Local energy businesses in the United Kingdom: clusters and localism determinants based on financial ratios

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Abstract

This paper presents the first financial analysis of the United Kingdom's local energy business sector. This analysis relies on financial ratios and degrees of localism as inputs for descriptive statistics, cluster, and canonical discriminant analyses. Our findings suggest that privately-owned energy businesses, typically with limited commitments to localities, account for the great majority of sectoral assets and turnover, and are in comparatively good financial condition. Highly-local energy businesses typically have low profitability and a high reliance on debt. The latter is the key variable differentiating them from other less local energy businesses. Moreover, we find financial commonalities within different groups of local energy businesses, which correlate with their specific level of localism. In the context of increasing digitalisation in energy markets, more technological innovation may help strengthen local energy businesses' revenue sources and value creation. Further research is needed in terms of investibility, specific financing terms and conditions, and geographical aspects of value creation, retention, and delivery to localities. This work can improve the understanding of sectoral dynamics and development needs, with value for policy making to incentivise investment in this emerging sector.

Keywords: local energy businesses, cluster analysis, canonical discriminant analysis, degrees of localism, financial ratios

1. Introduction

The United Kingdom (UK) energy sector has developed over a long period, from small, decentralised systems [1], which were gradually replaced by larger scale, centralised, generation in a state-owned system, before privatisation in the 1990s, which broadly perpetuated a centralised system [2,3]. New participants in this sector [4], including some "less-experienced" organisations from other sectors [5-8], have recently become involved in local energy initiatives, either through pilot projects [9] or as legally-constituted businesses [10]. The latter development enables characterisation of a UK local energy business (LEB) sector, which currently encompasses businesses with a diverse mix of owners, sizes, degrees of localism and smartness, revenue sources, and technologies [10]. Local, smarter energy systems are expected to support decarbonisation, reduce overall transition costs to a net zero carbon system, and improve local welfare [11-14].

Large-scale renewable energy projects are attractive for investors because of competitive costs, environmental standards, and greenhouse gas emissions regulations, among other elements [15]. This is true in countries like Germany and the UK, where such projects have been developed relatively quick [16], although an emergent interest in decentralised systems, connected to/feeding power supply into the lower voltage distribution network has also come up. Examples of financial support for these energy businesses include venture entrepreneurs who support riskier or early-stage projects [17], private banks which offer 'green' products - e.g. mortgages or eco-deposits - [18-20], mezzanine capital or equity finance [21,22], crowdfunding - e.g. UK Crowdcube or Seedrs - and community shares[1] [23], and public funding [24]. However, LEBs may have been slow to effectively penetrate the UK market; some authors have argued that there is a lack of financial support for LEBs and noted potential innovation constraints due to cost of debt [25]. Others claim an excessively centralised financial system [26] and

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[1] See https://ukerc.ac.uk/news/financing-community-energy-in-brave-new-world/ for more detailed examples.

a need to strengthen financing and support for (small and medium) low carbon investments without relying on costly grant finance programmes borne by public finances [24].

Characterising the UK LEB sector in financial terms can produce insights into factors that account for its pattern of development and (financially viable) operation, in turn enabling increased and faster penetration by practitioners in the market. An informed understanding of the sector can be established by assessing its resources (assets), obligations (liabilities), and financial performance. This understanding would provide a tangible basis for analysing the value to be derived from allocation of additional resources via financing, private investments, and government aid schemes. In this paper, therefore, we develop a financial assessment of the sector by analysing a database of UK legally-constituted businesses [10], aiming at answering the following research questions:

a) What is the financial condition of the UK LEB sector?;
b) Do UK LEBs have common financial characteristics?;
c) Which financial indicators correlate with the development of "highly-local" energy businesses?; and
d) How can knowledge about the financial status of the LEB sector be used to stimulate innovation and value creation for more local, smarter energy businesses?

This work uses the authors' LEB degrees of localism framework [10] - a novel way to assess how "local" energy businesses are - and financial ratios to produce an original empirical analysis, as yet unexplored in the literature. Thus, this paper enriches and informs discussion about the potential value from a local energy sector in the UK market.

The paper comprises the following sections. Section 2 discusses the literature providing the theoretical background. Section 3 explains the methods used to characterise the financial status of the UK LEB sector. The fourth section develops the methods and provides the results. Lastly, sections 5 and 6 discuss respectively the findings and conclusions.

2. Theoretical background

This work is based on the approach developed by Fuentes González et al. [10], who constructed a database of UK legally-constituted local energy businesses. They then characterised a UK local energy sector using information on companies' ownership, size, energy technologies, revenue sources, and benefits provision to communities. The authors devised a qualitative scale to estimate degrees of localism and smartness, and used this to categorise LEBs in a matrix; the qualitative scale is used later in this paper [2]. Localism was estimated using a four-point scale, with constituent elements of relationships with stakeholders (via global participation in projects), asset ownership, and decision-making processes involvement at a local level [10,13].

As (UK) businesses are required to publish financial statements, financial ratios [3] can be used to characterise LEBs' financial status. Financial ratios are established tools used by many actors to support decision-making related to business stability and growth [36]. They have been used since the beginning of the 20th century, initially to assess credit-worthiness [27-29]. Altman [30] later tested their empirical validity and reliability by using financial ratios to predict corporate bankruptcy for a sample of American companies [31,32]. The same predictive tests were then applied to UK companies [33-35]. Such indicators have allowed comparative assessments of companies' financial status [37,38]. As financial ratios are derived from financial statements, their applicability transcends specific industries [39], making them a useful measure of financial status of businesses, including energy businesses [36,40-43].

Indicators of localism can be used with financial ratios as inputs for cluster analysis and discriminant analysis. Cluster analysis is a data mining method applied to multidimensional datasets to identify patterns or similarities [44]. Detailed examination of clustering methods is beyond the scope of this work. Discriminant analysis is a technique used to classify or allocate an observation into one of various *a priori* groupings dependent on the features of the observation [30]. Field [45] notes that discriminant analysis can be seen as the reverse process of MANOVA; it also provides an assessment of optimum discrimination between groups, based on several predictors. We use this particular feature in our analysis. Numerous applications of these statistical analyses address energy and financial matters, including a taxonomy of community energy initiatives [46], regulatory analysis of gas companies [47], and renewable energy sectoral analyses [38,48,49]. Both cluster and discriminant analyses are relatively well-known tools and have been used in different contexts. However, there is no (sectoral)

[2] As the title indicates, this paper is focused on localism estimates as key variable for analysis, given the low numbers of LEBs exhibiting higher levels of smartness.
[3] Quotients formed by different financial statements accounts that are useful for assessing businesses' financial condition.

analysis showing the relationship between corporate financial structures, measured through financial ratios, and local involvement or ownership, using 'degrees of localism'. Delving into the above relationship can help practitioners to understand the current UK LEB sector and its financial performance, which then offers insights into outstanding financial support that may be needed. This paper can potentially boost the UK market share of LEBs.

We provide a novel approach by characterising degrees of localism and financial ratios through cluster and canonical discriminant analyses, in order to answer the research questions stated in the Introduction. The specific methodology is explored in the next section.

3. Methods

3.1. Financial and business data collection

Information derived from companies' financial statements, which was used for calculating financial ratios, was extracted from Bureau van Dijk's FAME©. This information is part of the database mentioned in the previous section [10]. Only entities directly running energy activities as *"core business"*, regardless of overall corporate structure (e.g. holding, investment vehicle or stand-alone entity) [10], were analysed. The yearly accumulative number of companies with useful financial information is detailed in Table 1.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Companies	168	213	259	309	374	478	568	608	601

Table 1. Yearly accumulative number of companies with useful financial information available for analysis

An array containing each company's annual financial information was then constructed using Julia© 1.5.0, to calculate financial ratios based on Ross et al. [50]. The financial ratios considered in this work [4] [5] are detailed in Table 2.

Type of indicator	Financial ratios
a) Liquidity:	$\text{Current ratio} = \frac{\text{Current assets}}{\text{Current liabilities}}$ $\text{Cash ratio} = \frac{\text{Bank accounts}}{\text{Current liabilities}}$
b) Leverage:	$\text{Debt ratio} = \frac{\text{Total liabilities}}{\text{Total assets}}$ $\text{Equity multiplier ratio} = \frac{\text{Total assets}}{\text{Total shareholders' funds}}$ $\text{Debt to Earnings Before Interest, Taxes, Depreciation, and Amortisation (EBITDA) ratio} = \frac{\text{Total liabilities}}{\text{EBITDA}}$
c) Efficiency:	$\text{Assets turnover ratio} = \frac{\text{Turnover}}{\text{Average total assets}}$
d) Profitability:	$\text{Net profit margin} = \left(\frac{Net\ income}{Turnover}\right) \times 100$ $\text{EBITDA margin} = \left(\frac{EBITDA}{Turnover}\right) \times 100$ $\text{Return on Assets (ROA)} = \left(\frac{Net\ income}{Total\ assets}\right) \times 100$ $\text{Return on Equity (ROE)} = \left(\frac{Net\ income}{Total\ shareholders'\ funds}\right) \times 100$

Table 2. Financial ratios considered in this work

Two approaches for handling data and calculating all ratios were taken: top-down and bottom-up. The former utilised descriptive statistics and the latter used cluster and canonical discriminant analyses. The utilisation of these approaches is justifiable because the dataset involves entities of different sizes which are subject to differing financial disclosure regimes; some micro, small, and medium entities do not detail enough information on financial accounts. Furthermore, there is a "lifetime effect"; some companies are "younger" than others. These situations result in dissimilarities in the available information, therefore a need for exploring the data thoroughly emerges.

[4] The average values shown in the denominator for both efficiency ratios are calculated considering the average between the amount for the financial account of the year under analysis and the amount for the financial account of the previous year. For the first year under analysis, only the amount for the financial account of that first year was considered.
[5] Profitability ratios are calculated percentually.

