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Characterising a local energy business sector in the United Kingdom: participants, revenue sources, and estimates of localism and smartness.

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Abstract

Local and decentralised energy initiatives increasingly contribute to decarbonising energy systems. This trend is facilitated by emergence of new actors, ownership modes, business practices, and value sources in energy markets. However, there is no systematic account of the businesses which comprise this emerging sector in the UK, and there are no standardised criteria for what may constitute a "local", potentially "smart", sector. Through development, and descriptive statistical analysis, of a database of legally-constituted energy businesses, we therefore provide a first characterisation of the local energy business sector in the United Kingdom. We develop qualitative indicators to categorise businesses according to their position in a matrix showing degrees of "localism" and "smartness". Our findings reveal an emergent sector comprising diverse organisations, including those with limited energy market experience. Embryonic business innovations are being translated into various revenue sources. However, most businesses have as yet made limited use of digital systems for smart operation; likewise, despite distinctive forms of localism, many aspects remain to be addressed. This finding implies opportunities for this sector to create value through more extensive orientation to localism and smartness. Further research is needed, using more detailed surveys of a representative sample of local energy businesses.

Keywords: Database, Mapping, Business model, Distributed generation, Local energy

1. Introduction

Energy market liberalisation is associated with successive socio-technical and political-economic changes worldwide, incorporating new private sector actors, forms of ownership, government institutions, legislation, and technologies [1-4]. Historically the United Kingdom (UK) energy system evolved from decentralised, small systems [5] to publicly-owned, larger, and centralised power plants and grids, before privatisation in the 1980s-1990s [6,7]. Privatisation resulted in entrance of new actors [5,6,8], including a minority of organisations from other sectors - e.g. universities [9,10] and social enterprises [11], and new forms of ownership and businesses [12,13]. Additionally, concerns over climate disruption have mobilised widespread policy and legal commitment to decarbonisation [14]. However, the paths to a zero-carbon transition are subject to scrutiny and uncertainty [15], encompassing debates around the potential for more decentralised energy systems [16] to support decarbonisation and reduce overall transition costs. Indeed, the UK has been an active participant in such debates, developing a variety of decentralised, local energy initiatives and demonstration projects[1] [2]. Hence, despite a recent history of highly centralised energy systems and markets in the UK, changes in policy (particularly climate protection), technologies, and market configuration are opening up opportunities for more decentralised, local energy businesses (LEBs).

Some authors emphasise the role of local authorities (LAs) working with the private sector [17,18] to leverage investment [19]; others attend to the design of municipally-owned energy systems [20]. Local or municipal

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[1] See https://www.centrica.com/innovation/cornwall-local-energy-market for an example
[2] See https://www.aberdeenheatandpower.co.uk/about/ for an example

government involvement does not, however, seem a "sine qua non" condition for local energy, at least in the UK. Private businesses are engaging and delivering value locally, through commercial partnerships[3] and direct (usually financial) benefits to communities[4]. Government policies also recognise the role of private businesses in local energy [21]. Likewise, local energy infrastructures can involve non-traditional actors with various motivations, forms of value delivery, experience, and skills. Some voices even highlight the role of self-sustaining [22], renewable-based local energy systems in achieving a 100% renewable energy system [20,23]. Digitalised solutions are also increasingly expected to support decarbonisation [18] and local energy systems design [24]; businesses are already incorporating digital solutions for residential customers [25] which implies new business models as well as changes to long-established ones [26-30]. Therefore, a useful characterisation of LEBs needs to estimate how "smart" these businesses are.

What constitutes "local" and "smart" in energy supply or services is, however, subject to debate. In the context of energy systems, "local" has various meanings, including: community or local ownership stakes, geographical scope, compliance with legal or regulatory guidelines, resource proximity, and forms of service provision. Research also highlights the multiple conceptualisations, or lack of a unified definition, of "smart" [31]. Some authors focus on digitalisation in business operation [29] and others focus on the role of digital systems in integration across energy vectors [23,32,33].

Debate about the future of LEBs can therefore be enriched by empirical analysis of the ownership structures, and energy technologies, of current businesses, as well as variations in forms of "localism" and "smartness". Such empirical analysis can inform policy making, incentive mechanisms and strategies for the development of resilient decentralised, clean, affordable and democratic energy systems. There are two main challenges. First, as shown above, there is no unified definition of "local" and "smart", although preliminary conceptualisations can be found; this is key to characterising the sector. Second, to our best knowledge, there is no available empirical data that helps to characterise a sector comprised of LEBs. We aim to address these gaps by providing the first UK LEB sector characterisation, based on developing and analysing a new database of legally-constituted businesses (i.e. not pilot projects but companies). We use descriptive statistical analysis of the database, and develop a "localism" and "smartness" matrix, to address the following research questions: a) what kind of organisations are participating in a LEB sector in the UK? b) what energy services and technologies are involved? and c) what is their degree of localism and smartness?

Using the constituents of "local" and "smart" defined in [18], and complementing these with a literature review, we develop a qualitative scale characterising degrees or levels of localism and smartness. "Localism" is defined as businesses with relationships to local stakeholders, local involvement in decision-making, and (some) local ownership of assets. "Smartness" is defined as businesses using real-time information and communication technologies, automating aspects of business operation and systems regulation, and using machine learning or artificial intelligence to inform decision-making and engage people.

This work contributes to state-of-art evidence and debate about the potential for a growing UK local energy sector: it provides a characterisation of LEBs, using not only previous research and theory, but also new evidence. Moreover, the analysis provides a novel approach, based on qualitative indices and a matrix, to estimating degrees of "localism" and "smartness". Thus, this paper can inform policy and regulatory change, identify further energy business opportunities, and enrich discussion between academia, communities, industry and governments.

The paper comprises the following sections. In section 2, a literature review of UK and European academic and grey literature provides the theoretical background. Section 3 explains the method used to construct the business database. The fourth section provides an empirical characterisation of the UK LEB sector, derived from descriptive statistical analysis of the database and a matrix, which shows estimated degrees of localism and smartness. Section 5 discusses the findings and section 6 concludes.

