local authorities are more likely to be 'leaders' whereas those in Northern Ireland are more likely to be 'laggards'. Leaders are more likely to take on complex multi-actor projects (e.g., heat networks) as part of integrated local energy programmes consistent with energy and climate targets.

The outlook for local authorities is changing. In Scotland, for example, a renewed emphasis on smart local energy provision within decarbonisation plans should further strengthen the capacity of local authorities (Tingey and Webb 2020). In contrast, the 'City Region Deals' in England aim to devolve more finance and responsibility for economic growth rather than decarbonisation, alongside relatively new institutional structures of local energy hubs and local enterprise partnerships (LEPs) (Kuzemko and Britton 2020).

1.3 What are local energy 'system' projects?

In this report, we use the term **local energy system projects** specifically to mean local energy projects implementing integrated or 'systems' type solutions across supply, distribution and demand. This broadly follows the UKERC definition of **energy system demonstrators** and the CSE definition of **integrated local energy projects**. This means we do not focus on other types of local and community energy such as community-owned renewable power projects.

Energy system demonstrators are a particular form of (usually local) energy project for deploying and testing multiple technologies to support low-carbon system operation (Flett et al. 2018). The emphasis on system operation means improved ways of integrating, coordinating and balancing supply and demand resources, particularly on electricity networks, but with some multi-vector approaches across power, heat and transport systems. Energy system demonstrators also make explicit the interest in decarbonisation which is common to some but not all local energy projects.

Integrated local energy projects as defined by the Centre for Sustainable Energy (CSE) emphasise place-based solutions with elements of demand and supply, involving more than one technology or service (Bridgeman et al. 2019). This is fairly similar to UKERC's energy system demonstrators terminology. Inclusion of 'integration' or 'system' alongside local energy emphasises the multi-sector (supply, network, demand) characteristics of more recent local energy projects. Examples of integrated local energy project types by CSE include demand response, renewable heat and electricity, distributed storage, smart EV charging, and smart system management. Project motivations and objectives range widely, from decarbonisation and fuel poverty reduction to revenue generation and testing replicable business models (Bridgeman et al. 2019).

Smart, local energy systems (SLES) are a particular form of local energy project involving multi-vector, multi-technology solutions to system integration, management and flexibility challenges. The Prospering From the Energy Revolution (PFER) programme, funded through the UK Industrial Strategy, seeks to develop, test and scale up SLES that deliver cleaner, cheaper and more resilient energy. There are four selection criteria for PFER demonstration projects: (i) provide cleaner, cheaper, more desirable energy services for the end user; (ii) lead to more prosperous and resilient communities; (iii) prove new business models that are suitable for investment and can grow and replicate in the 2020s; (iv) provide evidence on the impacts and efficiency of novel energy system approaches by the early 2020s.[1] By implication, PFER defines smart local energy systems by outcomes rather than by constituent elements. This leaves some interpretive flexibility as to what is and is not an SLES.

The EnergyREV research consortium, funded through PFER, similarly does not define what SLES are, but rather defines what SLES should do: create value beyond business-as-usual, and deliver local co-benefits. Energy system elements are characterised as: multiple vectors, supply and demand, socio-technical, and institutional (Ford et al. 2019). These elements are local if they involve local and community stakeholders, local decision-making, or local asset ownership. Local in such cases can be defined spatially, socially, or by the location of network infrastructure and generation resources. Smart elements are characterised as information and communication technologies (ICTs), automation and self-regulation, ability to learn system dynamics, and smarter decision-making. These characterisations of the three constituent elements of SLES are extremely broad and so hard to implement as definitional terms (e.g., as search criteria for identifying existing SLES-type projects). As they make reference to multi-vector, multi-technology systems with local decision-making, ownership or other engagement characteristics, they are closest in definitional terms to UKERC's energy system demonstrators.

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[1] Four leading edge demonstrators to jumpstart energy revolution – GOV.UK.

2 Data and method

2.1 What data did we use to analyse common types of local energy system project?

We built on the UKERC Energy System Demonstrators database to analyse the geographic, scale, technological, and institutional characteristics of local energy system projects. Flett et al. (2018) provide descriptive statistics of their n=119 energy system demonstrator projects in terms of location, scale, budgets, funding, sectors, energy vectors, technologies, as well as consumer engagement. We extend their database to n=147 projects by searching for more recent projects using the same search criteria and methods. (See Appendix for descriptive statistics of the extended dataset. Each project has a unique identifier in the dataset from DIP1 to DIP149).

The physical scale of projects is measured as: lab, site (a single location, e.g., a building), small (select locations in an area, e.g., a housing estate), community (village, town or part of a city), region (local authority area or areas), national (more dispersed). Over half the projects in the dataset were in SE England or Scotland.

The projects demonstrated a total of 42 different types of technology. To make analysis of technological characteristics more tractable, we developed a reduced set of 6 technology groupings which aligned with projects' rationales and scopes. These 6 technology groupings were also designed to align with the needs of the EnergyHub and UCL-BRAIN models used in the EnergyREV modelling project called 'Smart Local Energy Systems in a Whole Systems Context'.