In the top-down approach, financial ratios were calculated annually (from year 2010 to 2018) for the aggregate figures (sum of companies' accounts), based on two categories shown in [10]: firstly, ownership; and secondly, localism and smartness estimates. Concerning ownership, the specifics are shown in Table 3:

Classifications	Detail of businesses
Private	Privately-owned businesses; referred as *"private"* in [10]
Municipal	Local authority-owned businesses; referred as *"municipally-owned"* in [10]
Third sector	Businesses owned by community(-oriented) organisations, such as trusts, foundations, or community groups (sometimes via bencoms, development trusts or charities); referred as *"trust/foundation/community"* in [10]
Universities	Businesses owned by universities; referred as *"university-onwed"* in [10]
Community interested	Community interest companies (CIC) [6], mostly privately-owned or owned by other CICs, not included in *"Third sector"* classification; referred as *"community interest"* in [10]

Table 3. Ownership-based classifications and specifics

Localism and smartness ratings reflect the estimates of how local and smart energy businesses are in reality, based on the following qualitative scale [10] shown in Fig. 1:

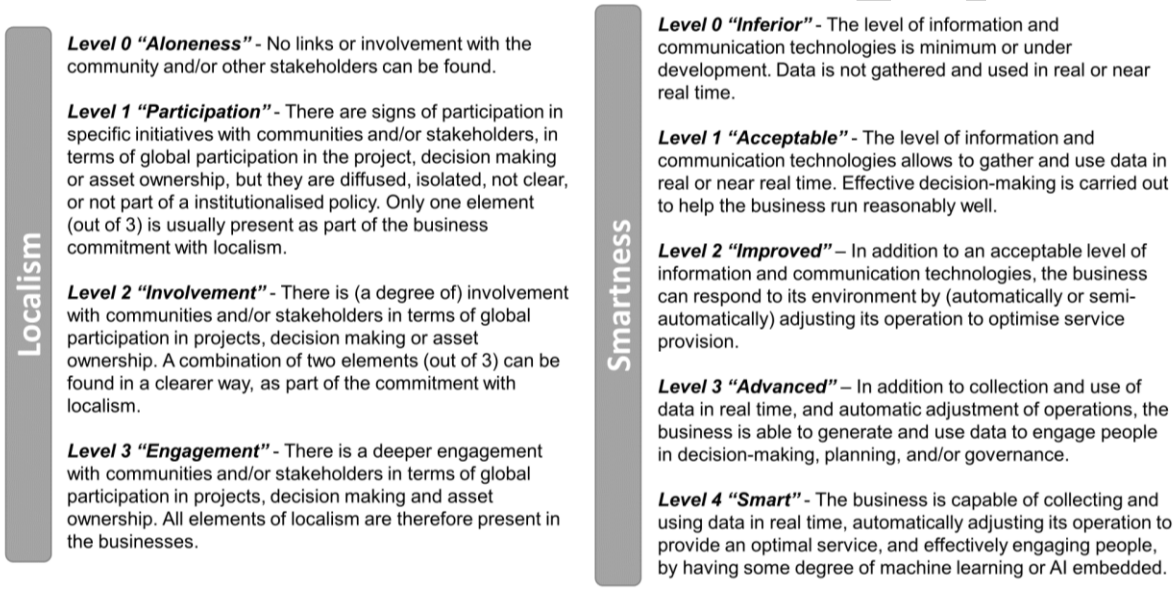


Fig. 1. Qualitative scale for localism and smartness estimates [10]

The above scale allowed characterising a UK LEB sector as revealed in [10]. We then used combinations of localism and smartness ratings as follows: LEBs rated as level 1 for both localism and smartness were catalogued as *1-Participation/1-Acceptable*; LEBs defined as level 2 for localism and level 1 for smartness were labelled as *2-Involvement/1-Acceptable*, and so on [7].

By following this approach (top-down), we can then obtain aggregated information about key financial aspects of LEBs, to answer research question *a)* on the sectoral financial status. The number of companies analysed in this approach (Table 1) is detailed by category in the supplementary material.

In the bottom-up approach, annual financial ratios were calculated for each company and then used as inputs for cluster and canonical discriminant analyses, considering data from year 2018 only (N = 316), the year with the highest number of financial ratios calculated per company. Through cluster analysis, we aim to secure insights into potential clusters of LEBs with financial similarities, answering research question *b)*. With canonical discriminant analysis, we aim to secure insights into the (financial) elements that could influence the development of "highly-local" (*level 3-Engagement*) energy businesses, answering research question *c)*.

[6] A Community Interest Company (CIC) is defined in UK law as a type of limited company conceived to benefit communities rather than shareholders. Accordingly, this type of company does not necessarily imply ownership by community-based organisations, although CICs are assumed to have high degrees of localism due to its (legal) nature.

[7] Localism *Level 0 - Aloneness* attempts to represent businesses that are (much closer to) centralised energy businesses, as well as provide a basis for mapping, through one scale only, the evolution from centralised to local, decentralised levels of doing energy businesses.

Both top-down and bottom-up analyses can provide extra insights into the financial status of the sector, providing the basis for conjectures about the stimuli for innovation and value creation, answering research question *d)*.

3.2. Statistical procedures

The top-down approach utilised descriptive statistics performed using Julia© 1.5.0; the bottom-up approach utilised cluster analysis and canonical discriminant analysis performed using R© 4.0.2 and RStudio© 1.3.1093, alongside the following R© packages: dplyr [51], cluster [52], factoextra [53], ggplot2 [54], Rtsne [55], dbscan [56], fpc [57], clustMixType [58], heplots [59], and candisc [60].

In the bottom-up approach, we performed four runs of analysis, considering different data treatment, to explore the data thoroughly and reduce effects from outliers, skew and kurtosis deviations, and unequal variances; an additional justification is that, in large samples, significance tests can be unreliable measures of statistical significance [45]. Run-1 and Run-3 (N = 316) did not consider highly correlated variables, measured through Pearson's correlation coefficient ($r > 0.8$ for high correlation), and all financial ratios were logarithmically transformed in Run-3. The logarithmic transformation is as follows: for variables without negative values within the series, the formula $log_{10}(\text{Financial ratio}_i + 1)$ applies for each i company; for variables with negative values, the formula $log_{10}(\text{Financial ratio}_i + abs(min(\text{Financial ratio})) + 1)$ applies for each i company. Additionally, in Run-2 and Run-4 (N = 287) outliers were removed, and Run-4 involved financial ratios logarithmically transformed as above. Outliers were spotted through standardisation (Z-scores) of observations [45]; $\text{Z-scores} > \pm 3.29$ were considered as outliers. Logarithmic transformation can improve skew and kurtosis deviations, and unequal variances [45]. Removing outliers can reduce distortions on a parameter estimate and its associated error estimate, improving accuracy. LEBs' degrees of localism [10] were the categorical variable considered in both cluster and canonical discriminant analyses.

Dataset dissimilarity heatmaps were obtained for each run of analysis using daisy function with Gower distance, to examine data patterns; such examination corroborated their existence. A sanity check was then carried out on the dissimilarity matrix to corroborate the most and least similar pairs of companies.

Hierarchical agglomerative clustering (HAC), k-prototypes, partitioning around medoids (PAM), and density-based clustering (DBSCAN) were the chosen clustering methods for analysis. The clustering methods were compared to each other through within-cluster sum of squares (WSS) - the lower value (i.e. variance) the better - and average silhouette width (SIL) - the closer value to one the better (i.e. observations in a cluster that are close to each other but separated from other clusters). These metrics were also used, alongside the elbow method, to explore the best number of clusters. HAC was performed considering different linkage criteria, namely Ward's criterion, complete-linkage, and average-linkage. The best combination of cophenetic correlation coefficients (CCCs) - the higher value the better (i.e. dendrogram's objects linking and original observations pairwise distances have a high correlation) - and meaningful dendrograms were considered for selecting the final linkage criterion. To visualise the shape and meaningfulness of clusters, t-distributed stochastic neighbour embedding plots (t-SNE) were also examined.

Concerning canonical discriminant analysis, we tested discriminant functions' ability to discriminate among groups by assessing the following outputs [45,61-63], where the higher these values, the better. Firstly, eigenvalues, i.e. diagonal of the HE^{-1} matrix which represents the ratios between systematic and unsystematic variances for each discriminant function [8]. Secondly, canonical correlation, i.e. goodness or the r value between each discriminant function for the categorical variables with the corresponding discriminant function for the continuous variables, and squared canonical correlation (effect size). Finally, F-statistic, via Rao's approximation [64]. Furthermore, as Wilks' Λ represents the ratio between error variance and total variance for each discriminant function, large eigenvalues lead to small values for Wilks' Λ, which is the outcome sought. We also obtain reduced-rank HE plots to visualise the projection of linear combinations that account for the most significant variation between group means relative to error, i.e. how each discriminant function or linear combination discriminates among groups, and to identify variables' correlations and contributions to discrimination.

[8] The HE^{-1} matrix is obtained from the multiplication of the model (hypothesis) sum of squares and cross-products matrix, H, and the inverse of residual (error) sum of squares and cross-products matrix, E.

4. An exploratory financial characterisation of UK local energy businesses

4.1. Top-down approach

Aggregated information on UK LEBs' finances, shown below, provides a sectoral perspective on their financial condition. We first reveal information on the annual aggregated assets and turnover. We then show how LEBs fund their assets, measured as the proportion of liabilities (debt) and shareholders' funds (equity). Finally, we include specific ratios to see how well LEBs' assets help create value measured through efficiency and profitability ratios.