[3] See https://www.goodenergy.co.uk/our-energy for an example
[4] See https://www.banksgroup.co.uk/projects/renewables/hook-moor for an example

2. Literature review: Characterising Local Energy Businesses

2.1. Opportunities for more local, smarter energy business

The historically evolving energy mix has encompassed not only centralised production, but also opportunities for developing local, and latterly "smarter", innovations [18] in the context of changing environmental governance since the early 1990s [34]. Yet, business models like bilateral contracts or incentives-based schemes (e.g. feed-in-tariffs, renewable portfolio standards, net metering, etc.), which can offer guaranteed long-term revenues and fixed cost generation assets, are key to supporting opportunities for local and smart business model innovations [35]. The above may help increase energy business diversity. Such diversity could provide opportunities to create, capture, and deliver value, including, for example, services to improve reliability and flexibility, and to reduce carbon, and ease congestion on distribution networks [36]. Other examples of opportunities for value creation and delivery are emerging retail business models, such as wholesale prices with a cap, flat prices regardless of consumption, intermediaries as brokers or bill providers, combined energy service provision and on-site generation (typically rooftop solar PV), and back-end services - compliance and billing - for new companies [37].

New energy business models, derived from such innovations, are expected to break away from current market sectoral silos through local systems integration and digitalisation [12]; the latter concept involves digital technologies or platforms which can be considered as foundations for smart energy systems. Indeed, digitalisation offers opportunities for facilitating local systems integration, incorporating electric vehicle (EV) charging points [38-42], district heating [43-45], energy efficiency and retrofitting[5] [46], other demand-side measures [47] including energy storage [42], and even energy systems demonstrators [48]. Digitalisation can also enable businesses with few capital assets to target new services, such as intermediation via aggregators or digital platforms, peer-to-peer exchange, mini-grids, or off-grid [35], which can favour the inclusion of "less-experienced" actors. Incumbents are however also likely to be interested in sharing benefits derived from flexible demand management [49-51].

Most analysis of LEBs is derived either from classifications/archetypes of (potential) LEB models, or small-n case studies of specific businesses supplying various local energy services, or combinations of these, as discussed below.

2.2. Classifications, archetypes, and case studies of local energy business models

Typologies of LEB models aim to describe and differentiate between different options for local energy services provision. They approach the classification task in different ways, focusing variously, as mentioned above, on small-n case studies, classifications/archetypes of (potential) LEBs models, or a combination of both.

Several examples of specific case studies of UK LEBs can be found in the literature. Bioenergy-based business innovations [52] is one example. They currently involve electricity and/or biofuels/biofertilisers production and gas injection into the grid; such initiatives may also involve local stakeholders in feedstock collection. Hiteva and Sovacool [11] illustrate UK LEBs, focusing on a cooperative which works on retrofitting and energy demand management, and one municipally-owned supplier which buys from the wholesale market offering favourable conditions and tariffs for customers; revenues cover overheads and contribute to further savings. Webb et al. [53] examine a sample of LA-oriented UK energy projects, mostly focused on sustainable heat and retrofitting. Most of projects are integrated into existing council structures, capacities, and cross-sector partnerships. Independent businesses are however emerging, and these are both commercial and non-profit entities, including public ESCos, private-led ESCos, and community benefit societies (Bencoms)[6]. LAs involved in energy services [54], using different governance models [55], may also act as intermediaries between private and public interests, due to their territorial planning powers, knowledge, and resources [56]. Other organisations also offer energy-related services at specific locations, such as university campuses [9]. Community-owned energy production initiatives deliver value to localities [57-59]. New small and medium enterprises, and some households, are also becoming key actors [60,61] in energy production.

An example of classifications/archetypes of (potential) LEBs models is a classification proposed by PWC [62], which is explored as follows. First a *transmission or distribution network manager,* focused on hard infrastructure and advancing system features including reliability, as well as deriving revenues from distributed generators through charges for network connections. This could imply further services, extending the existing *distribution*

[5] See https://www.gov.scot/publications/energy-efficient-scotland-route-map/ for an example.
[6] A legal form for organisations that wish to operate on a not-for-profit basis for purposes that benefit the community as a whole. See https://www.uk.coop/bencom

network operators (DNOs) through new business models described below, and/or more investment in digitalisation to gain flexibility using local resources [63,64]. The latter is in line with the UK electricity market regulator plans for local energy markets [65]. Second a *product innovator* investing in data analytics for development of superior products, satisfying different needs in order to engage customers, and build up brand reputation and business expansion. Third a *Partner of Partners* bundles conventional and new energy services through a network of qualified providers. Fourth a *value-added enabler* captures detailed market data to provide insights into consumption patterns, and to supply currently inaccessible information with value for customers and businesses. Finally, a *Virtual utility* acts as aggregator and intermediary between distributed generators, and/or as integrator of other energy services provided by third parties. Another example is a definition of emerging UK local energy services' archetypes stated by Ivanova et al. [66]; they distinguish between *local consumer services* (including ESCos, energy efficiency, advice, and fuel poverty amelioration); *local generation* (community-owned/managed assets); *local supply* (including LAs-based projects); *micro-grids* (parallel or independent decentralised grids), and (trial) *virtual private networks* for local balancing within current networks.

Starting from a prosumer perspective, Brown et al. [67] combine theoretical concepts with specific (trial) cases, to establish and analyse business archetypes, which are explored below.

First, *basic prosumer* is conceptualised as those (subsidy-based) distributed generation projects, which are installed behind the meter for self-consumption and injection into the grid through a licensed supplier and DNO. Second, *micro-grids* are described as locally owned and operated small, low-voltage distribution networks, with a virtual energy company potentially responsible for billing customers who consume within the local network. Third, a *local energy company* is understood as an in-front-of-the-meter local generation entity using the existing DNO-owned network through a licenced supplier, to provide better rates for local customers. A trial project in North Wales is highlighted. Fourth, *Peer2Peer models* are conceived as prosumer-based (distributed) generation trading (among themselves) without a third party supplier, but with a third-party platform. A trial project in Cornwall involving a UK energy company and a platform provider – Piclo – is highlighted under this category [67]. In countries like France, Sweden and Germany, for example, peer-to-peer initiatives also help co-fund EV charging infrastructure. Consumers rent the best-located charging point from companies or individuals, also eventually allowing them to buy electricity [68].

Fifth, a *flexibility service provider* is conceived as inherently-flexible projects that can paired with more intermitted distributed energy sources to offer voltage optimisation, real-time supply and demand matching, price arbitrage, and other grid services. A trial project in the Orkney Islands, which uses onshore-wind-based excess generation to storage heat is highlighted under this category [67]. Market participants, including demand-side projects [69,70], can exploit hierarchical structures through local aggregators for greater feasibility [71], and need to manage their flexibility capital, namely *"the capacity to responsively change patterns of interaction with a system to support the operation of that system"* [72]. For example, estimates based on countries like Sweden and Germany suggest significant opportunities for hour-to-hour flexibility in use of residential heating [73]. Technological platforms – like Piclo in the UK [74] or Enera in Germany [75] – are key enablers, as they allow timely, accurate, and effective coordination and supply and demand matching.