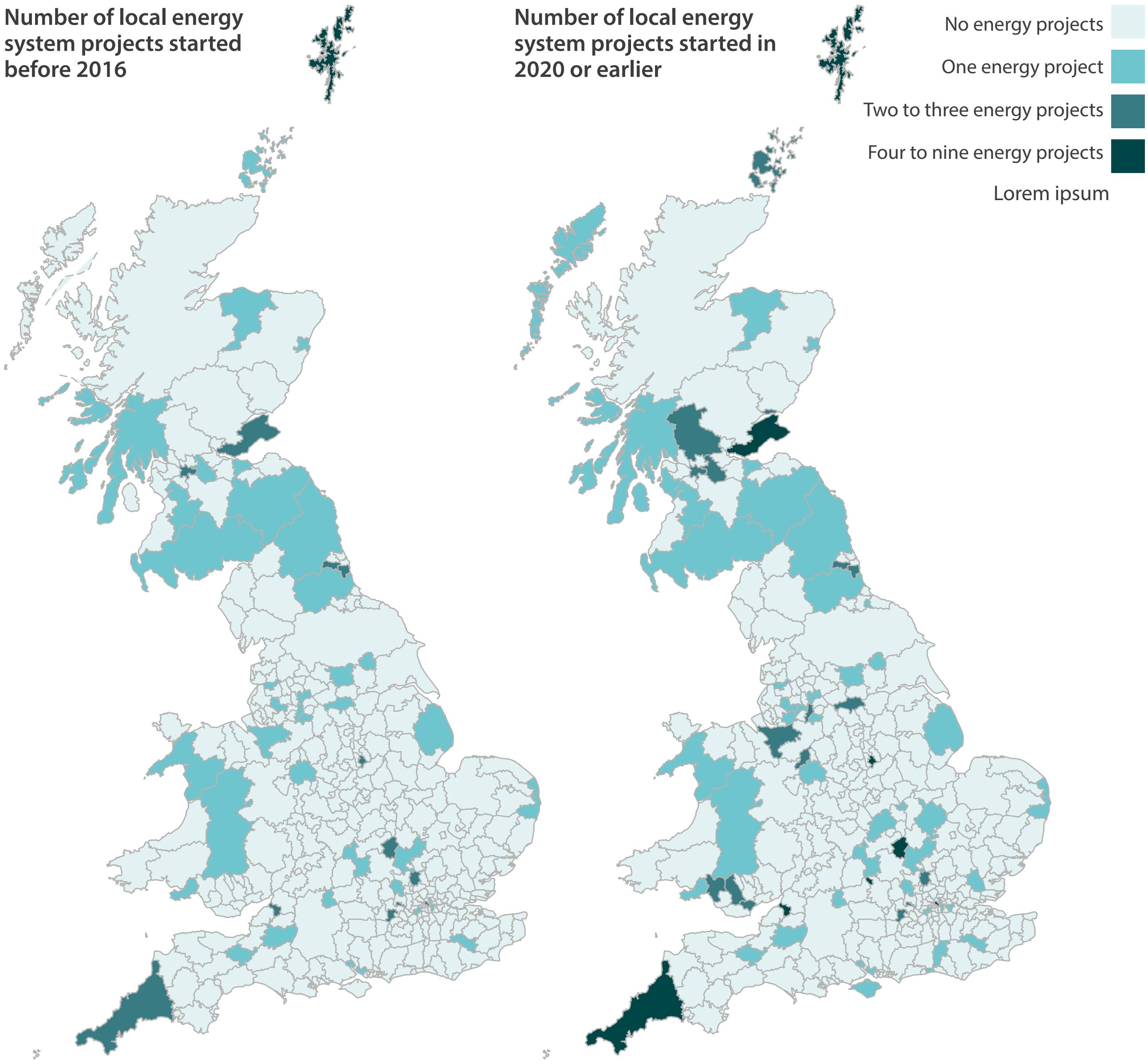
These 6 technology groupings are defined as follows:

- **Variable Renewables**: intermittent or variable renewable power generation technologies - e.g., solar PV, solar thermal, wind
- **Generation & Storage exc. Renewables**: non-renewables distributed generation and storage technologies - e.g., gas boilers, CHP units, battery storage, thermal storage
- **Electricity Grid Integration**: flexibility and power grid integration technologies - e.g., demand response, load control, vehicle-to-grid (V2G)
- **Local Electricity Network**: technologies for managing and balancing local power systems - e.g., microgrids, smart meters, data acquisition technologies
- **Energy Carriers & Coupling**: alternative energy carriers and coupling between energy vectors - e.g., hydrogen, fuel cells, biofuels, PowerToX, heat networks, heat pumps
- **Energy End-Us**e: all energy end-use, management and control technologies - e.g., efficiency improvements, smart controls, vehicles (electric, gas, hydrogen).

2.2 How have the characteristics of local energy system projects changed over time?

Figure 1 shows the spatial diffusion of projects by local authority area over the past decade in England, Scotland and Wales. (Only one project in the dataset was in Northern Ireland). Roughly half the projects in the sample started in 2016 or later. Using chi-square and Mann-Whitney U tests, we compared the scale, technological and institutional characteristics of earlier (pre-2016) and later (2016-) projects to see if these had changed significantly over time.

We found no changes over time in projects' geography or scale. We found later projects were *significantly more likely* to have budgets of £2.5m or over ($p<.05$).



Number of local energy system projects started before 2016

Number of local energy system projects started in 2020 or earlier

Figure 1: Spatial diffusion of local energy system projects in England, Scotland and Wales. Maps show cumulative number of projects started by 2015 (left) and by 2020 (right) at the spatial resolution of local authorities. Data extended by the authors from (Flett et al. 2018).

In terms of technological characteristics, we found no changes over time in the number of sectors covered, whether domestic or non-domestic sectors were covered, the number of technologies demonstrated, and which technology groupings were covered. We did find that later projects were *significantly more likely* to include a larger number of energy vectors (p<.01), specifically heat and/or transport in addition to electricity. This reflects the broader shift over time in local energy projects towards addressing flexibility and system integration challenges.

Although we found no difference between earlier and later projects in terms of number of technologies demonstrated, we did find that later projects were *significantly less likely* to be in our Local Electricity Network technology grouping (p<.05) but *significantly more likely* to be in our Energy Carriers & Coupling grouping (p<.05). The lower number of Local Electricity Network type projects in the later period is explained by the Low Carbon Network Fund which co-funded 29 projects, all of which started before 2016. The higher number of Energy Carriers & Coupling type projects in the later period is consistent with the shift towards multi-vector integration.

In terms of institutional characteristics, we found no changes over time in projects' use of multiple funding sources, use of EU funding sources, number of partners overall, and numbers of different types of partner (private, private, 3rd sector, and dedicated partnerships) although we did find that later projects were *significantly more likely* to include hybrid public-private organisations such as special purpose companies (p<.05). We found no changes in the type of partners which led projects, with the exception that later projects were *significantly less likely* to be led by private network operators. This is also explained by the concentration of Low Carbon Network Fund projects led by DNO-type companies in the earlier period.

2.3 How did we identify common types of local energy system project?

First, we examined relationships between geographic, scale, technological and institutional variables using cross-tabulations and chi-square tests to build up a picture of similarities and differences between the 147 projects in the dataset, and where these differences were significant. At this exploratory stage it became clear that DNO-led projects narrowly focused on electricity networks were a distinct type of project, and that other projects varied in size and scope, from single-vector site-specific projects with smaller budgets to multi-vector, dispersed projects with larger budgets.

Second, we used cluster analysis to identify common types of project in terms of either geography and scale, technologies, or institutions. Cluster analysis is a statistical procedure that links cases with similar characteristics together in groups or 'clusters' while ensuring clear distinctions between each cluster. Our initial exploratory analysis informed selection of which variables to use in the clustering. (See Appendix for full details of the cluster analysis method).

Finally, based on this composite picture, we ran an integrated cluster analysis using a reduced set of variables measuring geographic, scale, technological and institutional characteristics. We analysed the composition of projects in each cluster to confirm the interpretability and coherence of the clusters. We also tested for differences between the characteristics of projects in each cluster to confirm that each cluster had distinctive features.

3 Results

3.1 What common types of local energy system projects did we identify?

Full details of the explanatory analysis and cluster analysis by blocks of variable are provided in the Appendix. Here we report results from the final step of our methodology using integrated cluster analysis on the geographic, scale, technological and institutional characteristics of projects in the dataset (Figure 2). Note that one outlier project was excluded from the analysis (see Appendix for details).

We identified a clearly interpretable four cluster solution.