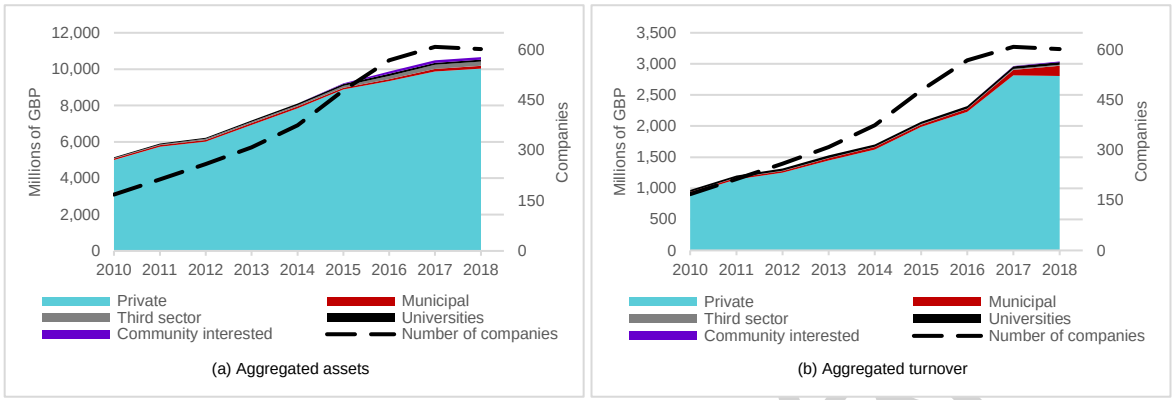


Fig. 2. Total annual aggregated assets and turnover grouped by ownership, including total number of companies under analysis

	Private	Municipal	Third sector	Universities	Community interested
Mean	7,737.27	107.17	114.78	83.00	60.18
Min	5,000.01	80.40	26.07	51.67	0.24
Max	10,021.28	159.62	240.46	110.31	133.41
SD	1,897.55	24.92	82.93	23.21	65.44

Table 4. LEBs' aggregated assets statistics from 2010 to 2018 by ownership (amounts in millions of GBP)

	Private	Municipal	Third sector	Universities	Community interested
Mean	1,801.55	54.25	7.03	38.28	3.26
Min	916.03	23.52	1.73	33.11	0.04
Max	2,816.81	165.80	17.20	43.25	10.79
SD	700.76	45.69	5.63	3.27	4.59

Table 5. LEBs' aggregated turnover statistics from 2010 to 2018 by ownership (amounts in millions of GBP)

Fig. 2(a) and Table 4 show that private companies mainly account for aggregated assets in the sector; this is partly influenced by the high number of such companies in the analysis ($min = 124$; $max = 462$; $mean = 306.56$). Municipal and third sector companies, on the one hand, and universities and community interested companies, on the other, contribute about equally to aggregated assets. Likewise, the aggregated turnover of the sector (Fig. 2(b) and Table 5) is derived primarily from private company sales, followed by municipal, universities, third sector, and community interested companies.

Regarding funding proportion, companies can be grouped as LEBs with a high reliance on long-term debt, namely municipal ($mean_{LT\ debt} = 0.76$; Fig. 3(b)) and third sector companies ($mean_{LT\ debt} = 0.59$; Fig. 3(c)). There are also LEBs with equivalent reliance on shareholders' funds, but much lower dependence on long-term debt, i.e. private ($mean_{LT\ debt} = 0.30$ & $mean_{equity} = 0.29$; Fig. 3(a)) and university ($mean_{LT\ debt} = 0.36$ & $mean_{equity} = 0.41$; Fig. 3(d)) companies. Community interested LEBs show a higher reliance on current debt ($mean_{current\ debt} = 0.61$; Fig. 3(e)).

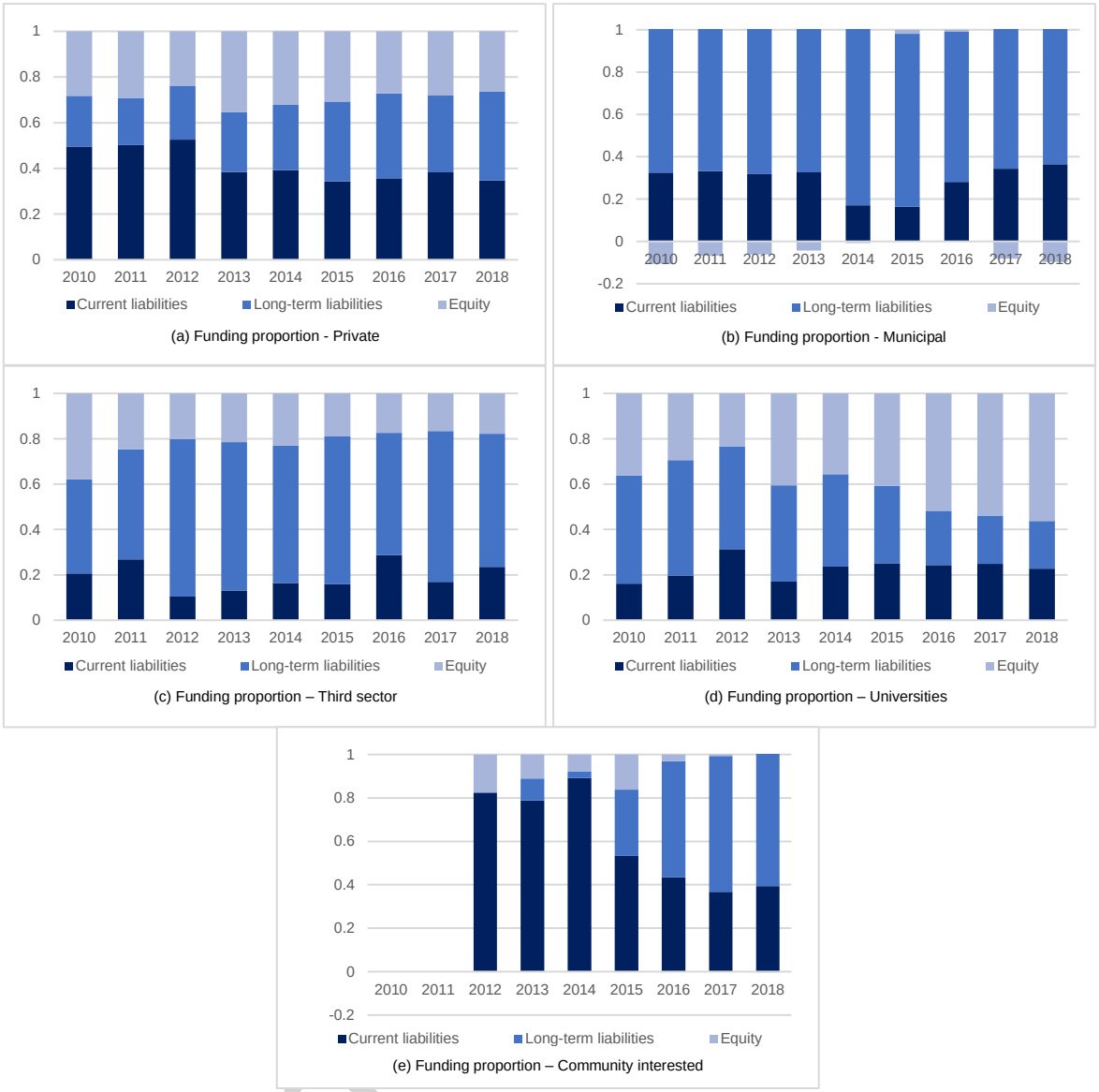


Fig. 3. LEBs' annual aggregated funding proportion by ownership (no community interested LEBs were found for years 2010 and 2011)

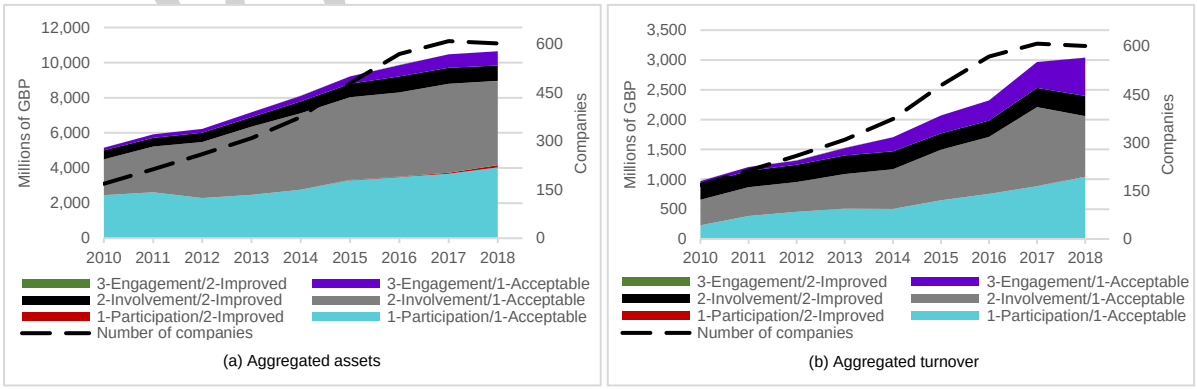


Fig. 4. Total annual aggregated assets and turnover grouped by localism/smartness ratings, including total number of companies under analysis

Fig. 4(a) and Table 6 show that LEBs associated with low levels of localism (*1-Participation* and *2-Involvement*) and smartness (*1-Acceptable*) equivalently contribute to the sectoral annual aggregated assets. Concerning turnover (Fig. 4(b) and Table 7), the same groups of LEBs present a well-defined, distinguishable proportional

contribution, on the one hand, alongside more local, smarter energy businesses categorised as *2-Involvement/2-Improved* and *3-Engagement/1-Acceptable*, on the other.

	1-Participation/1-Acceptable	1-Participation/1-Improved	2-Involvement/1-Acceptable	2-Involvement/2-Improved	3-Engagement/1-Acceptable	3-Engagement/2-Improved
Mean	3,010.80	45.51	3,939.68	692.34	421.16	4.82
Min	2,288.07	5.42	2,047.68	505.63	158.69	0.94
Max	4,044.28	115.75	5,069.02	917.70	813.35	12.31
SD	631.01	51.24	1,086.37	181.69	252.31	5.08

Table 6. LEBs' aggregated assets statistics from 2010 to 2018 by localism/smartness ratings (amounts in millions of GBP)

	1-Participation/1-Acceptable	1-Participation/1-Improved	2-Involvement/1-Acceptable	2-Involvement/2-Improved	3-Engagement/1-Acceptable	3-Engagement/2-Improved
Mean	601.40	4.13	753.78	293.86	250.73	2.05
Min	229.66	0.01	428.47	257.90	56.83	0.59
Max	1,049.31	14.39	1,321.79	336.18	641.41	3.02
SD	257.80	6.91	298.78	26.25	199.27	0.69

Table 7. LEBs' aggregated turnover statistics from 2010 to 2018 by localism/smartness ratings (amounts in millions of GBP)