Sixth, some businesses provide long-term, competitive end-services via an *energy services company or ESCo*, which may own the infrastructure and takes responsibility for service quality and reliability. *Solar-as-a-service* and *Heat-as-a-service* businesses are examples of this archetype. Other businesses offer *multi-vector services contracts*, with comprehensive retrofitting and efficient generation technologies either directly or indirectly through an ESCo [67,76]. Such contracts can offer heat or temperature comfort, hot water, (a fixed) electricity (volume), among other services. Profits are sometimes allocated to a community fund. One Dutch-based project with trials in the UK and another housing-based trial project in Trent Basin are included in this archetype [67]. Challenges, however, are related to creating and consolidating innovative value propositions and business models from an end-user perspective [77]. European examples include experiences of value proposition improvement and business model (re-)design. Case study comparison of one LA-led and one private-led sustainable urban district in France, shows that the LA-led project focused only on areas with grant funding, restricting improvements to value proposition and supply chain; the private-led project, by comparison, was able to implement more substantial transformations [78]. A Dutch retrofit ESCo creates value by investing in residential flats (which receive a share of profits) and establishing strong networks or partnerships with other entities to generate savings [11]. Three comprehensive retrofit programmes in France, Germany, and Finland are also analysed in the literature. Smarter and digital elements, as well as owners' involvement in a public-private-people partnership, are identified as key elements of differentiation in Finland [79]. This type of initiative may facilitate more customers becoming prosumers without worrying about the investment in assets.

Finally, regarding *transportation models*, prosumers may charge EVs using local generation and storage. *Mobility-as-a-service* enables prosumers share the use of third-party-owned EVs; some variants may also involve EVs and vehicle-to-grid (V2G) services in public transport. A community-owned bus-to-grid project based in Brighton is highlighted in this category [67].

As shown above, most research on LEBs has focused on either classifications/archetypes or case studies, or a combination of both; the main examples revealed above are summarised in Table 1. Business model classifications or archetypes imply that there are opportunities for innovation, because they distinguish between initiatives with variable degrees of smartness, supply chain coverage, local ownership, service configuration, etc., which have not been widely implemented. Most of the above business models are incipient indeed, although Mengelkamp et al. [80] note that a focus on flexibility trading, with an interoperable information system, seems to support business success. Working on all of the above-mentioned business models, as well as on other emerging innovations, may result in continuing sector growth and diversification. Opportunities are associated with factors such as climate policy, falling costs of distributed generation technologies, improved reliability and security, and the need to reduce heat demand by retrofitting. Case studies also show that LEBs may be owned and operated by new, "less-experienced" market entrants, including farmers, community groups, LAs, and digital systems innovators. Some of these actors may be more committed to localism than "more experienced" incumbents, as ways of opening markets, securing benefits, and improving transparency and engagement with stakeholders.

Case studies	Ref.	Classifications/archetypes	Ref.	Combined approach	Ref.
Bioenergy-based business innovations	[52]	Transmission or distribution network manager; distribution network operators; product innovator; partner of partners; value-added enabler; virtual utility	[62]	Basic prosumer; micro-grids; local energy company; Peer2Peer models; flexibility service provider; energy services company or ESCo; transportation models	[67]
Retrofitting and energy demand management cooperative; municipally-owned supplier	[11]				
LA-oriented energy projects	[53-56]	Local consumer services; local generation; local supply; micro-grids; virtual private networks	[66]		
University-based and Community-owned energy-related initiatives	[9,57-59]				
Energy-related projects in small, medium enterprises and households	[60,61]				

Table 1. Examples of LEBs-based cases studies and classifications/archetypes literature

Previous studies have not however characterised a UK LEB sector using information about number and types of entities, as well as their characteristics, or provide an integrated analysis of types of energy business in terms of degrees of localism and smartness. Unsurprisingly, existing evidence suggests an important role for digitalisation in new and existing energy businesses. However, the number of projects, installed capacity, technologies, customers, etc., remains unclear. Empirical analysis of legally-constituted businesses in terms of elements of localism and smartness [18], is therefore an appropriate start to assessing the current composition and status of any LEB sector in the UK. Sharper characterisation of such a sector is a useful contribution to supporting effective and sustainable sectoral growth, in the context of concerns over decarbonisation, decentralisation, digitalisation, and democratisation (4Ds) of energy systems. In the next section, we provide a first step towards such a characterisation.

3. Methods: database construction

We developed a database of 699 legally-constituted companies, providing a representative picture of the UK market. The key criterion for inclusion in the database was that a business addressed at least one constituent element of localism. The database primarily uses information provided by Bureau van Dijk through its database FAME©[7]. We extended this data by integrating information from other sources as follows. The process of identifying companies and gathering extra information used the terms "local", "community", "district", and "university" in the FAME database as filters on company names. Other specialised/sectoral websites [81-99] were also explored to identify more companies and capture extra information, where possible. Each company's parent entity was also checked in the FAME database to find and include related companies, where appropriate. Once a sample of companies was identified, their websites (where available), notes to the financial statements on UK Companies House website, media articles, and other online sources from Google© search engine (where available), were searched for extra information. This includes the number of customers, revenue streams or sources, technologies and installed capacity, provision of benefits to communities, and ownership, where available. Due to heterogeneity of information sources and lack of useful information in some cases, our database does not have complete uniformity of content about each company. Some comparisons presented here hence include only those companies where relevant information was available. The constituent elements of localism and smartness discussed in [18] were used to develop qualitative scales of each, and to structure a matrix. Best judgement and available information were used to estimate and map the degree of localism and smartness of each business included in our database. Details about the classification process and specific examples are in the supplementary material. A descriptive statistical analysis informs the findings.

4. An empirical characterisation of a UK local energy business sector

This section presents an empirical characterisation of a UK LEB sector based on legally-constituted businesses. Two points are developed: firstly, descriptive statistics are used to characterise businesses at a sectoral level; and secondly, their degree of localism and smartness is estimated using a matrix.

4.1. A sample-based descriptive statistical analysis of local energy businesses in the UK

Most of the businesses consist of private limited companies (94.8%). The reminder, circa 5%, comprises charitable organizations, companies limited by guarantee, limited liability partnerships, public alternative investment market companies, no-quoted public companies, and unlimited companies. Circa 93% of the sample individually have no, or just one, subsidiary. The remainder mostly have between two and five subsidiaries, as in Fig. 1. These subsidiaries show that there are other related companies which may also be part of the sector.