- **Cluster (1)**: Local energy system projects which were led by 3rd or public sector organisations and included demand-side technologies and sectors (n=41); median budgets of £3.3m (£0.6m - 7.2m).
- **Cluster (2)**: Local energy system projects were which led by private firms (but not DNOs) with relatively small budgets and narrow scopes to cover supply-side integration of electricity technologies in a single sector (n=24); median budgets of £2.4m (£0.4m - 5.8m).
- **Cluster (3)**: Local energy system projects which were led by private firms (but not DNOs) with relatively large budgets and broad scopes to cover multiple energy vectors integrating across demand, network, and supply-side technologies (n=34); median budgets of £4.0m (£1.2m - 13.4m).
- **Cluster (4)**: Local energy system projects which were led by DNO or similar firms and focused on electricity network improvements (n=47); median budgets of £1.8m (£0.4m - 10.1m).

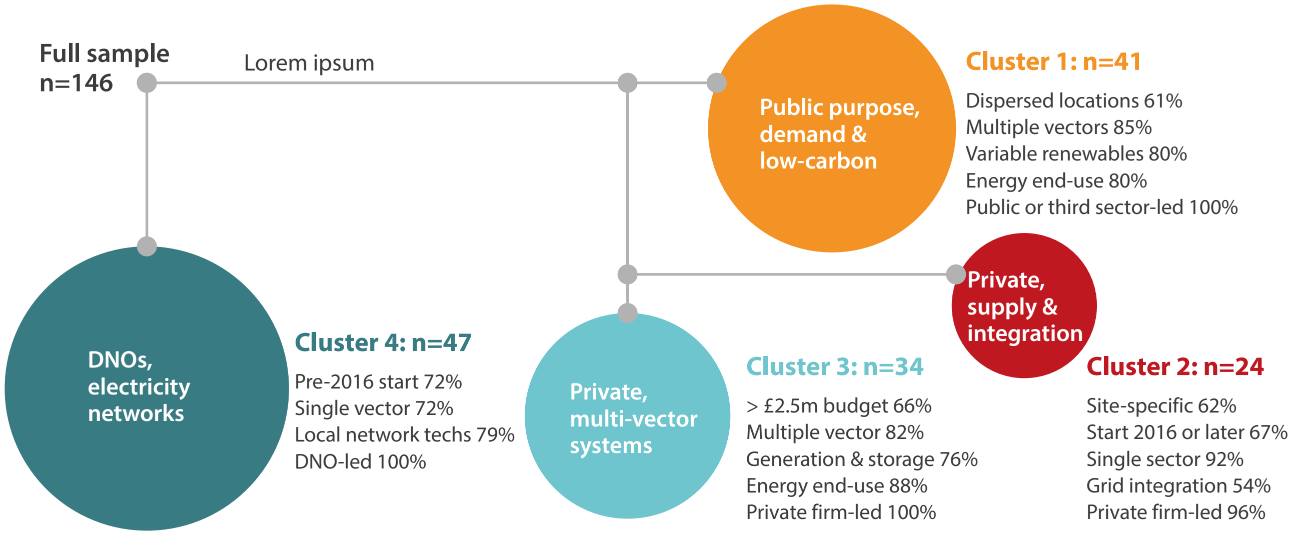


Figure 2: Four common types of local energy system project identified using cluster analysis of geographic, scale, technological and institutional characteristics of 146 projects. Cluster descriptions show % of projects within each cluster that share the distinguishing characteristics of that cluster.

Figure 3 summarises the characteristics of projects in each of the four clusters. Tests of difference (ANOVA) confirm significant differences in their technological and institutional differences, but less variation in their geographic and scale characteristics.

Figure 3: Percent (%) of local energy system projects with defined characteristics in each of four clusters. Between-cluster tests of difference for each characteristic (ANOVA) shown as significant (p<.01) or non-significant (n.s.).

		Geographic & scale characteristics				Institutional characteristics				
		Location	Scale	Budget*	Year start	Lead partner	Lead partner	Lead partner	Partners	Partners
Cluster	n	(Sub) urban	Dispersed	> = £2.5m	2016 or later	DNO or similar	Private exc. DNO	Third or public sector	Public	Third sector
1	41	76%	61%	58%	59%	0%	0%	100%	51%	90%
2	24	75%	38%	45%	67%	0%	96%	0%	38%	71%
3	34	79%	44%	66%	47%	0%	100%	0%	38%	82%
4	47	70%	53%	45%	28%	100%	0%	0%	34%	68%
All	146	75%	51%	53%	47%	32%	39%	28%	45%	78%
	ANOVA	n.s.	n.s.	n.s.	p<.01	(p<.01)**	p<.01	(p<.01)**	n.s.	n.s.

Notes: * Undefined budget for 20 projects so in total n = 126.
** Insufficient heterogeneity for ANOVA, but clear difference.

		Technological characteristics							
		Sectors	Energy vectors	Technology groupings					
Cluster	n	Multiple	Multiple	Generation & storage exc. Renewables	Variable renewables	Electricity grid integration	Local electricity network	Energy carriers & coupling	Energy end-use
1	41	32%	85%	66%	80%	39%	37%	51%	80%
2	24	8%	71%	54%	46%	54%	0%	8%	0%
3	34	38%	82%	76%	56%	44%	47%	47%	88%
4	47	34%	28%	36%	28%	60%	79%	19%	45%
All	146	30%	64%	57%	52%	49%	47%	33%	58%
	ANOVA	n.s.	p<.01	p<.01	p<.01	n.s.	p<.01	p<.01	p<.01

3.2 What are the rationales for each common type of local energy system project?

We do not have standardised data on each project's distinct motivations and objectives, so we cannot analyse this directly. However, the variation between project characteristics across the four clusters is indicative or suggestive of differences in project objectives. This ranges from projects with clear public purpose and involvement acting on energy end-use (Cluster 1) to those tackling wider energy-system challenges from electricity supply integration (Cluster 2) and electricity network balancing and management (Cluster 4), to flexibility through vector coupling and integrated system management (Cluster 3). These different project objectives are evident in both urban and more rural locations, at specific sites and dispersed across multiple sites, and involving public and 3rd sector partners as well as private firms.

There are some differences in the clustering both spatially and through time. Over half of all projects are in SE England and Scotland, but Scotland had a significantly higher proportion of Cluster 1 projects, whereas SE England had higher proportions of Cluster 2 & 3 projects. This points to a more conducive regulatory and funding environment for public sector and civil society-led projects in Scotland. Similarly there are some significant differences temporally. Recent projects started in 2018 or later are less likely to be in Clusters 1 & 4, and more likely to be in Cluster 2. This points to reductions in local authority capacity (austerity budget cuts) and available revenue support (feed-in tariff cuts) which have pushed projects to capture more diverse value streams.