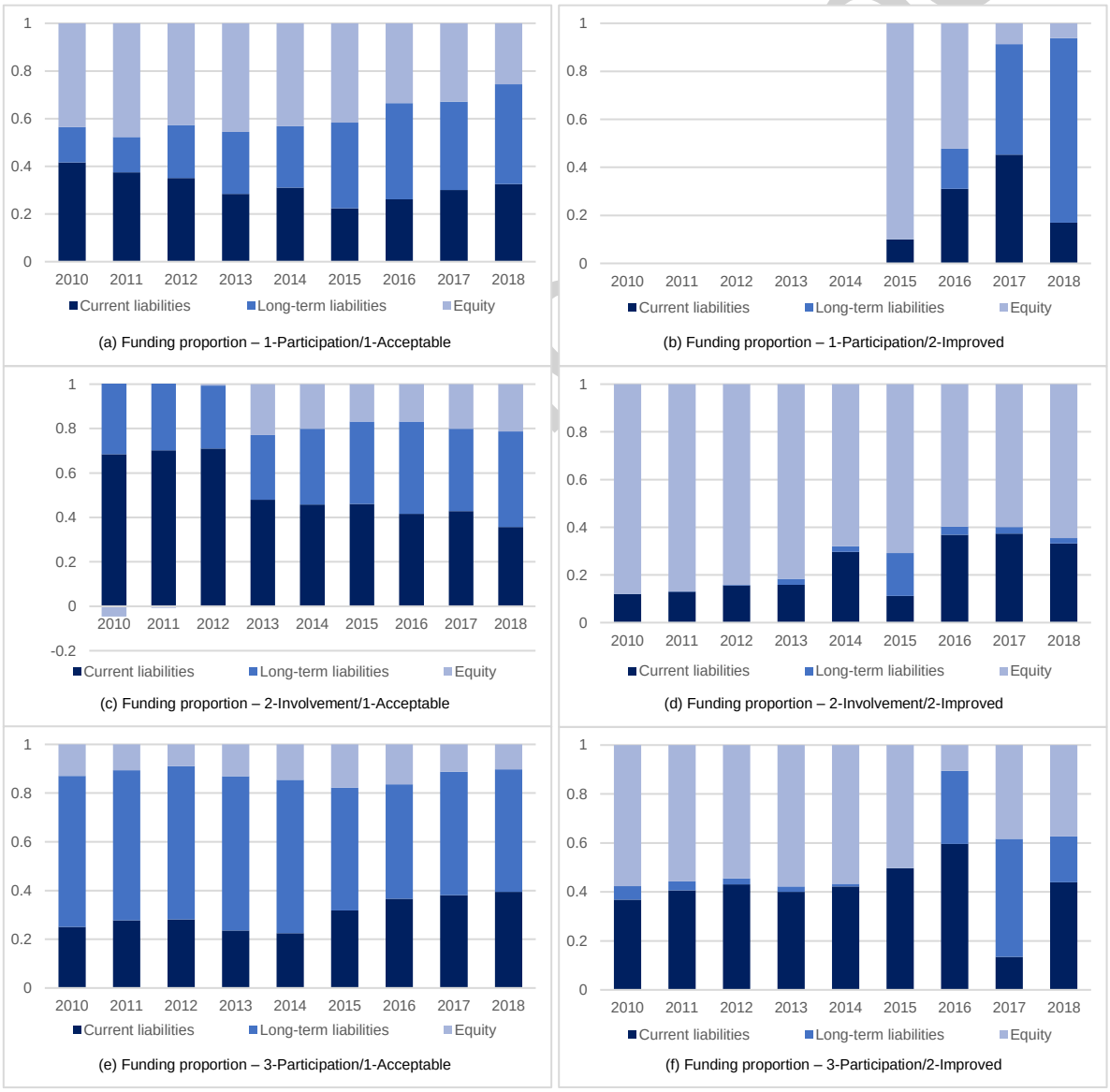


Fig. 5. Annual aggregated funding proportion by localism/smartness ratings (no LEBs assessed with ratings Participation/Improved were found from years 2010 to 2014)

Regarding funding, LEBs with higher levels of localism (*2-Involvement* and *3-Engagement*) but with the lowest smartness level (*1-Acceptable*) share a similar proportion of assets funded by equity ($mean_{equity} = 0.13$ for both groups; Fig. 5(c) and (e)). LEBs with a low level of localism (*1-Participation*) but with differing levels of smartness (*1-Acceptable and 2-Improved*) rely more on equity ($mean_{equity} \cong 0.40$ for both groups; Fig.5(a) and (b)), although less smart energy businesses (with level *1-Acceptable*) show a similar proportion for current and long-term debt ($mean_{current\ debt} = 0.32$; $mean_{LT\ debt} = 0.29$). LEBs which are more local and smarter, assessed with ratings *2-Involvement/2-Improved* (Fig. 5(d)) and *3-Engagement/2-Improved* (Fig. 5(f)), show a high reliance on equity and current debt ($mean_{current\ debt} = 0.23$ & $mean_{equity} = 0.74$ for the former; $mean_{current\ debt} = 0.41$ & $mean_{equity} = 0.47$ for the latter).

		Mean	Median	SD	Max	Min
Asset Turnover	Private	0.234	0.224	0.035	0.293	0.183
	Municipal	0.481	0.388	0.271	1.127	0.293
	Third sector	0.070	0.068	0.013	0.085	0.041
	Universities	0.507	0.508	0.112	0.641	0.366
	Community interested	0.320	0.082	0.575	1.597	0.012
ROA (%)	Private	3.221	3.198	0.899	4.889	1.744
	Municipal	0.791	0.743	4.284	4.641	-8.383
	Third sector	0.323	0.512	0.829	1.469	-1.336
	Universities	0.795	2.417	3.116	4.837	-3.481
	Community interested	1.405	0.048	5.039	12.667	-1.835

Table 8. Descriptive statistics for annual aggregated financial ratios grouped by ownership

		Mean	Median	SD	Max	Min
Asset Turnover	1-Participation/1-Acceptable	0.199	0.213	0.053	0.272	0.094
	1-Participation/2-Improved	0.063	0.038	0.079	0.172	0.003
	2-Involvement/1-Acceptable	0.197	0.201	0.032	0.268	0.162
	2-Involvement/2-Improved	0.460	0.496	0.102	0.589	0.324
	3-Engagement/1-Acceptable	0.581	0.621	0.199	0.814	0.344
	3-Engagement/2-Improved	1.112	1.291	0.687	1.792	0.049
ROA (%)	1-Participation/1-Acceptable	2.068	2.127	2.018	6.202	-0.383
	1-Participation/2-Improved	0.452	0.002	0.990	1.929	-0.127
	2-Involvement/1-Acceptable	2.495	2.354	1.167	4.513	0.313
	2-Involvement/2-Improved	12.659	13.306	4.170	18.344	7.228
	3-Engagement/1-Acceptable	0.502	0.457	1.795	3.110	-2.522
	3-Engagement/2-Improved	-1.571	-1.755	2.868	2.959	-7.151

Table 9. Descriptive statistics for annual aggregated financial ratios grouped by localism/smartness ratings

Using the mean of both ratios shown in Table 8, universities and municipal companies are the most efficient LEBs, where efficiency is measured through asset turnover ratio. Third sector and community interested companies are the least efficient. Moreover, municipal and community interested companies show the highest variability. In regards to profitability, private and community interested companies are the most profitable LEBs, though the latter group shows the highest variability, and third sector companies are the least profitable, with a low variability. Community interested companies and universities show the highest difference between the mean and median for efficiency and profitability, respectively. Table 9 shows that highly-local energy businesses (level *3-Engagement*) are the most efficient, although their results show a high degree of variability. Less local energy businesses (rated as *1-Participation/2-Improved* and *2-Involvement/1-Acceptable*) are the least efficient, showing a low variability in their results. LEBs which are "moderately-local" (level *2-Involvement*) are the most profitable ones, though involving more variability in results. Highly-local energy businesses (level *3-Engagement*) do not comparatively show an attractive profitability [9].

Tables 10 and 11 offer a summary of the above analysis.

	Assets	Turnover	Debt	Efficiency	Profitability
Private	+++++	£ +++++	Long-term debt low reliance	++	+++++
Municipal	+++	£ ++++	Long-term debt high reliance	++++	++
Third sector	++++	£ ++	Long-term debt high reliance	+	+
Universities	++	£ +++	Long-term debt low reliance	+++++	+++
Community interested	+	£ +	Short-term debt high reliance	+++	++++

Table 10. Summary of LEB assets, turnover, debt, efficiency, and profitability assessments by ownership, based on top-down approach (save for debt, a high number of "+" indicates high results)

[9] The differences between median and mean can be explained by the presence of outliers, as well as by the information limitations described in subsection 3.1, which can imply extreme values computed into some annual aggregated financial ratios.

	Assets	Turnover	Debt	Efficiency	Profitability
1-Participation/1-Acceptable	+++++	£+++++	Current and Long-term debt reliance	+++	++++
1-Participation/2-Improved	++	£++	Long-term debt high reliance	++	++
2-Involvement/1-Acceptable	++++++	£++++++	Current and Long-term debt reliance	++	+++++
2-Involvement/2-Improved	++++	£++++	Equity high reliance	++++	+++++++
3-Engagement/1-Acceptable	+++	£+++	Long-term debt high reliance	+++++	+++
3-Engagement/2-Improved	+	£+	Current debt high reliance	++++++	+

Table 11. Summary of LEB assets, turnover, debt, efficiency, and profitability assessments by localism/smartness ratings, based on top-down approach (save for debt, a high number of "+" indicates high results)

4.2. Bottom-up approach

For the cluster analysis, HAC with the complete-linkage criterion for Run-1 and PAM for Run-4 were the selected clustering methods. The median and mean are shown for each cluster to describe each solution (Tables 10 and 11) [10]. These results are compared to a benchmark, the cluster with the highest number of companies assessed with level *1-Participation* of localism: Cluster 1 for Run-1 and Cluster 5 for Run-4. Likewise, in Run-4, Cluster 2 was also selected as a benchmark for clusters 3 and 6 only, as these clusters group LEBs with the same level of localism (*2-Involvement*). To provide comprehensive comparisons, all results are shaded as follows: green represents a relatively better result than the one showed by the benchmark; orange represents a relatively worse result; and yellow represents a neutral result. Moreover, to see each cluster's shape under a reduced number of characteristics, t-SNE plots are also shown (Fig. 6). More details about the specific data considered for each case are provided in the supplementary material.

Table 12 shows that within Cluster 1 (benchmark), companies have liquid resources to pay their short-term liabilities, although they are significantly reliant on debt and are comparatively less efficient in generating income through their assets, but are highly profitable. When comparing Cluster 2 against the benchmark, LEBs present comparatively more liquid resources to cover current obligations, have less reliance on debt - some of them involving negative equity though -, and show a slightly higher efficient but a lower profitability. Cluster 3 compared to the benchmark has a higher capacity for paying current liabilities involving a higher availability of liquid resources and are efficient enough, though LEBs seem to rely more on debt and have a lower profitability. Compared to benchmark, Cluster 4, which can be seen as a cluster of outliers, has the most negligible proportion of liquid assets to cover short-term obligations and are the least profitable; a very high reliance on debt, also involving negative equity, is observed, although they look efficient enough to generate income. A more detailed description of each cluster, based on the LEBs characterisation revealed in [10], is provided in the supplementary material.