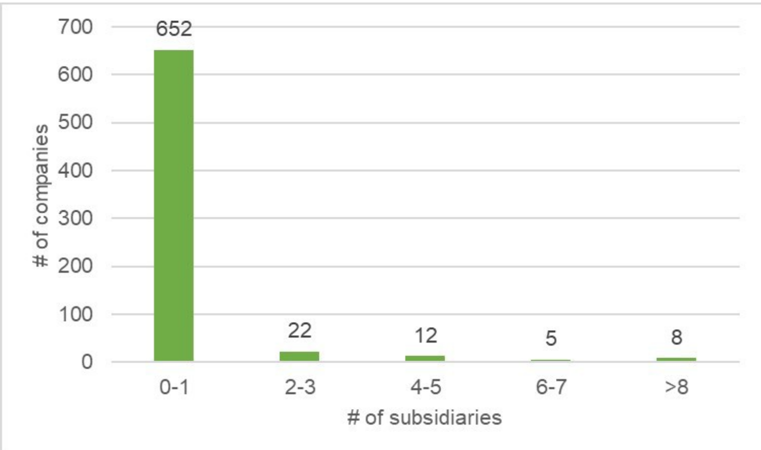

Fig. 1. Companies and their subsidiaries (N=699)

Some companies in our database were part of the same corporate structure. Fig. 2 shows a simplified version of corporate structures identified. One structure is a root company with a series of intermediate companies, which are linked to companies that run energy businesses. The latter entities may also invest in other energy businesses (yellow and green areas), which seems common in bigger companies and investment funds. The grey area involves a root company (which may run an energy business too) with an energy business subsidiary, potentially with more dependants. Some LA-based, community-oriented, and private companies operate under this structure. Under the purple area are some LA-based, community-oriented, and biogas-based companies. In this case, there is a common root company or owner which invests in companies that run (various) energy businesses; the latter may in turn

[7] A University of Edinburgh license was used for this study.

invest in subsidiaries. The red area represents the same idea, but here the root companies or owners are not the same. Most of these cases are investment funds, community-oriented entities, small/medium-scale producers, and LA-based organisations. More information may be available which we have not accounted for, due to resources and data limitations. Nevertheless, the examples above represent most of the cases where an over-arching corporate structure is observed.

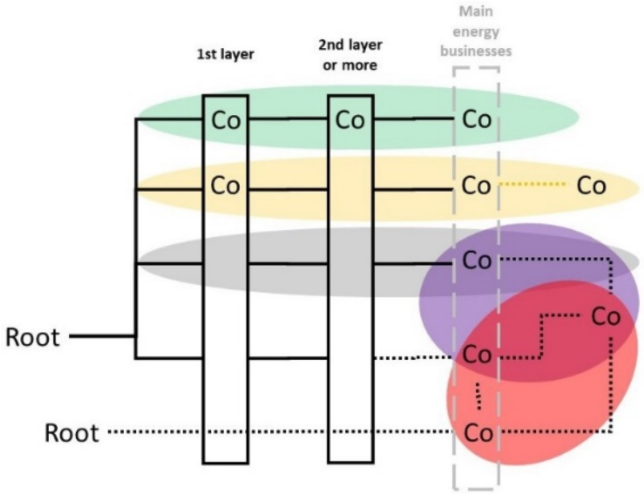

Fig. 2. Types of corporate structures in our sample

In order to identify their "purpose" in the context of a LEB sector, we classify all companies (including stand-alone entities) according to the following criteria. First, the term *core business* refers to any entity directly running energy services, regardless of overall corporate structure (e.g. holding, investment vehicle or stand-alone entity). Second, an *investment vehicle* is any company which is part of a corporate structure with a parent company and other dependent companies. Third, a *holding* is any company that contains other dependent companies without having a parent entity. More than 90% of the organisations in our database are directly carrying out energy business (core business and derived categorisations). Circa 9% of this group have a dual classification, either *core business/investment vehicle* or *core business/holding*. In the former classification, most companies were direct energy businesses, with dependent energy entities and a parent company[8]. In the latter classification, no parent company was found. The above classifications may imply overlapping categories. Including them, however, gives a better idea about what a local, decentralised energy business sector might look like in reality. The details are shown in Fig. 3.

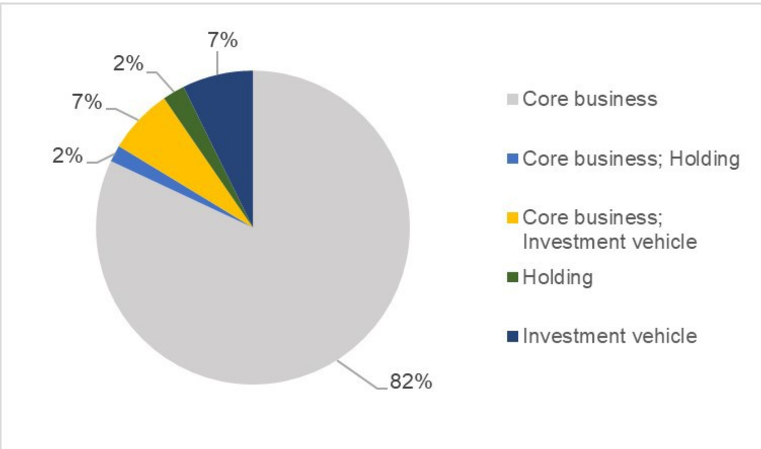

Fig. 3. Purposes of companies (N=699)

[8] In some cases, there was insufficient information about the role of an entity in running energy businesses directly or through subsidiaries; nor was it possible to include such subsidiaries in our database.

As noted in Fig. 4, most businesses are privately-owned (77%). Community interest companies comprise 6% of the sample[9] and others are owned by trusts, foundations or community groups (14%). Councils and universities own the remainder (3%). This information shows who is part of the sector, as well as offering some insights into stakeholder relationships and the way that benefits are provided.