3.3 What are illustrative projects for each of the common types?

We selected one project from the dataset to illustrate the characteristics of each cluster more clearly, and to highlight the differences between clusters:

- **Cluster (1)**: 3rd or public sector-led projects covering demand sectors: e.g., Active Homes Neath (DIP142) led by the Pobl Group in south Wales, with the stated aim of demonstrating how integrated renewable technologies can reduce energy consumption and provide people with a healthy living environment in a social housing development.
- **Cluster (2)**: private firm-led projects focusing on electricity supply integration: e.g., Bus2Grid (DIP8) led by SSE in London bus depots, with the stated aim of demonstrating electric vehicle-to-grid technologies and business models.
- **Cluster (3)**: private firm-led projects involving multiple energy vectors and full system integration: e.g., ReFLEX (DIP122) led by the European Marine Energy Centre in Orkney, with the stated aim of inter-linking local electricity, transport and heat networks into one controllable, overarching system including demand-side and storage resources.
- **Cluster (4)**: DNO-led projects focusing on electricity networks: e.g., Low Carbon Hub (DIP59) led by Western Power Distribution in East Lincolnshire, with the stated aim of integrating significant amounts of low-carbon generation on to electricity distribution networks while avoiding network reinforcement costs.

4 Implications

4.1 Our results show that one-size does not fit all in a diverse local energy landscape

Local energy system projects are designed and implemented for a wide variety of reasons. They also vary in their geographical, technological, and institutional characteristics. Understanding this heterogeneity supports analysis and policymaking. It makes clear there are no one-size-fits-all policy support mechanisms for local energy system projects. To be effective, specific funding and skills development programmes need to match the needs and characteristics of desired project types. Societal engagement is needed to discuss whether each project type merits similar levels of public policy support and funding, drawing on evidence of the different types of value created by each type at local and national levels.

The PFER programme initially funded four demonstrator projects: Energy Superhub in Oxford, ReFLEX in Orkney, Local Energy Oxford, and Smart Hub SLES in Sussex. Three of the PFER demonstrators lie within Cluster 3 which defines projects led by private firms, with an average of six other partners, involving multiple energy vectors and full system integration.[2] The fourth PFER demonstrator, Project Leo, lies in Cluster 4 as it is DNO-led even though its broad technological scope is more characteristic of Cluster 3.

Although the PFER programme aligns most clearly with Cluster 3, this is only one part of a much broader local energy system project landscape shown by the different clusters. Cluster 2 projects are more supply-side focused, Cluster 4 projects more network-focused, and Cluster 1 projects more demand-side focused, although projects in all of these clusters may include other elements.

Earlier we noted that the policy and funding landscape for local energy system projects is shifting. Examples include the ending or sharp reductions in revenue support mechanisms like FiTs, dramatic reductions in local authority budgets, increased emphasis on decarbonisation objectives, and the reduced availability of dedicated funding rounds for electricity network improvement. The resulting shift towards projects capturing different kinds of value streams is borne out in the data. We analysed a subset of 32 projects which started in 2018 or later (broadly the post-FiT era for new projects) and found they were significantly less likely ($p<.01$) to be in Cluster 1 (public purpose) and Cluster 4 (network upgrades) and significantly more likely ($p<.01$) to be in Cluster 2 (supply-side integration).

It's important to re-emphasise that the full UK landscape of community and local energy is wider still as the dataset analysed excludes projects without 'system' characteristics (Box 1). For example, a large number of community-led renewable power projects may be similar in technical configuration to local energy system projects in Cluster 2 but are not included in the dataset analysed.

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[2] The Prospering from the Energy Revolution (PFER) programme initially funded four smart local energy system (SLES) projects as demonstrators: Energy Superhub in Oxford, ReFLEX in Orkney, Local Energy Oxford (Leo), and Smart Hub SLES in Sussex.

Cluster 1 did include projects led by public sector or civil society organisations. There were some differences within Cluster 1 between these two subgroups. Compared to the 13 public sector-led projects, the 28 civil society-led projects were more likely to be rural or island-based (p<.001), site-specific (p<..01), with budgets less than £2.5m (p<.01), and with technologies in the Local Network (p<.001) and Variable Renewables groupings (p<.001). These project characteristics align with a large number of projects in the community energy sector which are not included in our dataset (Braunholtz-Speight et al. 2020). There were no differences between local authority and civil society-led projects within Cluster 1 on all the other project characteristics including sectors, vectors, and the other four Technology Groupings.

4.2 Our results are consistent with other findings on common project types

Various studies have provided useful typologies of local energy projects, although these are not directly comparable as they use different definitions of local energy.

1. UKERC Local Authority Engagement in Energy Systems (Webb et al. 2017b) identified common types of local authority-led projects from the 40 case studies analysed. The three main types were: (i) heat network infrastructure and supply to LA estate (including social housing); (ii) improving energy-efficiency of LA estate (including lighting); (iv) renewable electricity generation (including community partnerships). Four other but less common types were improving energy-efficiency of homes (including retrofits, heat pumps), municipally-owned gas and electricity supply, capacity building and training for low-carbon technologies, local smart grids.
2. UKERC Financing Community Energy (Braunholtz-Speight et al. 2020) used cluster analysis on the technological, organisational, and financial characteristics of 119 community energy projects to identify 12 common types. Three main types distinguished projects by technology: (i) on-site renewable generation, (ii) standalone renewable generation, (iii) demand-side activities. Each of these types was further distinguished by organisation (e.g., volunteer co-ops vs. companies with paid staff), by capital funding (e.g., community shares vs. loans), and by revenue streams (e.g., FITs and RO price-support schemes vs. service contracts).
3. CSE Evidence Assessment of Local Energy Projects (Bridgeman et al. 2019) analysed 36 integrated local energy projects and distinguished three main institutional configurations: (i) community-led projects to address local environmental and social problems, often with involvement of local authorities or other actors; (ii) DNO-led projects to address network management and resource integration challenges, often with technical support for project delivery from universities or user groups; (iii) local authority-led projects, either directly managed or through public-private partnerships and service contracting.
4. UKERC Energy System Demonstrators (Flett et al. 2018) analysed 119 projects for improving the operation of low-carbon energy networks, particularly electricity, but with a good proportion of multi-vector projects, and a wide range of technologies across demand, supply and network integration (e.g., smart control) technologies. No typology is offered, but detailed descriptive characteristics are provided for each project. The most common characteristics are electricity-related, OFGEM-funded projects in the built environment (particularly domestic) on single sites or local areas. The most common technologies trialled are smart controls, followed by solar PV, batteries, and then active network management.
5. Delta-ee, an energy consultancy (Delta-ee 2019), offer a useful 2x2 typology of local energy systems along two dimensions: (i) balancing and bounding - from locally balanced and spatially bounded (e.g., micro-grid) to unbounded and imbalanced (e.g., grid integrated); and (ii) ownership and control - from fully privately-run including potentially by incumbents to publicly or community-owned and run.

The clear insight from these and our typologies is that local energy is a catch-all for a very wide range of activities.

4.3 Our results are helpful for capturing project heterogeneity in systems models

System modellers analysing benefits, costs, and integration challenges of local energy system projects need to capture project heterogeneity in parsimonious ways. Our four cluster solution offered a simple framework for modelling different types of project and the distinctive system issues they pose or help resolve. These findings will support further analysis by the EnergyHub and UCL-BRAIN modelling teams within the EnergyREV consortium. A next step for further supporting modelling is to better understand how and why project types vary spatially.