As shown in Table 13, within Cluster 5 (benchmark), LEBs have liquid assets to cover their current liabilities, though with a significant reliance on debt, and they are comparatively inefficient but profitable. Cluster 1, compared to benchmark, involves a higher availability of liquid resources to cover short-term obligations, and shows low dependence on debt, significant profitability, and one of the highest efficiencies. Cluster 4, when compared to benchmark, shows enough resources to cover current liabilities involving a marginally higher availability of liquid assets, relies a little bit less on debt, and presents less efficiency and profitability. Compared against benchmark, Cluster 2 presents a good proportion of assets available for paying current obligations, lower reliance on debt, slightly higher profitability, and one of the highest efficiencies. Compared to Cluster 2, LEBs within Cluster 3 show a very low proportion of liquid resources to pay current liabilities, depend more on debt, and are less efficient and profitable. Again, compared to Cluster 2, companies within Cluster 6 show a higher proportion of current assets, though involving a lower balance in bank accounts, rely less on debt, and are less efficient and profitable. A more detailed description of each cluster, based on the LEBs characterisation revealed in [10], is provided in the supplementary material.

Fig. 6 shows that most clusters are distinct from each other under both clustering methods and data treatment considered in this work, save Cluster 4 in Run-1, interpreted as a cluster of outliers, and Cluster 1 in Run-4, which is mostly formed by LEBs with level *1-Participation* of localism plus a few highly-local energy businesses (level *3-Engagement*). The figure gives insights into the appropriateness of the cluster analysis performed and its results.

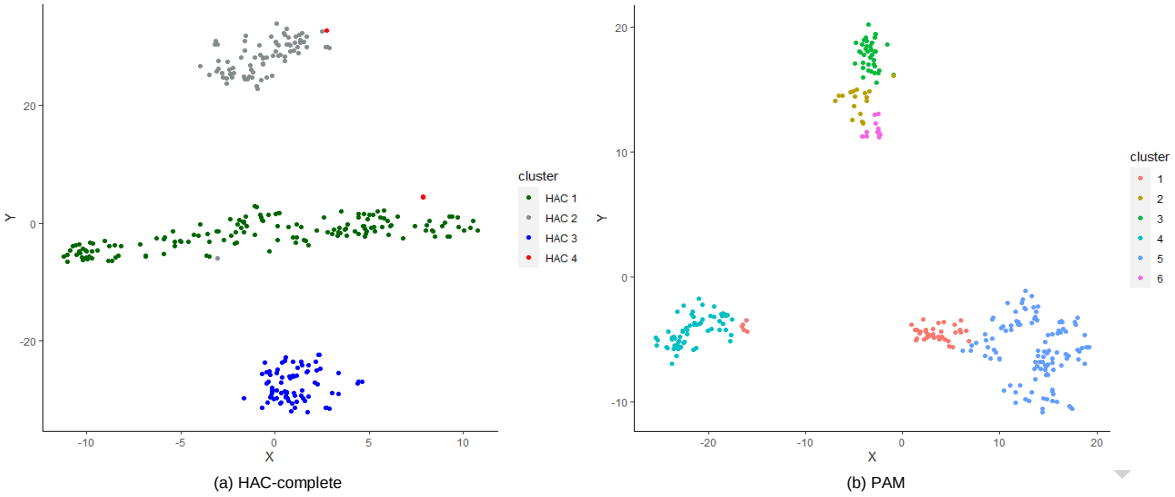
[10] We note that a comparison of the arithmetic means of log-transformed values (Run-4) is, in fact, a comparison of geometric means, as the anti-log of an arithmetic mean of log-transformed values is the geometric mean.

	N	Clusters	Levels of localism and number of companies		Current ratio 2018	Cash ratio 2018	Debt ratio 2018	Equity multiplier 2018	Debt to EBITDA 2018	Asset Turnover 2018	Net profit margin 2018	EBITDA margin 2018	ROA 2018	ROE 2018
Run-1 / HAC Complete	316	***C1***	***L1 - Participation = 154***	*Median*	***0.134***	***0.075***	***0.991***	***1.082***	***9.572***	***0.143***	***8.998***	***70.707***	***1.294***	***12.644***
				Mean	***1.837***	***0.824***	***0.833***	***26.737***	***13.234***	***0.217***	***7.904***	***62.321***	***2.695***	***149.206***
		C2	L1 - Participation = 1; L2 - Involvement = 81 (compared against C1)	*Median*	1.185	0.202	0.829	1.183	5.713	0.166	10.907	67.25	1.956	12.264
				Mean	8.287	2.766	0.705	-0.982	3.002	0.409	7.133	54.72	2.389	41.771
		C3	L3 - Engagement = 75 (compared against C1)	*Median*	0.926	0.429	0.974	1.019	11.959	0.116	-12.613	65.290	-1.735	21.198
				Mean	8.139	2.515	0.869	6.995	16.186	0.361	-18.003	51.840	-0.890	0.533
		C4	L1 - Participation = 4; L2 - Involvement = 1 (compared against C1)	*Median*	0.164	0.005	2.966	-0.509	-3.965	0.268	-254.600	-180.270	-94.850	48.240
				Mean	0.156	0.013	3.303	-0.526	3.261	0.297	-246.400	-126.700	-93.750	45.560

Table 12. Clusters determined through HAC with complete linkage criterion

	N	Clusters	Levels of localism and number of companies		Log Current ratio 2018	Log Cash ratio 2018	Log Debt ratio 2018	Log Equity multiplier 2018	Log Debt to EBITDA 2018	Log Asset Turnover 2018	Log EBITDA margin 2018	Log ROA 2018	Log ROE 2018
Run-4 / PAM	287	C1	L1 - Participation = 35; L3 - Engagement = 5 (compared against C5)	*Median*	0.767	0.499	0.053	2.981	2.353	0.094	2.717	2.146	3.514
				Mean	0.741	0.483	0.089	2.982	2.355	0.113	2.712	2.155	3.515
		C2	***L2 - Involvement = 20*** (compared against C5)	*Median*	***0.597***	***0.403***	***0.242***	***2.981***	***2.356***	***0.093***	***2.721***	***2.127***	***3.514***
				Mean	***0.617***	***0.369***	***0.229***	***2.980***	***2.356***	***0.114***	***2.696***	***2.145***	***3.515***
		C3	L2 - Involvement = 37 (compared against C2)	*Median*	0.070	0.011	0.297	2.981	2.369	0.060	2.716	2.125	3.515
				Mean	0.108	0.031	0.279	2.980	2.373	0.075	2.710	2.118	3.519
		C4	L3 - Engagement = 62 (compared against C5)	*Median*	0.274	0.152	0.300	2.981	2.375	0.047	2.717	2.116	3.515
				Mean	0.278	0.179	0.285	2.983	2.381	0.060	2.713	2.119	3.510
		C5	***L1 – Participation = 113***	*Median*	***0.044***	***0.025***	***0.306***	***2.977***	***2.372***	***0.053***	***2.720***	***2.122***	***3.514***
				Mean	***0.098***	***0.034***	***0.303***	***2.976***	***2.380***	***0.063***	***2.710***	***2.121***	***3.515***
		C6	L2 - Involvement = 15 (compared against C2)	*Median*	1.153	0.076	0.055	2.981	2.354	0.059	2.718	2.139	3.513
				Mean	1.092	0.222	0.053	2.981	2.354	0.073	2.717	2.139	3.513

Table 13. Clusters determined through PAM method



(a) HAC-complete (b) PAM

Fig. 6. t-SNE plots for clustering methods and solutions

Table 14 summarises the validation metrics (detailed in subsection 3.2) for Run-4, as the discriminant functions obtained in this case are the ones that best discriminate among groups; they have comparatively better validation metrics, therefore these discriminant functions are selected for analysis. Yet, when corroborating the assumption of homogeneity of covariance matrices, all cases showed significant results for Box's M Test - $p = 2.2e^{-16}$. However, this test is overly sensitive to departures from normality and to large samples [45,59]. Likewise, some authors [65] claim that MANOVA, the reverse process of and the basis for canonical discriminant analysis, is robust against the above issue when group sizes are over 30. The validation metrics for all runs of analysis, as well as the covariance matrices for Run-4, are supplied in the supplementary material.

	Discriminant Functions	Explained variance	Eigenvalues	Canonical correlation	Canonical R squared	Wilks Lambda	Aprox. F	Sig.
Run-4	1	74.322	0.179536	0.39014	0.152209	0.79827	3.6568	$6.458e^{-07}$
	2	25.678	0.062031	0.241677	0.058408	0.94159	2.1478	0.03171

Table 14. Discriminant functions and validation metrics for Run-4

Table 15 and Fig. 7 show how the above-mentioned discriminant functions discriminate among groups based on LEBs' degrees of localism. The standardised discriminant function coefficients for both discriminant functions, equivalent to the standardised *b*-values in a linear model, are shown in the first two columns of Table 12. The columns named "Structure matrix" show how each financial ratio contributes to group separation. By examining discriminant function "1", which mainly explains the variance (74.32%), we note that debt to EBITDA (0.454), debt ratio (0.439), and cash ratio (0.143) highly contribute to group separation when considering LEBs with levels *1-Participation* and *3-Engagement* of localism. Conversely, the current ratio (-0.461), asset turnover ratio (-0.287), and ROE (-0.228) highly contribute to group separation for LEBs with level *2-Involvement* of localism. These results can be seen in Fig. 7 through each vector's length. The corresponding centroids or class means, which can also be seen in Fig. 7 are 0.087 (LEBs with localism level *1-Participation*), -0.663 (for localism level *2-Involvement*), and 0.521 (for localism level *3-Engagement*).