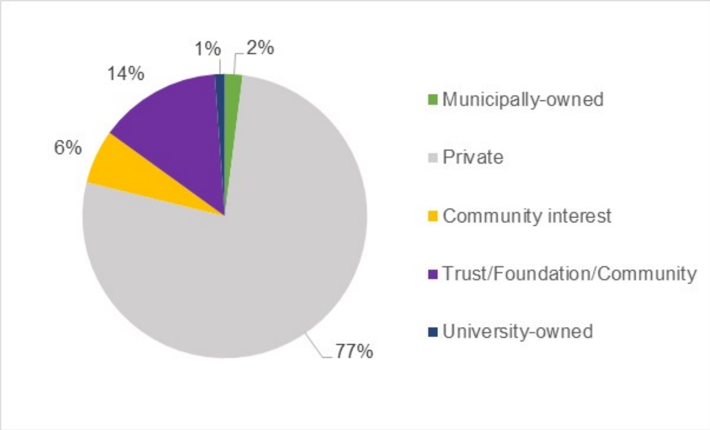

Fig. 4. Companies ownership (N=699)

We use companies' average assets and adopt the Companies House[10] company accounts guidance thresholds as a proxy to determine the size of each company. Our criteria are detailed as follows:

- Micro entity, average assets are less than £316,000
- Small company, average assets are between £316,001 and £5,100,000
- Medium company, average assets are between £5,100,001 and £18,000,000
- Large company, average assets are greater than £18,000,000

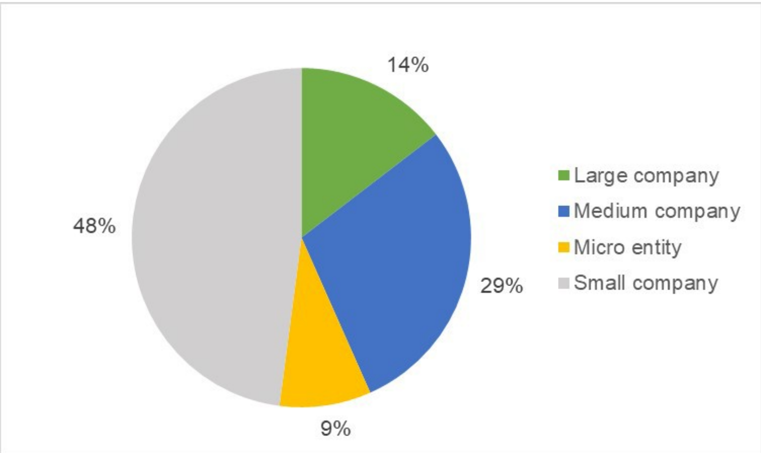

Fig. 5. Size of companies based on average assets (N=699)

We use an asset-based definition, because the largest proportion of assets should be fixed, which would not vary significantly over the period of business operation. Furthermore, assets represent all the resources needed to generate sufficient income or turnover to cover business costs. Assets are hence a good proxy for estimating company size. Fig. 5 shows that almost half of the businesses in our sample are small (typically with one employee), 29% are medium-sized (typically with five employees), 14% are categorised as large (typically with 37 employees), and 9% are categorised as micro (typically with 1 employee).

[9] A type of limited company conceived to benefit communities rather than shareholders.
[10] See https://www.gov.uk/government/publications/life-of-a-company-annual-requirements/life-of-a-company- part-1-accounts

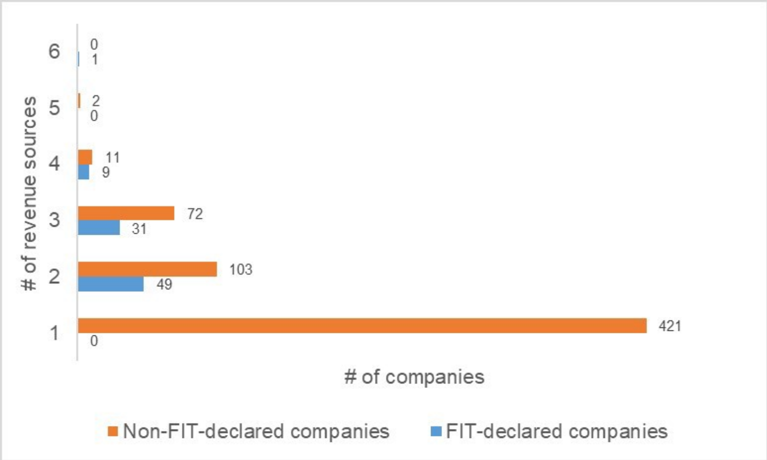

Fig. 6. Number of revenue sources by number of companies (N=699)

Fig. 6 examines companies' revenue sources with the aim of gaining insight into how they generate income. Most of the businesses (421 out of 699) have just one revenue source. Of these, 276 sell electricity to the grid[11] using renewable sources or technologies such as solar PV (118 businesses with circa 652 MW of estimated capacity), wind (97 businesses with approximately 713 MW), hydro (50 businesses with around 30 MW), and biogas (11 businesses with nearly 15 MW). The remainder, 145 out of 421 businesses, are mainly involved in gain on investments[12] (67), heat and power services (27), power purchase agreements or PPA (18), district heating (8), retail supply of electricity (6), retail supply of gas and electricity (4), benefits management (3), and enhanced frequency response services (2).

The sample also includes businesses which have two or more revenue sources (188 out of 699). In addition to selling electricity to the grid, most of these businesses (154 out of 188) have revenues from renewable obligation certificates (ROC), PPA, production of biofertiliser, gain on investments, food, and general, waste management. The main technologies used by these businesses are onshore wind (932 MW of estimated capacity related to 53 businesses), solar PV (462 MW related to 44 businesses), biogas (115 MW related to 29 businesses), offshore wind (1802 MW related to 9 businesses), and waste-to-energy (130 MW related to 7 businesses). In addition, there are storage, hydro, combined heat and power (CHP), and biomass technologies in use, although each of these technologies is associated with less than 6 businesses. A proportion of the businesses receive public subsidies. Almost 13% (90 out of 699) declare receipt of Feed-in-Tariff (FiT) benefits. Most of these businesses have two (49) or three (31) revenue sources. The main related technologies are solar PV (33 businesses with nearly 118 MW of estimated capacity), wind (23 businesses with circa 33 MW), biogas (21 businesses with approximately 38 MW), hydro (14 businesses with nearly 330 MW), and CHP (6 businesses with circa 2.9 MW); the remainder consists of one storage business (1.2 MW) and one heat pump. The main additional revenue sources, apart from the FiT, are sales of electricity to the grid, PPAs, gain on investments, production of biofertiliser, sales of gas to the grid, heat and power services, and renewable heat incentive benefit (RHI).

[11] In the case of no explicit information about the energy company's revenue sources, it is assumed that, given the company's nature and purpose, its main revenue source is the production and sale of electricity to the grid (which may be either connected or not to the trunk transmission system).
[12] This is not limited to investments in financial instruments, but includes investments in energy businesses as well.