4.4 Our results have important limitations

There are important limitations to our analysis of common types of local energy system project. First, the dataset only captures a sample of local energy system projects so is not representative of the much broader landscape of local and community energy in the UK. Second, the dataset does not measure rationales, value streams nor success criteria per project, so we cannot assess if and how some common types of project were more successful than others, nor whether later projects learnt from earlier projects in this respect. Third, the dataset is biased towards projects with capital funding from public or public-private sources for which data are more transparently reported. Many additional projects using private capital funding are not included in the analysis.

5 Appendix

5.1 Most common project characteristics

Modal frequencies describe the most common project characteristics in our dataset of 147 local energy projects, extended from (Flett et al. 2018):

The most common types of geographic and scale characteristics per project are:

- most common region = SE England (then Scotland)
- most common geography = urban (then suburban)
- most common scale = small (then community)
- most common budget = £1-5m (then <£1m)
- most common start date = 2013 or earlier (then 2016-17)

The most common type of technological characteristics per project are:

- most common number of technologies = 3-4 (then 1-2)

The most common types of technological characteristics across all projects are:

- most common technology grouping = Generation & Storage exc. Renewables (then Energy End-Use)
- most common technologies = solar PV (then smart controls)
- most common sectors = domestic (then non-domestic)
- most common energy vectors = electricity (then heat)

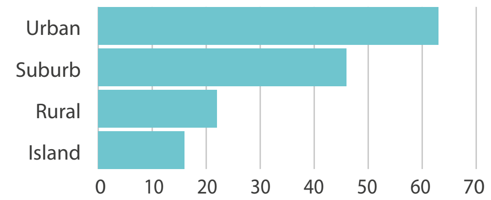
The most common types of institutional characteristics per project are:

- most common funding source = InnovateUK (then Low Carbon Network Fund)
- most common number of partners = 4-6 (then 1-3)
- most common lead partner by type = private sector (then 3rd sector)
- most common lead partner by subtype = private sector grid or network operator (then private sector industry or manufacturing)

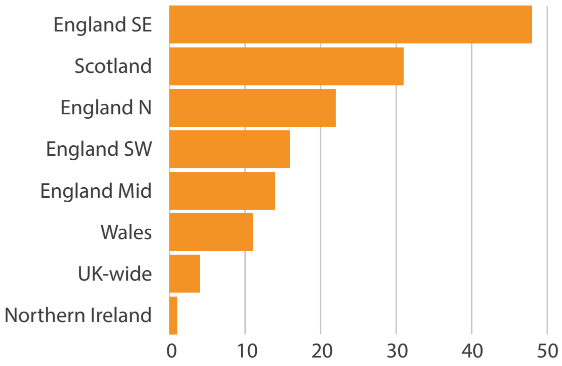
5.2 Sample characteristics

These figures show the full set of descriptive characteristics of our dataset of 147 local energy projects, extended from (Flett et al. 2018).