	Standardised coefficients		Structure matrix	
Ratios/ DFNs	1	2	1	2
Log Current ratio 2018	-1.047	0.897	-0.461	0.687
Log Cash ratio 2018	1.237	0.408	0.143	0.609
Log Debt ratio 2018	0.209	0.598	0.439	-0.128
Log Equity multiplier 2018	0.047	0.275	0.049	0.320
Log Debt to EBITDA 2018	0.408	-0.002	0.454	-0.083
Log Asset Turnover 2018	-0.197	0.171	-0.287	0.108
Log EBITDA margin 2018	0.121	0.133	0.121	-0.033
Log ROA 2018	-0.046	-0.450	-0.156	-0.156
Log ROE 2018	-0.206	-0.225	-0.228	-0.215

Table 15. Standardised coefficients and structure matrix for Run-4 discriminant functions

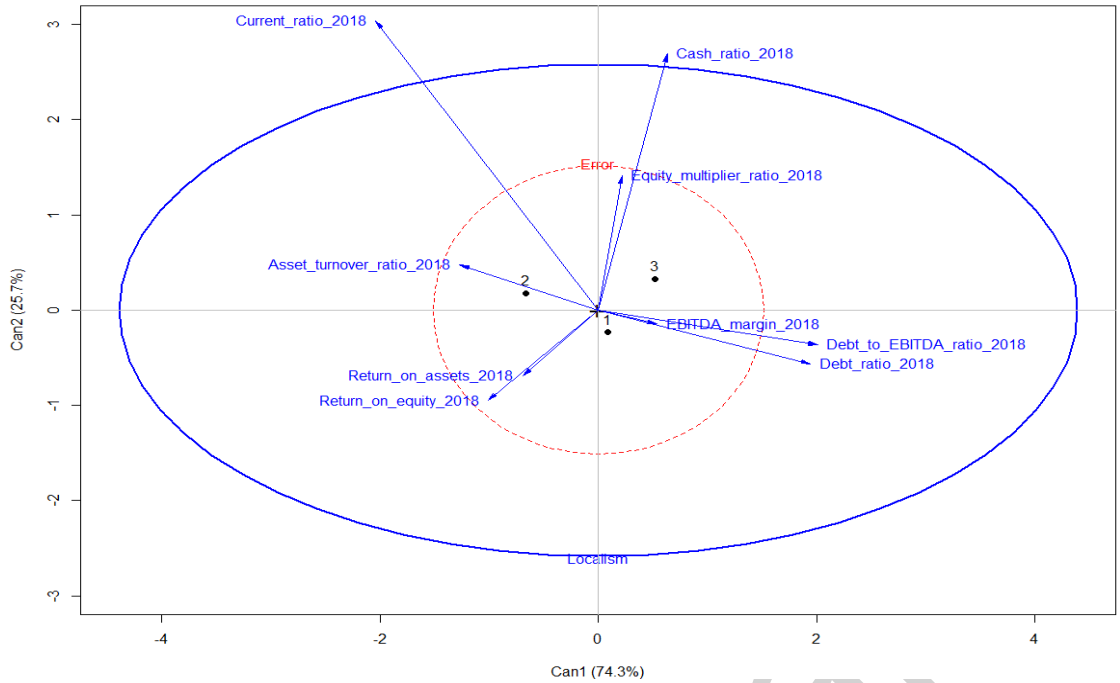


Fig. 7. Reduced-rank HE plots for Run-4 discriminant functions (variables are log-transformed)

The discriminant analysis then provides the following insights: on the one hand, highly-local (*level 3-Engagement*) alongside negligibly-local (*level 1-Participation*) energy businesses have comparatively higher debt and cash in the bank. This evidence therefore suggests that debt, and to some extent bank deposits, correlate more with the development of these LEBs. It also suggests that these LEBs are chiefly affected by the same financial factors, indicating further underlying commonalities not explored in this work. On the other hand, moderately-local energy businesses (level *2-Involvement*) are more efficient, profitable, and have more current assets than other LEBs.

5. Discussion

In relation to our first research question concerning the financial condition of the UK LEB sector, the top-down approach shows that universities, municipal, third sector, and community interested companies barely contribute to the aggregated assets and turnover of the sector, as evident when private LEBs, with low degrees of localism, are excluded from the analysis.

The financial state of some LEBs with high levels of localism may be comparatively unhealthy. For example, municipal companies show negative equity and high reliance on (long-term) debt. Likewise, third sector LEBs are comparatively inefficient in creating value, measured by turnover generation through assets, and appear to be less profitable than other businesses. A potential complication for third sector companies is their high reliance on (long-term) debt; however, no negative equity was found. This finding raises the question of whether this is due to assets producing less energy, charging lower energy prices, businesses' lifespan, other motivations when running businesses, or having more costly financial arrangements; we leave this question for further research.

If localism/smartness ratings are considered, LEBs with the highest level of localism (*3-Engagement*) and low levels of smartness (*1-Acceptable*), which include municipal and third sector LEBs, show a high reliance on long-term debt; conversely, highly-local energy businesses with higher levels of smartness (*2-Improved*) are associated with a higher reliance on current debt. However, regardless the level of smartness, these LEBs have low profitability, but are comparatively more efficient due to the financial performance of universities and municipal companies.

Depending on the specific type of company and localism/smartness ratings, some LEBs seem to have comparatively "healthier" finances, notably private negligibly- and moderately-local energy businesses (*1-Participation* and *2-Involvement*). However, detailed examination of key financial elements, such as terms and conditions of liabilities and other financial instruments, would be needed to understand the reasons for LEBs' current financial condition, which is beyond the insights provided by this paper.

To answer our second research question on financial commonalities of UK LEBs, the cluster analysis supports earlier estimates of LEBs' degrees of localism provided by [10]. Most clusters include LEBs not only according to their financial ratios, but also according to their degrees of localism. Therefore, our results suggest that such estimates have validity, although more quantitative analysis is needed to test consistency of results. The cluster analysis shows that it is possible to find financial commonalities across LEBs and that within a specific level of localism, such LEBs can show financial commonalities. These findings raise questions for further research about how well localism estimates can predict financial conditions.

As to the factors explaining the development of highly-local energy businesses, answering our third research question, the canonical discriminant analysis suggests that financial ratios related to debt, and to some degree to bank deposits, are essential when discriminating between LEBs within level 3 of localism (*Engagement*). This finding supports the claim that most of these highly-local energy businesses need to rely significantly on (long-term) debt to run their businesses, which has been highlighted in [46]. The relevance of bank deposits may be explained by money available to pay debt obligations and operational expenses, which may be especially relevant for private LEBs with limited local commitment (localism level *1-Participation*). Such private companies, which sometimes involve several revenue sources and technologies, were discriminated together with highly-local energy businesses. More evidence is needed to explore the specifics of LEBs' financing, including terms and conditions of debt, the role of equity instruments, and more innovative financial instruments (e.g. securitisation), among others.

State-of-the-art evidence [66-69], mainly focused on operations and patents, is not yet conclusive on the relationship between good financial performance (measured through financial ratios) and innovation, nor on the specific financial factors that may account for such patterns. Yet, some conjectures can be provided as an answer to our final research question. The 'going concern' principle suggests that any company should find the most appropriate ways to deliver their products or services to the market to keep producing income. Such income (after expenses) may be allocated to reinvestments or benefiting shareholders (and/or stakeholders). Financial health combined with innovation, for example through digitalisation, may help LEBs to get smarter (if desired) and then increase or strengthen their revenue sources, which may thus lead to more value creation. However, getting smarter may take particularly longer for highly-local energy businesses. Financing involving appropriate terms and conditions, effective business administration, public policies that support decentralisation, among other factors, can accelerate a transition towards smarter local energy businesses.

It is important to assure LEBs a good access to suitable financing and levels of investment, which seems especially relevant for highly-local energy businesses. The state-of-the-art literature explores different options to consider. For example, collaterals and covenants [70] can help cover risks and improve debt affordability. Partnerships in exachange for (some) property or stake in revenues [18,21], as well as pro-poor-public-private-partnerships (5P) [71,72] could incentivise private investments in deprived places without affecting local stake. Corporate structures based on Special Purpose Vehicles (SPVs) can facilitate: transfers of liabilities to other related entities [22], investment costs coverage, funding availability [73], revolving funds collection and usage [26], and securitisation of small energy assets [15,25,26]. Hybrid corporate structures (e.g. close-end funds and consumer stock ownership plans) [20,74-76], which simultaneously exploit legal and economic features of profit and non-profit companies, and third-party-on-site installations (potentially involving leaseback) [21,77], could be options for more deprived investors to participate in energy projects.

Based on the content shown above, some policy-relevant recommendations are given as follows:

1. To inform policy to support development of the sector, it is necessary to implement a standardised disclosure regime, considering not only digitised financial information, but digitised information on business aspects, such as energy technologies, installed capacity, benefits provisions and beneficiaries, number of customers and employees, etc.
2. To assure appropriate access to financing and levels of investment, an adequate policy framework needs to consider the promotion of diverse financial mechanisms designed to the potential needs of LEBs, such as refinancing, working capital, long-term (re-)investments, etc. Apart from the mechanisms shown in the above paragraph, other instruments like long-term loans, bonds or debentures, mezzanine debt, among others, could also help improve access to financial resources.
3. If private investment is not enough, an adequate policy framework needs to consider the provision of financial aid guaranteed mechanisms or monetary incentives to exclusively boost investments in digital technologies. To focus and optimise public funding commitment, such mechanisms should consider degrees of localism, business plans, and projected cash flows.

We recognise that there are factors not accounted for in this work. One example is LEBs' explicit position on profit maximisation and delivery of benefits locally or income generatation "only" to survive and deliver value locally (not-for-profit organisations). Another example is how LEBs' installations location relates to value creation and delivery to localities[11]; this relationship should be clarified through a detailed survey, involving a representative sample of LEBs, alongside econometric techniques. The ambiguous evidence on debt and financing terms and conditions is also an example. This work offers insights into the UK LEB sector's financial condition without delving into the specific reasons; interviewing LEBs managers and examining and comparing financing information could help understand such reasons.

6. Conclusion

This paper provides a financial characterisation of UK LEBs based on two approaches, top-down through descriptive statistics and bottom-up through cluster analysis and canonical discriminant analysis; their rationale is as follows. Firstly, there is limited existing evidence about the financial condition of the sector. Secondly, the heterogeneity of companies, data limitations, and opportunities for managing and reducing bias.

Highly-local energy businesses make a small contribution to the sector's finances and show high reliance on debt and low profitability. Additionally, there are financial commonalities across different sub-groups of LEBs, which seem to correlate with localism estimates. Leveraging innovation through digitalisation may help strengthen LEBs value creation. Although some groups of LEBs appear to be financially more robust than others, more information is needed to identify the specific reasons.

The evidence presented here enriches the ongoing discussion about prospects for local, smart energy systems. This work can help interested parties to better understand financial dynamics and needs, with the aim of promoting adequate policies, incentives, and investments (re-)allocations for continuous and sustainable sectoral growth. We encourage further research on the emerging UK LEB sector, particularly in regards to quantitative and qualitative assessments of localism, business investability, financing terms and conditions, and geographical aspects of value creation and benefits for localities.