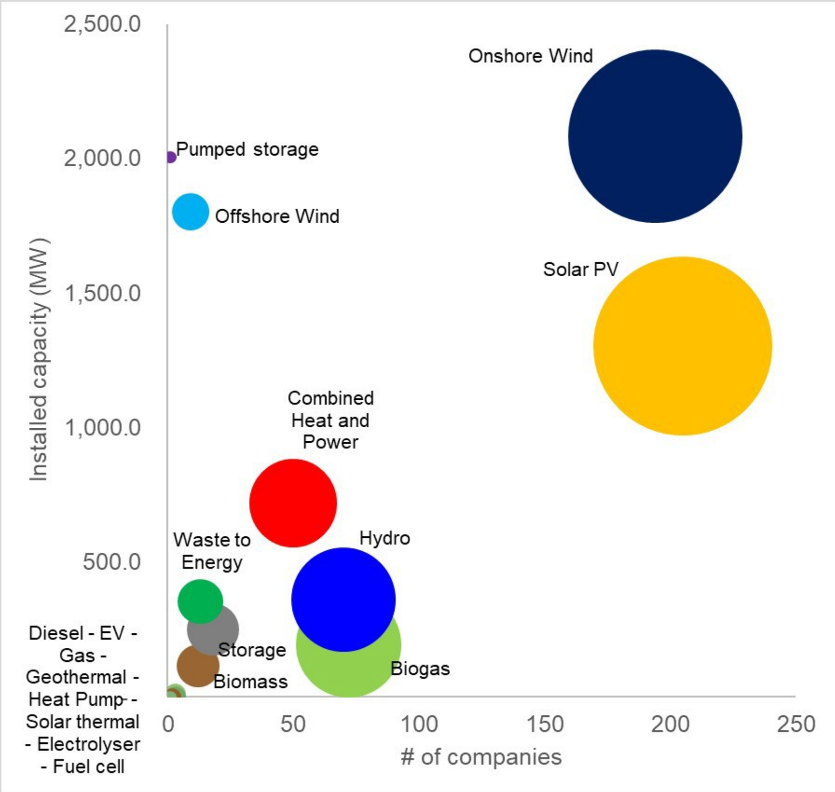

Fig. 7. Estimated installed capacity by source/technology and related number of companies (N=606)

Fig. 7 shows the estimated installed capacity by technology and number of companies involved in a particular technology (each bubble's size is determined by the number of companies). If we consider the quotient between these variables, which gives an idea of the average capacity, the largest are associated with pumped storage, offshore wind, waste-to-energy, CHP, storage, and onshore wind. In contrast, those related to diesel, heat pumps, solar thermal, electrolyser, and fuel cell sources or technologies are the smallest[13]. Biomass, Biogas, Gas, Solar PV, and Hydro projects are in an intermediate range. The most recurrent associations between energy sources or technologies and revenue sources across businesses are shown in Table 2. This offers insights into how each technology contributes to revenues. Further research is needed to examine other aspects like value proposition and financing capital investments.

[13] No information about installed capacities was available for the three EV and one geothermal projects included in our database.

Energy source/technology	Revenue source
Pumped storage	Selling electricity to the grid; Tourism attraction
Wind offshore	ROC; Selling electricity to the grid
Waste to Energy	Selling electricity to the grid; Waste management
CHP	Heat and power services
Storage	
Wind onshore	
Solar PV	Selling electricity to the grid
Hydro	
Diesel	
Biogas	Fertiliser; Food waste management; Selling electricity to the grid
Biomass Gas	District Heating
Heat Pump	FiT; Selling electricity to the grid
Solar Thermal	Gain on investments; Heat and power services; Other non-energy services
Electrolyser Fuel cell	Hydrogen energy storage

Table 2. Most recurrent associations between energy sources/technologies and revenue sources

An important aspect of LEBs is how they interact and engage with stakeholders, especially in relation to project implementation/delivery/benefits, routine decision-making, or ownership [18]. These aspects should independently lead to the creation, offer, and delivery of direct monetary and/or non-monetary value for localities. We say "independently" because an organisation may not be open to local ownership. Instead, it may engage locally in either project implementation/delivery/benefits or decision-making. We focused on collecting data about companies from whom information on (direct) benefits for communities was available. As revealed in Fig. 8, more than one third (36%) of the businesses declare the delivery of some type of benefit to communities, chiefly comprising community funds. There are also businesses that provide benefits through local ownership, and others, such as community interest companies, are assumed to deliver benefits by virtue of their legal structure. Further research is needed to assess how effectively such energy businesses are providing benefits to communities or localities, and the corresponding social and economic implications.

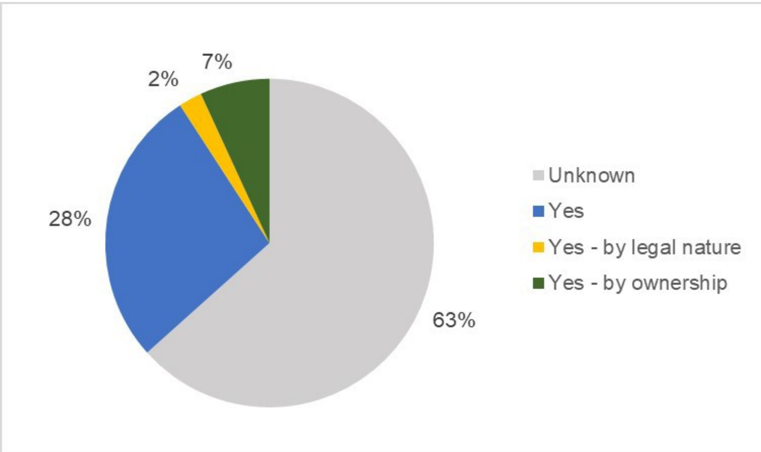

Fig. 8. Companies from whom information on (direct) benefits for communities was available (N=699)

4.2. Estimated localism and smartness in UK local energy businesses

Degrees, or types, of localism and smartness of LEBs were estimated using a matrix to allocate each company to one of the quadrants: *"Energy Systems"* (ES), *"Smart & Local Energy Systems"* (SLES), *"Local Energy Systems"* (LES), *and "Smart Energy Systems"* (SES) (Fig. 9). A *"Transition"* category or quadrant is also used to indicate potential for movement towards the zone where more local, smarter systems or businesses can be allocated[14]. The results are derived from a qualitative scale for constituent elements of localism and smartness, which are detailed in the Introduction. Depending upon the identified elements, a rating from 0 to 4 (five levels) for smartness and

[14] We refer to "system" instead of "business" in the matrix because we do not want to limit the application of this matrix and methodology to businesses/companies only. Instead, we want to extend the use of these tools to other energy-related research subjects, where possible.

from 0 to 3 (four levels) for localism were assigned to each company. Each company was then mapped in the matrix through the pair of localism and smartness. More details of matrix categorisations, and the qualitative scale and assessment procedure, are given in the supplementary material. The green and red arrows represent optimistic and pessimistic trajectories, if these energy businesses were one rating higher or lower (different from our estimate) along both axes, respectively.