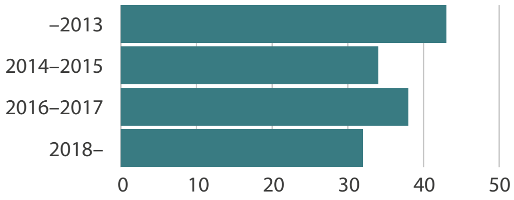
Geography
per project



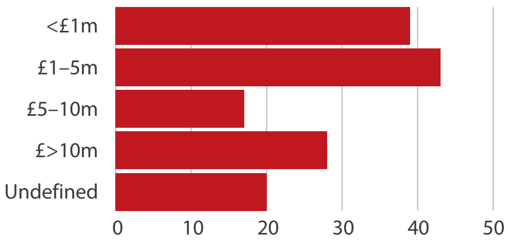
Region
per project



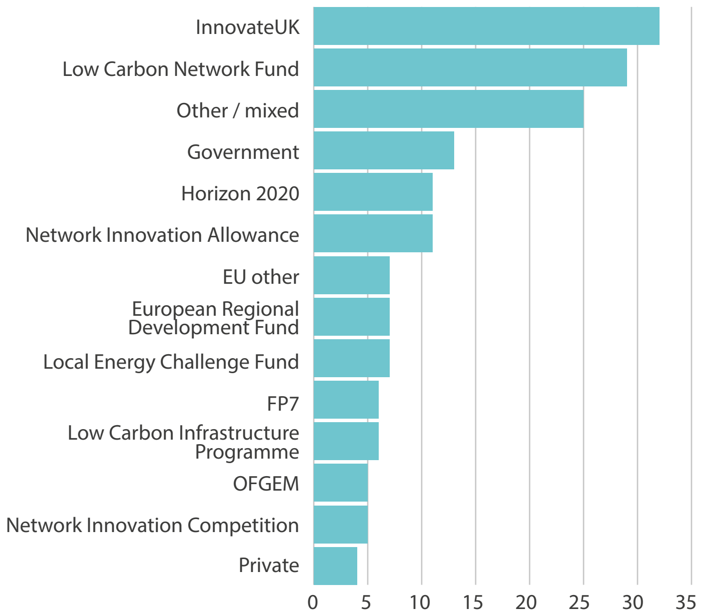
Start date
per project



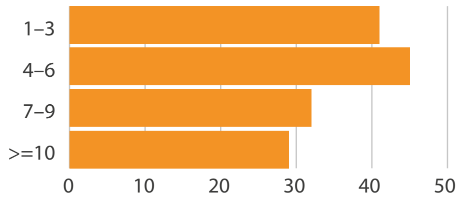
Budget
£million, per project



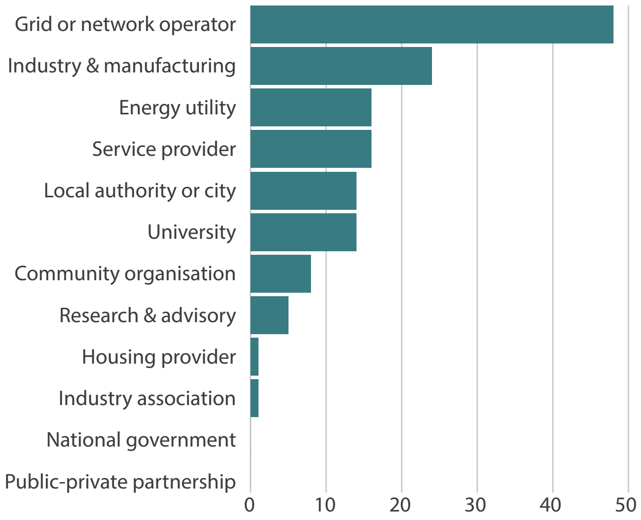
Funding sources
all projects



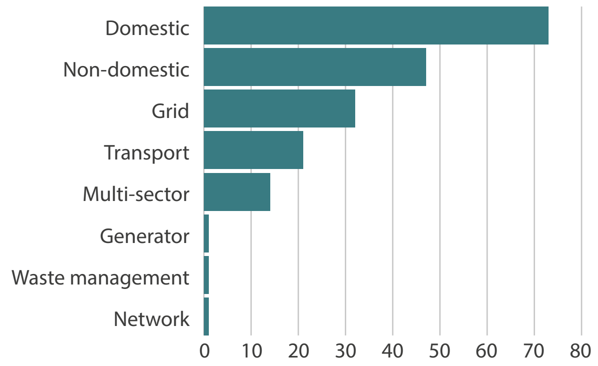
Number of partners
per project



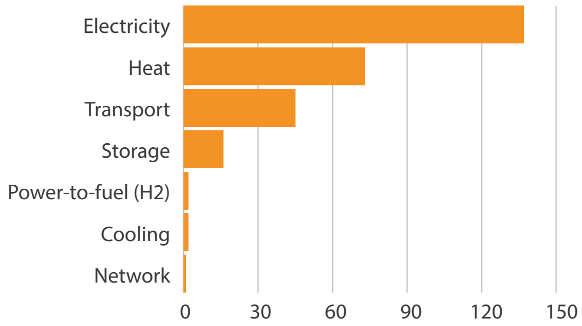
Lead partner by sub-type
per project



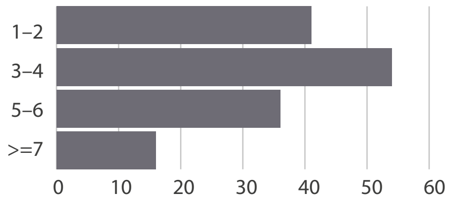
Sectors
all projects



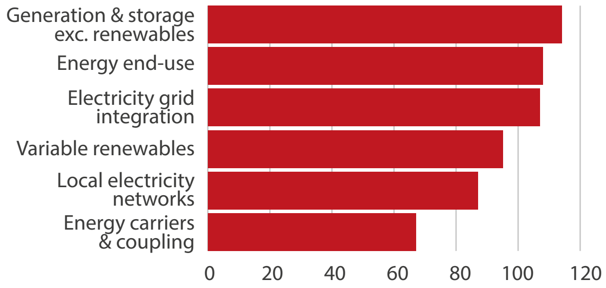
Energy vectors
all projects



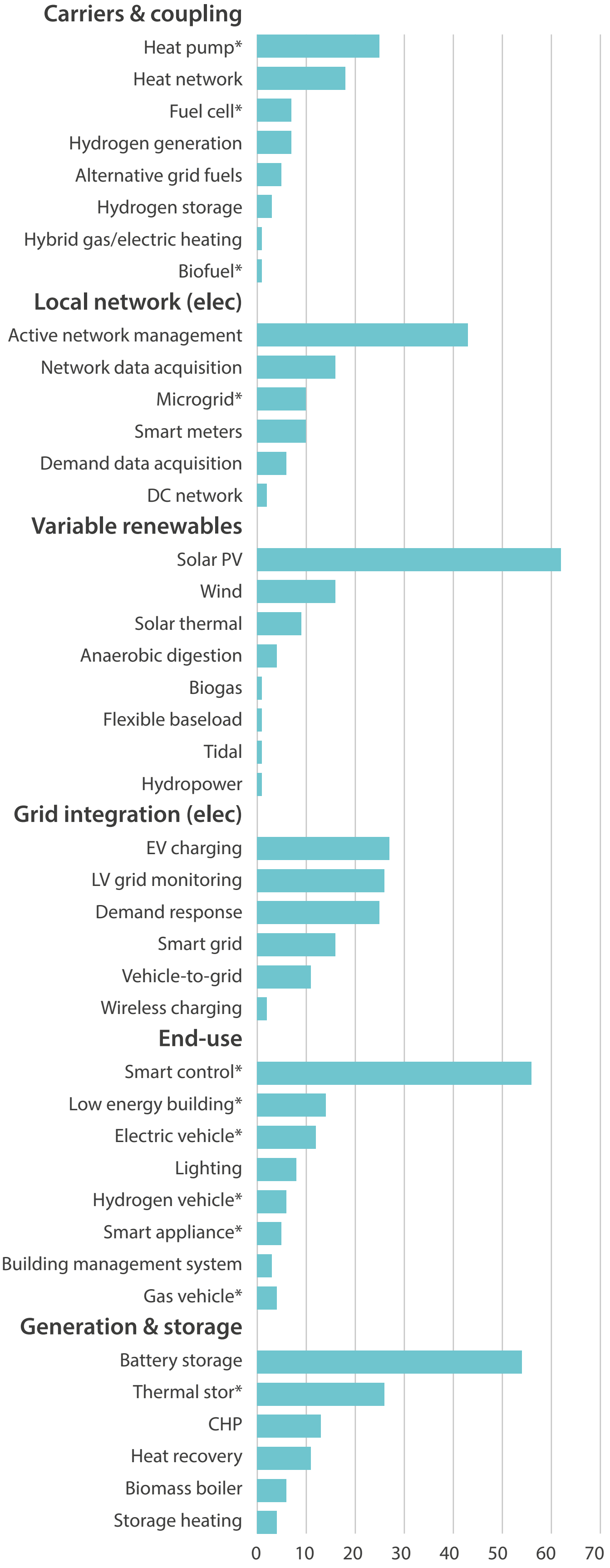
Number of technologies
per project



Total number of technology groupings
all projects



Total number of technologies
all projects



5.3 Cluster analysis methods & findings

We used hierarchical cluster analysis in SPSS 25 to identify groups of project with similar characteristics in the dataset. We used dummy variables (binary categories) with squared Euclidean distance as a measure of similarity. As cluster solutions are sensitive to outliers, we first used a single linkage (nearest neighbour) clustering method to identify outlier projects which were only weakly related to all other projects in terms of their characteristics. We then screened out these outliers in the main analysis using Ward's clustering method which finds clusters of similar sizes and low within-cluster variance. We examined 2, 3 and 4 cluster solutions by testing for differences across the cluster variables in order to clearly differentiate and characterise the types of project in each cluster.

We followed this cluster analysis procedure on blocks of variable independently: geographic and scale characteristics; technological characteristics; institutional characteristics. We then ran an integrative cluster analysis with all blocks of variable. Full SPSS syntax and output are available on request.

Cluster analysis: geographic and scale characteristics

We used four variables to identify common types of project in terms of their geography and scale:

- **geography**: rural (includes island) vs. urban (includes suburban)
- **scale**: site-specific vs. dispersed
- **start year**: earlier (pre-2016) or later (2016 or later)
- **budget**: lower budget (<£2.5m) vs. higher budget (>=£2.5m)

20 projects had undefined budgets (missing data) so were excluded.

Using the single linkage clustering method, we identified two outliers in the sample of 127 projects (DIP9, Cambridgeshire Solar Carport, and DIP57, Levenmouth Community Energy Project). Both these are rural and site-specific but higher budget projects (with the anomaly being their higher budgets given their other scale characteristics). We removed these two outliers from the main cluster analysis.