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[11] Although it is not necessarily related to LEBs' installations location, the registered office location of LEBs is detailed in the supplementary material for informative purposes.

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Local energy businesses in the United Kingdom: clusters and localism determinants based on financial ratios - Supplementary Material

1. Companies considered for performing Top-Down approach

Years	Total Number of LEBs	Municipal	Private	Third sector	Universities	Community interested
2010	168	5	124	32	7	0
2011	213	6	159	41	7	0
2012	259	6	200	42	7	4
2013	309	6	242	49	7	5
2014	374	6	304	49	7	8
2015	478	8	386	59	8	17
2016	568	10	435	81	8	34
2017	608	14	462	86	8	38
2018	601	14	447	92	8	40

Years	Total Number of LEBs	Participation / Acceptable	Participation / Improved	Involvement / Acceptable	Involvement / Improved	Engagement / Acceptable	Engagement / Improved
2010	168	27	0	91	3	46	1
2011	213	36	0	115	3	58	1
2012	259	59	0	132	3	64	1
2013	309	81	0	151	4	72	1
2014	374	117	0	178	4	74	1
2015	478	156	4	211	4	102	1
2016	568	190	5	224	5	142	2
2017	608	205	10	228	5	158	2
2018	601	205	12	211	4	167	2

2. Statistical details for continuous variables considered in Bottom-up approach

Run-1

	n	mean	sd	median	min	max	range	skew	kurtosis
Current ratio 2018	316	4.98	23.99	0.53	0.03	334.04	334.01	10.26	122.09
Cash ratio 2018	316	1.72	9.47	0.12	0	136.25	136.25	11.19	140.69
Debt ratio 2018	316	0.85	0.51	0.98	0	4.89	4.89	2.2	15.6
Equity multiplier ratio 2018	316	14.43	233.91	1.11	-954.13	3141.92	4096.06	10.46	130.45
Debt to EBITDA ratio 2018	316	11.12	29.17	9.25	-223.47	183.64	407.1	-0.78	36.15
Asset turnover ratio 2018	316	0.3	0.63	0.14	0.02	5.64	5.62	5.98	40.23
Net profit margin 2018	316	-2.47	56.51	3.72	-633.33	94.83	728.16	-5.84	53.68
EBITDA margin 2018	316	54.87	53.85	67	-452.38	446.59	898.97	-2.84	37.32
Return on assets 2018	316	0.24	16.5	0.6	-131.65	87.75	219.4	-3.07	25.63
Return on equity 2018	316	84.4	1417.88	15.55	-3250	24792.31	28042.31	16.69	288.93

Run-2

	n	mean	sd	median	min	max	range	skew	kurtosis
Current ratio 2018	287	2.48	5.15	0.43	0.03	32.96	32.93	3.71	15.24
Cash ratio 2018	287	0.91	2.4	0.12	0	21.15	21.15	5.81	39.76
Debt ratio 2018	287	0.81	0.38	0.97	0.01	1.87	1.86	-0.81	-0.36
Equity multiplier ratio 2018	287	0.77	58.66	1.15	-491.22	465.75	956.97	0.14	33.22
Debt to EBITDA ratio 2018	287	10.45	10.56	9.57	-67.48	63.54	131.02	0.17	13.81
Asset turnover ratio 2018	287	0.22	0.27	0.14	0.02	2.25	2.23	5.27	32.18
Net profit margin 2018	287	3.91	29.6	4.62	-111.53	68.25	179.78	-0.48	0.94
EBITDA margin 2018	287	61.76	24.67	69.09	-69.49	163.57	233.06	-1.11	4.29
Return on assets 2018	287	1.88	7.44	0.82	-51.75	29.16	80.91	-0.65	10.29
Return on equity 2018	287	19.9	137.13	15.18	-1708.33	531.78	2240.12	-7.07	89.35

Run-3

	n	mean	sd	median	min	max	range	skew	kurtosis
Log Current ratio 2018	316	0.36	0.42	0.18	0.01	2.53	2.51	1.92	4.59
Log Cash ratio 2018	316	0.19	0.3	0.05	0	2.14	2.14	3.04	12.41
Log Debt ratio 2018	316	0.25	0.12	0.3	0	0.77	0.77	-0.27	1.49
Log Equity multiplier ratio 2018	316	2.97	0.18	2.98	0	3.61	3.61	-14.93	253.54
Log Debt to EBITDA ratio 2018	316	2.36	0.17	2.37	0	2.61	2.61	-12.03	154.08
Log Asset turnover ratio 2018	316	0.09	0.11	0.06	0.01	0.82	0.81	4.16	19.48
Log Net profit margin 2018	316	2.79	0.16	2.8	0	2.86	2.86	-16.4	279.97
Log EBITDA margin 2018	316	2.7	0.16	2.72	0	2.95	2.95	-15.68	262.94
Log Return on assets 2018	316	2.11	0.14	2.12	0	2.34	2.34	-12.48	184.45
Log Return on equity 2018	316	3.51	0.21	3.51	0	4.45	4.45	-15.02	256.56

Run-4

	n	mean	sd	median	min	max	range	skew	kurtosis
Log Current ratio 2018	287	0.32	0.34	0.15	0.01	1.52	1.51	1.23	0.78
Log Cash ratio 2018	287	0.16	0.21	0.05	0	1.02	1.02	1.61	2.06
Log Debt ratio 2018	287	0.25	0.1	0.3	0.01	0.49	0.48	-1.04	-0.09
Log Equity multiplier ratio 2018	287	2.98	0.03	2.98	2.67	3.15	0.49	-3.72	54.72
Log Debt to EBITDA ratio 2018	287	2.37	0.03	2.37	2.2	2.61	0.41	3.56	33.26
Log Asset turnover ratio 2018	287	0.08	0.05	0.06	0.01	0.42	0.41	3.02	12.73
Log Net profit margin 2018	287	2.8	0.02	2.8	2.58	2.86	0.28	-2.85	22.71
Log EBITDA margin 2018	287	2.71	0.04	2.72	2.4	2.95	0.56	-3.09	38.52
Log Return on assets 2018	287	2.13	0.03	2.12	1.87	2.34	0.48	-0.95	26.71
Log Return on equity 2018	287	3.51	0.02	3.51	3.19	3.58	0.39	-10.21	141.77

3. Bottom-up validation metrics for each case and clustering method

		PAM	HAC	k-prototypes	DBSCAN
Run-1	WSS	0.483	0.437	0.429	0.868
	Silhouette	0.715	0.719	0.669	0.681
	Selected method		X		
	# Clusters		4		
	N		316		
	Clusters structure		C1=154, C2=82, C3=75, C4=5; with CCC=0.827 (complete)		
Run-2	WSS	1.364	1.193	3.580	3.327
	Silhouette	0.551	0.518	-0.113	-0.152
Run-3	WSS	0.930	0.734	1.672	2.273
	Silhouette	0.638	0.585	0.088	0.299
Run-4	WSS	0.999	1.075	1.770	4.065
	Silhouette	0.533	0.495	0.351	-0.191
	Selected method	X			
	# Clusters	6			
	N	287			
	Clusters structure	C1=40, C2=20, C3=37, C4=62, C5=113, C6=15			

4. Detailed descriptions of clusters based on Fuentes González et al. [10]

Run-1 / HAC Complete

N	Clusters	Levels of localism and companies	Cluster description - based on Fuentes González et al. [10] -
316	C1	L1 - Participation = 154	Private companies chiefly owning small/medium-scale businesses, which mostly rely on solar PV (96 companies), onshore wind (29), biogas (14), CHP (11), and storage (6) technologies. Circa 5% manage two or more technologies. The majority (86) only have one revenue source, being "selling electricity to the grid" their prevailing source (67) followed by "PPAs" (14). None or limited available information on direct benefits to communities is found.
	C2	L1 - Participation = 1; L2 - Involvement = 81	Private companies owning typically small/medium businesses (59), which mostly relay on onshore wind (50), solar PV (11), waste-to-energy (6), biogas (4), CHP (3), storage (3), offshore wind (2), and pumped storage (1) technologies. Circa 4% manage two technologies. Most of companies have two or more revenue sources (55), "selling electricity to the grid" (51) and "ROCs" (34) being their most prevalent sources; it is also possible to find cases with income derived from "feed-in-tariffs" (6) and "RHI" (1). Available information on benefits provision to communities was found for 39 companies.
	C3	L3 - Engagement = 75	A mix of university, municipal, third sector, and community interested companies (92%). Most of companies rely on solar PV (63%), onshore wind (16%), CHP (13%), and hydro (12%) technologies; there are companies (8) exploiting more than one technology. Almost 89% of companies show available information on - or are assumed to provide - benefits to communities. More than a half of companies (50) only have one revenue source, being the most prevalent "selling electricity to the grid" (33) and "heat and power services" (9). "Feed-in-tariffs" can be found in most of cases with more than one revenue source (22).
	C4	L1 - Participation = 4; L2 - Involvement = 1	Private biogas-based companies (4) - plus one electricity supplier for EVs – chiefly involved in waste management, heat and power services, and biofertiliser production. No company has available information on direct benefits provision to communities.