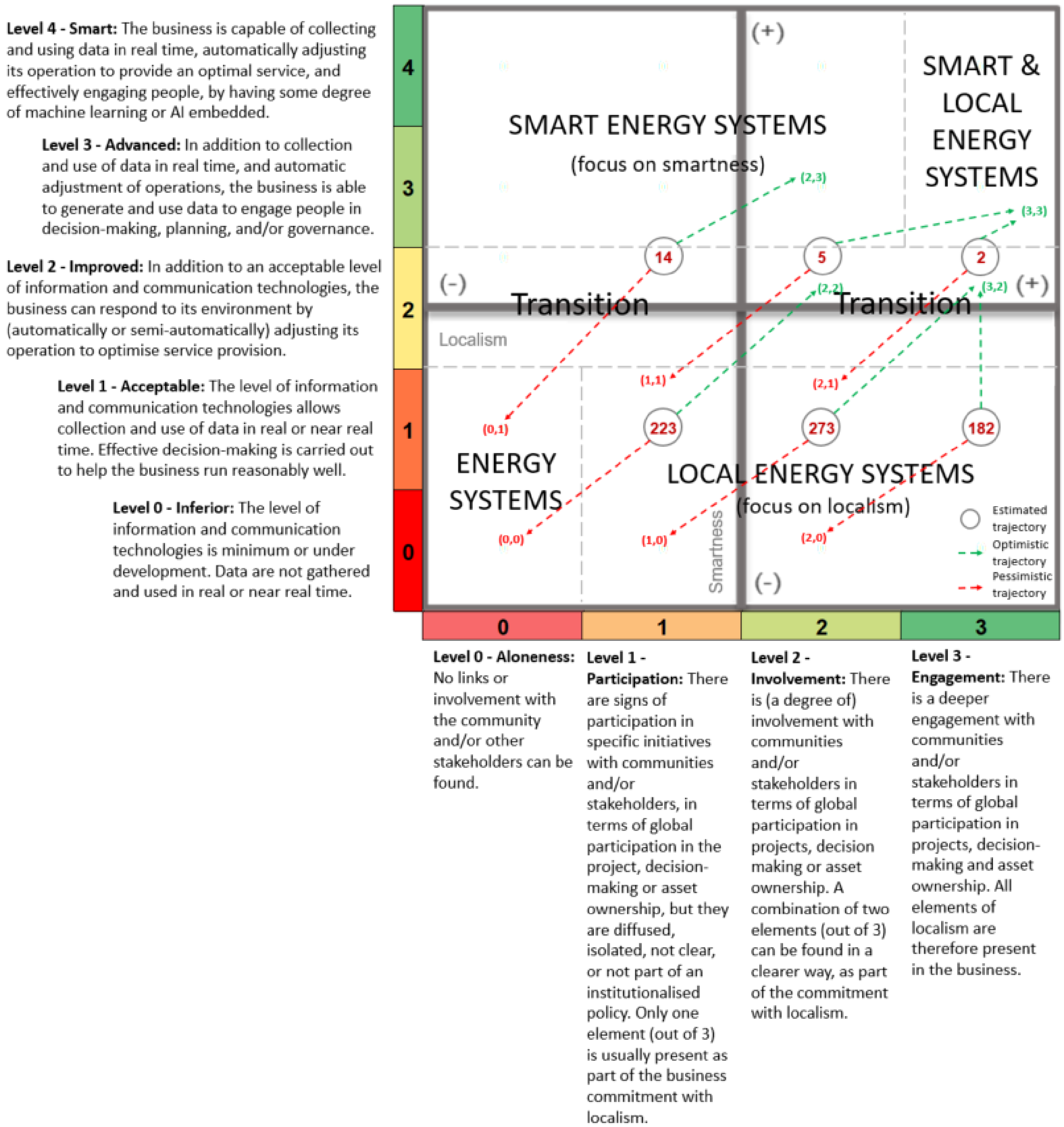

Fig. 9. Smart and local energy systems categorisation matrix (N=699)

Estimates show that few LEBs have as yet integrated digital systems (concentration in rating 1 for smartness), and that orientations to localism are varied (spread across ratings 1 and 3). There is at present limited development of smart systems in LEBs, which also vary in their orientation to the local sphere. Evidence suggests that some businesses are moving towards digitalised operations (defined here as “Transition”).

Tables 3, 4, and 5 show the ownership, company size, and distribution of benefits for each quadrant of the matrix. In terms of ownership (Table 3), privately-owned companies are most likely to have low levels of localism (ratings 1 and 2). Third-sector organisations and more socially-oriented businesses unsurprisingly show high levels of localism (rating 3). Nevertheless, there are some privately-owned businesses with high levels of localism. This implies that, among local energy providers, there are: increasing numbers of privately-owned businesses, such as those owned and operated by farmers and landowners; companies which engage with communities or residents or participate in partnerships with LAs and/or third sector organisations; investment funds open to any investor; and district energy (residential management) entities. This evidence reveals increasing localism with a mix of business ownership.

Ownership	LES (1,1)	Transition (1,2)	LES (2,1)	Transition (2,2)	LES (3,1)	Transition (3,2)
Municipally-owned					14	
Private	223	14	273	5	22	
Community interest companies					43	
Trust/Foundation/Community					95	2
University-owned					8	

Table 3. Ownership distribution of companies by ratings combination (N=699)

Delving into Table 4, the companies' distribution across sizes and LES categorisation ratings is varied. Yet no micro entity appears in the intermediate Transition zone with localism ratings of 2 or 3. These results could denote that no micro entity can as yet afford the resources for a high degree of both smartness and localism. Only two large companies are allocated to the Transition zone, which could indicate that such businesses are either primarily focused on "traditional" energy services, with low levels of both localism and smartness, or are committed to strengthening their services by delivering some form of local value. The above may be a viable form of business innovation to achieve higher levels of smartness.

Size	LES (1,1)	Transition (1,2)	LES (2,1)	Transition (2,2)	LES (3,1)	Transition (3,2)
Large company	37		58	2	5	
Medium company	89	6	68	3	34	1
Small company	93	7	130		104	1
Micro entity	4	1	17		39	

Table 4. Size distribution of companies by ratings combination (N=699)

A small number of businesses are close to operating as a SLES (levels 3 of localism and 2 of smartness), due to their participation in storage initiatives, as well as their social, community, or public ownership (2 businesses). A further five businesses either work with LAs, or provide some direct benefits to communities (levels 2 of localism and 2 of smartness) and participate in storage initiatives, but are less comparable to an integrated SLES model, given that they are privately owned or "less local". Some of these "less local" businesses are defined as "smarter" (14 businesses with levels 1 of localism and 2 of smartness), given their involvement in storage initiatives which provide flexibility services for system operation.