Using Ward's clustering method, we identified a clearly interpretable two cluster solution for 125 projects distinguished by budget:

- Cluster 1 (n=64) tended to be earlier (63%) but consistently lower budget (92%).
- Cluster 2 (n=61) tended to be later (67%), more urban (84%) but consistently higher budget (100%).

A three cluster solution split Cluster 1 into two sub-clusters distinguishing rural from urban projects.

A four cluster solution split Cluster 2 into two sub-clusters distinguishing earlier from later projects.

Common types of project in terms of geography and scale, can therefore be summarised as:

1. Smaller budget projects which are (1a) urban (n=40), or (1b) rural (n=24)
2. Larger budget projects which are (2a) earlier (n=20), or (2b) later (n=41)

Cluster analysis: technological characteristics

We used eight variables to identify common types of project in terms of their technological characteristics:

- **sectors**: single vs. multiple
- **vectors**: single vs. multiple
- **technology groupings** (6 variables, all yes vs. no): Local Electricity Networks, Electricity Grid Integration, Energy Carriers & Coupling, Generation & Storage exc. Renewables, Variable Renewables, Energy End-Use

Using the single linkage clustering method, we identified two outliers in the sample of 147 projects. One of these (DIP15, Cranbrook Solar Thermal District Heating) is a multi-sector, multi-vector project in the Energy Carriers & Coupling technology grouping, but also had Grid Integration technologies which are more characteristic of single vector power network-type projects. The other (DIP124, Smart Hub SLES) is a single vector project in the Variable Renewables technology grouping, but also had Energy Carriers & Coupling technologies which are more characteristic of multi-vector projects. We removed these two outliers from the main cluster analysis.

Using Ward's clustering method, we identified a clearly interpretable two cluster solution for 145 projects distinguished by vectors:

- Cluster 1 (n=49) tended to be single vector (70%), i.e., electricity only, with Local Electricity Network (86%) and Electricity Grid Integration (80%) technology groupings.
- Cluster 2 (n=96) tended to be multi-vector (67%), i.e., electricity with heat, transport, or other vectors, with Energy Carriers & Coupling (48%) and Generation & Storage exc. Renewables (72%) technology groupings.

A three cluster solution split Cluster 1 into two sub-clusters distinguishing single sector projects particularly with Energy End-Use technology groupings, and multi-sector projects.

A four cluster solution split Cluster 2 into two sub-clusters distinguishing multi-vector projects with supply-demand integration through Energy Carriers & Coupling, Variable Renewables, and Energy End-Use technology groupings, from single sector projects with no Energy Carriers & Coupling technologies.

Common types of project in terms of technological characteristics can therefore be summarised as:

1. Electricity network projects with emphases on (1a) end-use integration (n=33), or (1b) multiple sectors (n=16)
2. Multi-vector projects with emphases on (2a) systems coupling and supply-demand integration (n=51), or (2b) generation and storage in a single sector (n=45)

Cluster analysis: institutional characteristics

We used five variables to identify common types of project in terms of their institutional characteristics:

- **lead organisation** (3 variables, all yes vs. no): led by private firm exc. DNOs, led by DNO-type firms, led by 3rd or public sector organisations
- **partners** (2 variables, both yes vs. no): project partners included public sector organisations, project partners included 3rd sector organisations

Other variables capturing number of funding sources, use of EU funding, and involvement of private sector partners were excluded as they were all dominated by a single type of project (single funding sources, no EU funding, project partners included private firms).

Using the single linkage clustering method, we identified one possible outlier in the sample of 147 projects (DIP142, Active Homes Neath). This project is led by a 3rd sector organisation, and includes both 3rd and public sector organisations as partners. We found other similar projects in the dataset and so decided not to exclude this outlier.

Using Ward's clustering method, we identified a clearly interpretable three cluster solution for 147 projects distinguished by lead partners:

- Cluster 1 (n=48) were all led by DNO-type firms (100%).
- Cluster 2 (n=42) were all led by 3rd sector or public sector organisations (100%).
- Cluster 3 (n=57) were all led by private firms excluding DNOs (100%).

A four cluster solution split Cluster 3 into two sub-clusters distinguishing private sector-led projects with 3rd and public sector organisations as partners, from projects without public organisations as partners.

Common types of project in terms of institutional characteristics can therefore be summarised as:

1. DNO-led projects (n=48)
2. 3rd and public sector-led projects (n=42)
3. Private sector-led projects which (3a) involve 3rd and public sector organisations (n=24), or (3b) do not involve the public sector (n=33)

Cluster analysis: summary by blocks of variable

Our initial cluster analysis using blocks of variable identified:

- 4 common types of project defined by geographic and scale characteristics: small urban (n=40), small rural (n=24), large earlier (n=20), large later (n=41);
- 4 common types of project defined by technological characteristics: electricity network with end-use integration (n=33), electricity network with multiple sectors (n=16), multi-vector with supply-demand integration (n=51), multi-vector with generation and storage in a single sector (n=45);
- 4 common types of project defined by institutional characteristics: DNO-led projects (n=48), 3rd and public sector-led projects (n=42), private firm-led projects with 3rd and public sector partners (n=24), private firm-led projects without public sector involvement (n=33).

Cluster analysis: integrated analysis on geographic, scale, technological and institutional characteristics

We initially used all the clustering variables from previous analysis to identify common types of project overall:

- **geographic & scale characteristics**: 4 variables measuring projects' location, site-specificity, timing and budget
- **technological characteristics**: 8 variables measuring projects' sectoral coverage, energy vectors, and 6 technology groupings
- **institutional characteristics**: 5 variables measuring projects' lead organisations, and partner organisations

20 projects had undefined budgets (missing data) so were excluded.

Using the single linkage clustering method, we identified one outlier in the sample of 127 projects (DIP9, Cambridgeshire Solar Carport). This is a rural, site-specific but higher budget project and had been identified as an outlier solely for its geographic and scale characteristics (small-scale but high budget). It also has a single energy vector (electricity) but no technologies in the Local Electricity Network technology grouping, and is led by a public sector organisation but without 3rd sector participation. We removed this outlier from the main cluster analysis.

Using Ward's clustering method with the full set of 17 variables did not converge on a solution. As a rule of thumb, roughly m clustering variables are appropriate for a sample of 2^m, suggesting around 7 clustering variables for our sample of 126 projects.

We reduced the initial set of 17 variables by prioritising those which had been influential in distinguishing clusters in previous analysis. This led to a set of 9 clustering variables:

- **geographic & scale characteristics**: 2 variables measuring projects' location and budget
- **technological characteristics**: 4 variables measuring projects' energy vectors, and 3 technology groupings
- **institutional characteristics**: 3 variables measuring projects' lead organisations

Using Ward's clustering method with this reduced set of 9 variables, we identified a clearly interpretable four cluster solution for 126 projects. The first significant differentiation was between DNO electricity network projects and all other types of project, particularly those with greater complexity and scope:

- Cluster 1 (n=44) were all led by DNO-type firms (100%) with a clear emphasis on a single energy vector (70%) in the Local Electricity Network technology grouping (80%).
- Cluster 2 (n=82) were led by private firms excluding DNOs (61%) or by 3rd and public sector organisations (38%) with a strong emphasis on multiple energy vectors (80%).