Benefits provision	LES (1,1)	Transition (1,2)	LES (2,1)	Transition (2,2)	LES (3,1)	Transition (3,2)
Unknown	223	14	193	2	11	
Yes			66	3	122	1
Yes - by legal nature					16	
Yes - by ownership			14		33	1

Table 5. Benefits provision distribution of companies by ratings combination (N=699)

Over half of the businesses (55%) included in the LES and Transition categorisations, with levels 2 and 3 of localism, provide local benefits (Table 5). Hence, localism does not necessarily mean improved or direct benefits to communities.

5. Discussion

Although previous research has not explicitly characterised a (UK) LEB sector, it has provided useful classifications or archetypes and case studies. Yet, as there are no previous (UK) LEB sectoral characterisations based on legally-constituted businesses, an explicit comparison of our results with other works is not feasible at present. Our results are however aligned with the state-of-art evidence discussed in section 2, indicating that our characterisation is a step in the right direction. Further research that uses (and improves) the qualitative assessment developed in this paper is needed to facilitate explicit and more detailed comparisons.

Our approach can be applied to other countries. We expect that results derived from the application of our approach will chiefly depend on countries' commitment to the energy sector decentralisation, technological progress and its transfer to energy initiatives, and organisational forms that own and/or run energy projects. For instance, we conjecture that in low- and middle- income countries we could expect (highly-)centralised energy systems, potentially with some isolated locations involving local initiatives, though with comparatively low benefits for communities, decision-making involvement and local ownership degrees. Moreover, energy initiatives in such countries may face either lower technological progress or more difficulties to transfer advanced technologies to energy projects than in high-income countries. Yet, relationships between centralised and decentralised systems are likely to be complex and dependant on the specific context, configuration of a particular country or market, which would benefit from further research. Approaches like ours can contribute to promoting a better and socially fair distribution of energy resources, by accurately informing how local, and also smart, energy market incumbents are and by showing existing research gaps. Our approach can therefore facilitate an appropriate resources allocation for those local, potentially smart, projects in need.

Earlier theoretical and empirical evidence implies potential for significant development of more local, smarter, UK energy businesses, based on innovation opportunities that are bringing "less-experienced" actors into the market; these include third sector organisations, LAs, and farmers. Such businesses are already addressing elements of digitalisation, consumer involvement/engagement, prosumerism, local ownership and supply chain development. They are also expected to address the 4Ds more effectively than conventional energy businesses. The state-of-art evidence is, of course, a useful foundation for classifying and understanding (potential) LEBs, but typically lacks empirical evidence about the characteristics of participants at a sectoral level, and about degrees of localism and smartness. Our database development, statistical analysis and matrix modelling have begun to address this gap.

The key findings show that most businesses in our sample are private limited companies involved in conventional, non-integrated energy vectors across a range of asset scales. They are predominately small and medium companies, mainly using established solar PV and onshore wind technologies. The evidence nevertheless suggests that opportunities are being translated into new and varied types of business and value propositions. Indeed, many current LEBs have more than one revenue source. For example, organisations such as bioenergy or waste-to-energy businesses cover a wider section of the supply chain, and therefore have multiple revenue sources. There are also businesses deriving revenues from aggregation (3), carbon dioxide production (1), hydrogen energy storage (1), microgrid operation (1), electricity supply for EVs (1), water supply (2), and even tourism services (1). Yet public funding remain significant for some entities. Hence, based on the empirical data about UK legally-constituted energy businesses, we see embryonic forms of innovation and diverse entrepreneurial activities and value sources.

Some businesses are part of complex corporate structures which involve holdings and/or investment vehicles, or joint ventures with only projects in common. Furthermore, our findings, in agreement with the state-of-art literature, demonstrate that a diverse group of actors, including those with little experience in the energy sector, such as universities, farmers, community groups, and LAs, are formally and effectively involved in more local, decentralised energy businesses in the UK. This is not to the exclusion of established private sector actors.

Based on our qualitative scale and matrix (Fig. 9), we estimate that most of these businesses have not yet integrated digital, or smart, systems. The main factor that differentiates businesses seems to be use of digital systems to enable semi-automated service optimisation, mostly through storage. This includes some community-oriented companies. More information is however needed to understand the trajectory of companies.

In relation to localism, we estimate that there are different levels of commitment across distinct types of ownership, including private companies, with an important role for micro, small, and medium companies. There is scope for businesses to use more innovative ways, beyond monetary benefits, to create and strengthen ties with local stakeholders. These local engagement activities could include participation in decision-making beyond benefits delivery, further opportunities for ownership shares, community/public/private partnerships, and new financial instruments or corporate structures that attract more investors.

Much of the (commercial) stimulus for a more local and (potentially) smarter, UK energy system might come from the increasing scale of distributed generation connected to the distribution grid. However, more distributed generation creates problems for a system designed to be one-way flow from transmission to point of use or consumption, with DNOs having limited digital systems to monitor and manage real time supply and demand. This problem is now being addressed by the British regulator [65]. In this context, there is considerable scope for developing a UK LEB sector, with new businesses structured around maximising efficiencies from distributed generation and demand management, and integrating heat, power, storage and mobility at local scale. Such integrated systems are expected to reduce costs of transition to a net zero carbon system, as well as improving local welfare [100]. The constituent elements of localism and smartness considered in this paper play a key role in such transition. The (final) trajectory will be significantly influenced however by governments and policy-making to create the market framework conditions for a stronger decentralised, democratic, decarbonised, and digitalised UK energy system.

Our findings suggest that key policy requirements are:

1) Further development of criteria for establishing and growing a LEB sector. Our methodological approach, extended by new quantitative data from a representative sample of LEBs, provides one option.
2) Support for investment in integrated smart, local businesses with a local stake in clean energy.
3) A unified financial business disclosure regime to support transparency, informed policy, and effective development of the sector.

6. Conclusion

This work offers a novel approach to characterising a UK LEB sector. Through database construction and analysis, it provides insights into participants, energy businesses and technologies, and their degrees of localism and smartness. The analysis demonstrates that a UK LEB sector is emerging. The findings provide a foundation for policy development to support investment in smart and local energy systems. Our approach is open to improvement, particularly where our analysis of “local” and “smart” business components could be strengthened by detailed LEB surveys. Future research is needed on quantitative assessments of localism and smartness, financial characteristics of UK LEBs, more innovative ways to create and strengthen ties with local communities, funding instruments and mechanisms, and design and effective application of new business models by incumbents as well as new entrants.

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