The second significant differentiation was in Cluster 2 between projects led by 3rd or public sector organisations including demand-side technologies, and projects led by private firms with a less clear technological emphasis:

- Cluster 2a (n=29) were all led by 3rd or public sector organisations (100%) and almost all included technologies in the Energy End-Use technology grouping (90%).
- Cluster 2b (n=53) were led by private firms excluding DNOs (94%) with more variety in the technology groupings included.

The third significant differentiation was in Cluster 2b between higher budget projects with multiple energy vectors, and lower budget projects with a narrow technological focus such as variable renewables:

- Cluster 2bi (n=29) were higher budget (97%) and multiple energy vector projects (100%) with almost half in the Energy Carriers and Coupling technology grouping (41%).
- Cluster 2bii (n=24) were lower budget (96%) and more likely to be single energy vector (42%) with two thirds in the Variable Renewables technology grouping (67%).

We ran a sensitivity test on the robustness of the four cluster solution by dropping budget as a clustering variable as this boosted the sample size back up to 146 projects (as the 20 projects with undefined budgets could be re-included). Using this reduced set of 8 clustering variables we confirmed a four cluster solution with very similar interpretation but more projects per cluster. The only minor difference was in the third and final differentiation between private sector-led projects (Cluster 2b) which was differentiated more clearly between projects with broad scope and technologies in multiple groupings including demand and supply (Cluster 2bi), from projects with narrow scopes focused on supply-side integration (Cluster 2bii). We use this four cluster solution on the larger set of 146 projects in our final analysis.

Common types of project in terms of geographic, scale, technological and institutional characteristics can be therefore be summarised as:

1. 3rd or public sector-led projects including demand-side technologies and sectors (n=41)
2. private sector-led projects with lower budgets and narrow scopes to cover electricity only on the supply-side and in a single sector, potentially including transport (n=24)
3. private sector-led projects with higher budgets and broad scopes to cover multiple energy vectors integrating across demand, network, and supply technologies (n=34)
4. DNO-led electricity network projects (n=47)

One final sensitivity check was prompted by a reviewer spotting that Project Leo (one of the four PFER demonstrators) was assigned to Cluster 3 despite being led by a DNO (Scottish & Southern Electricity Networks). This was the result of Project Leo being incorrectly coded as being led by SSE (coded as an energy utility) rather than SSEN (coded as a DNO). We ran a sensitivity test on the robustness of the four cluster solution with Project Leo correctly coded. The four cluster solution was confirmed, but with Project Leo reassigned to Cluster 4 along with other DNO-led projects. The inclusion of Project Leo in this cluster makes the overall scope of DNO-led projects more diffuse as Project Leo tests new business models and end-use technologies (under the umbrella 'District System Operator' concept), compared to the earlier network-upgrade type projects also in Cluster 4.

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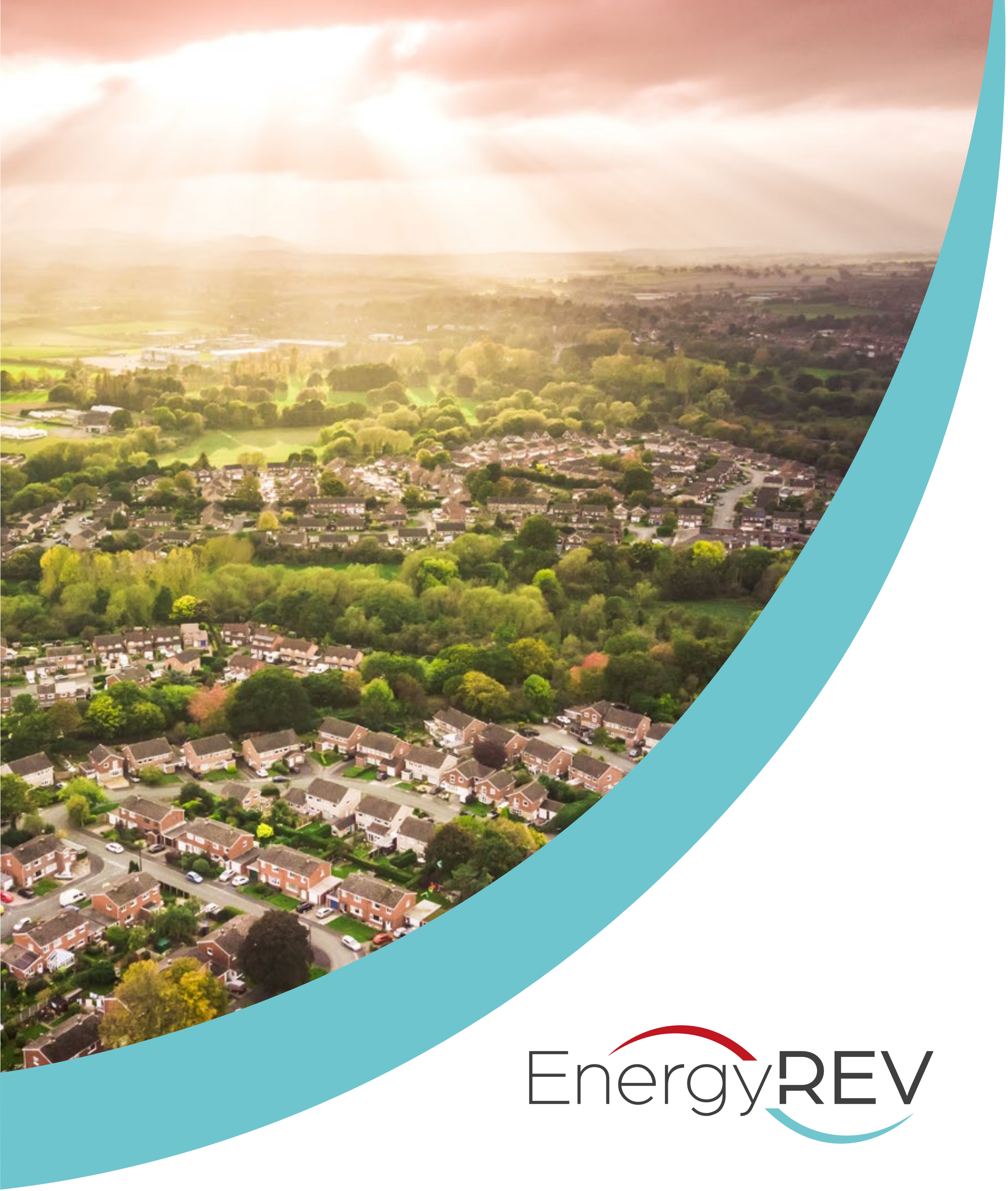

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About EnergyREV

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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