Run-4 / PAM

N	Clusters	Levels of localism and companies	Cluster description - based on Fuentes González et al. [10] -
287	C1	L1 - Participation = 35; L3 - Engagement = 5	Mostly private companies (88%), with a small proportion of third sector entities (10%) and one university, comprising micro, small, and medium businesses (63%). Businesses typically rely on onshore wind (21), solar PV (6), biogas (4), CHP (4), Hydro (3), offshore wind (3), storage (2), biomass (1), and waste-to-energy (1) technologies. Most of companies manage only one technology (36). Circa 50% of companies have more than one revenue source (18). The most recurrent energy sources for all companies are "selling electricity to the grid" (20), "PPA" (17), and "feed-in-tariff" (7). Only four companies have available information on - or are assumed to provide - benefits to communities.
	C2	L2 - Involvement = 20	Private companies, typically large and medium (16), with circa a half of them (13) having available information on - or are assumed to provide - benefits to communities, which mainly rely on onshore wind (9), waste-to-energy (4), and biogas (2); the remainder invest in CHP, solar PV, and offshore wind technologies. These companies mostly have more than one revenue source (17), being "Selling electricity to the grid" (15), "ROC" (7), and "waste management" (5) the recurrent sources.
	C3	L2 - Involvement = 37	Private companies, mostly small and medium (81%), predominantly with available information on - or are assumed to provide - benefits to communities (51%), which chiefly rely on onshore wind (23), solar PV (9), and storage (3) technologies; the remainder relies on biogas, CHP, and offshore wind technologies. Most of companies (33) manage only one technology. Circa 50% of companies have more than one revenue source. At a general level, the most prevalent sources are "selling electricity to the grid" (35) and "ROC" (12).
	C4	L3 - Engagement = 62	A mix of university, municipal, third sector, and community interested companies (92%). A majority (56) are small and medium businesses, and a number of 57 companies have available information on - or are assumed to provide - benefits to communities. Most of companies rely on solar PV (45), onshore wind (8), CHP (8), and hydro (5) technologies; some companies (6) exploit more than one technology. The remainder of technologies involves biomass, diesel, EVs, storage, waste-to-energy, electrolyser, and fuel cells. A majority (43) of companies have only one revenue source being "selling electricity to the grid" (32) and "heat and power services" (8) the recurrent sources. "Feed-in-tariffs" (18) can be found within those companies with more than one revenue source.
	C5	L1 – Participation = 113	Private companies predominantly owning small/medium-scale businesses (101), mostly managing only one technology (107) and relying on solar PV (89), biogas (11), onshore wind (7), CHP (6), and storage (4) technologies. The majority (64) only have one revenue source, being "selling electricity to the grid" their prevailing source (58). None or limited available information on direct benefits to communities is observed.
	C6	L2 - Involvement = 15	Mostly small/medium private companies (12), with a third of them (5 out of 15 companies) having available information on - or assumed to provide - benefits to communities, which mainly rely on onshore wind (14 out of 15 companies) technologies – plus one business based on pumped storage -. Their revenue sources are "selling electricity to the grid" (15), "ROCs" (13), and income from touristic services (pumped storage-based project).

5. Discriminant functions and validation metrics for each case

	Discriminant Functions	Explained variance	Eigenvalues	Canonical correlation	Canonical R squared	Wilks Lambda	Aprox. F	Sig.
Run-1	1	60.464	0.080040	0.27223	0.074109	0.87984	2.0094	0.005797
	2	39.536	0.052336	0.223009	0.049733	0.95027	1.7736	0.072601
Run-2	1	76.43	0.153692	0.36499	0.133218	0.82756	3.0440	$2.634e^{-05}$
	2	23.57	0.047397	0.212728	0.045253	0.95475	1.6411	0.113
Run-3	1	66.549	0.109362	0.313976	0.098581	0.85445	2.7729	0.000123
	2	33.451	0.054971	0.22827	0.052107	0.94789	2.1026	0.035339
Run-4	1	74.322	0.179536	0.39014	0.152209	0.79827	3.6568	$6.458e^{-07}$
	2	25.678	0.062031	0.241677	0.058408	0.94159	2.1478	0.03171

6. Covariance matrices for Run-4

Localism: 1	Log Current ratio 2018	Log Cash ratio 2018	Log Debt ratio 2018	Log Equity multiplier ratio 2018	Log Debt to EBITDA ratio 2018	Log Asset turnover ratio 2018	Log EBITDA margin 2018	Log Return on assets 2018	Log Return on equity 2018
Log Current ratio 2018	0.100027	0.059161	- 0.025614	0.001059	- 0.002622	0.006059	0.000264	0.003722	0.000250
Log Cash ratio 2018	0.059161	0.045870	- 0.016889	0.000464	- 0.001946	0.003340	0.000942	0.002982	0.000099
Log Debt ratio 2018	- 0.025614	- 0.016889	0.010984	- 0.000226	0.001172	- 0.001460	- 0.000623	- 0.001735	0.000050
Log Equity multiplier ratio 2018	0.001059	0.000464	- 0.000226	0.001231	- 0.000017	0.000100	- 0.000015	0.000046	0.000167
Log Debt to EBITDA ratio 2018	- 0.002622	- 0.001946	0.001172	- 0.000017	0.000860	- 0.000175	- 0.000222	- 0.000252	- 0.000036
Log Asset turnover ratio 2018	0.006059	0.003340	- 0.001460	0.000100	- 0.000175	0.001556	- 0.000230	0.000434	0.000088
Log EBITDA margin 2018	0.000264	0.000942	- 0.000623	- 0.000015	- 0.000222	- 0.000230	0.000806	0.000593	- 0.000014
Log Return on assets 2018	0.003722	0.002982	- 0.001735	0.000046	- 0.000252	0.000434	0.000593	0.000912	- 0.000005
Log Return on equity 2018	0.000250	0.000099	0.000050	0.000167	- 0.000036	0.000088	- 0.000014	- 0.000005	0.000223

Localism: 2	Log Current ratio 2018	Log Cash ratio 2018	Log Debt ratio 2018	Log Equity multiplier ratio 2018	Log Debt to EBITDA ratio 2018	Log Asset turnover ratio 2018	Log EBITDA margin 2018	Log Return on assets 2018	Log Return on equity 2018
Log Current ratio 2018	0.191731	0.046823	- 0.030997	- 0.000568	- 0.003608	0.000020	0.001990	0.004585	- 0.000930
Log Cash ratio 2018	0.046823	0.043943	- 0.005467	- 0.000212	- 0.002046	0.002265	0.000217	0.002721	- 0.000155
Log Debt ratio 2018	- 0.030997	- 0.005467	0.012103	- 0.000101	0.000933	- 0.000759	- 0.000130	- 0.001720	0.000262
Log Equity multiplier ratio 2018	- 0.000568	- 0.000212	- 0.000101	0.000180	0.000035	0.000114	0.000087	0.000051	0.000008
Log Debt to EBITDA ratio 2018	- 0.003608	- 0.002046	0.000933	0.000035	0.000627	0.000049	0.000295	- 0.000156	0.000031
Log Asset turnover ratio 2018	0.000020	0.002265	- 0.000759	0.000114	0.000049	0.004789	- 0.000563	0.001080	0.000097
Log EBITDA margin 2018	0.001990	0.000217	- 0.000130	0.000087	0.000295	- 0.000563	0.002197	0.000416	- 0.000036
Log Return on assets 2018	0.004585	0.002721	- 0.001720	0.000051	- 0.000156	0.001080	0.000416	0.001811	- 0.000009
Log Return on equity 2018	- 0.000930	- 0.000155	0.000262	0.000008	0.000031	0.000097	- 0.000036	- 0.000009	0.000128

Localism: 3	Log Current ratio 2018	Log Cash ratio 2018	Log Debt ratio 2018	Log Equity multiplier ratio 2018	Log Debt to EBITDA ratio 2018	Log Asset turnover ratio 2018	Log EBITDA margin 2018	Log Return on assets 2018	Log Return on equity 2018
Log Current ratio 2018	0.054475	0.042215	- 0.011452	- 0.000509	- 0.001303	0.005462	- 0.000659	0.002882	0.001286
Log Cash ratio 2018	0.042215	0.037096	- 0.010531	- 0.000350	- 0.001009	0.004260	- 0.000920	0.002267	0.000884
Log Debt ratio 2018	- 0.011452	- 0.010531	0.007269	0.000004	0.000848	- 0.002905	0.000570	- 0.001384	- 0.000104
Log Equity multiplier ratio 2018	- 0.000509	- 0.000350	0.000004	0.000606	- 0.000078	- 0.000058	0.000079	- 0.000002	- 0.000843
Log Debt to EBITDA ratio 2018	- 0.001303	- 0.001009	0.000848	- 0.000078	0.001033	- 0.000509	- 0.000284	- 0.000217	- 0.000021
Log Asset turnover ratio 2018	0.005462	0.004260	- 0.002905	- 0.000058	- 0.000509	0.003464	- 0.000598	0.001148	0.000193
Log EBITDA margin 2018	- 0.000659	- 0.000920	0.000570	0.000079	- 0.000284	- 0.000598	0.001319	0.000081	- 0.000043
Log Return on assets 2018	0.002882	0.002267	- 0.001384	- 0.000002	- 0.000217	0.001148	0.000081	0.000819	0.000093
Log Return on equity 2018	0.001286	0.000884	- 0.000104	- 0.000843	- 0.000021	0.000193	- 0.000043	0.000093	0.001616

7. LEBs' registered offices per location considered in top-down approach (N_{2018} = 601)

England			**421**	**Scotland**			**151**
March	1	Lewes	1	Aberdeen	5	Isle Of Mull	2
Andover	1	Liverpool	7	Acharacle	1	Isle Of South Uist	1
Barking	1	London	194	Alloa	3	Keith	1
Basingstoke	1	Lydney	1	Anstruther	1	Kinross	1
Bedford	9	Maidenhead	1	Ardgay	2	Kirkwall	3
Belper	4	Manchester	4	Balerno	1	Kirriemuir	1
Berwick-Upon-Tweed	1	Market Harborough	1	Ballygrant	1	Lanark	1
Birmingham	1	Milton Keynes	11	Banff	3	Laurencekirk	1
Bishop Auckland	1	Moreton-In-Marsh	3	Blairgowrie	1	Lerwick	1
Blackburn	5	Morpeth	1	Bowmore	1	Lochailort	1
Blackpool	2	Newcastle Upon Tyne	2	Brechin	1	Lochearnhead	1
Bognor Regis	2	Newport	1	Bridgend	1	Lochgelly	1
Bournemouth	1	Newton Aycliffe	1	Cairndow	1	Lochgilphead	3
Bridgwater	1	Norwich	1	Callander	1	Lockerbie	1
Bristol	5	Nottingham	4	Carluke	1	Mallaig	2
Bury St Edmunds	1	Oxford	2	Dumfries	3	Muir Of Ord	1
Chesham	1	Penryn	8	Dunbeath	1	Oban	2
Chester	1	Penzance	4	Dundee	2	Orkney	7
Chichester	1	Plymouth	1	Dunkeld	1	Perth	5
Chippenham	3	Radstock	5	Edinburgh	34	Peterhead	1
Christchurch	1	Reading	8	Ellon	1	Pitlochry	1
Colne	1	Rickmansworth	3	Forfar	2	Port Glasgow	1
Corsham	1	Runcorn	1	Fort William	1	Scarinish	1
Coventry	10	Sandy	1	Glasgow	9	Shetland	1
Crook	1	Scarborough	1	Glenrothes	1	St Andrews	1
Derby	2	Scunthorpe	1	Huntly	1	Stonehaven	1
Devizes	1	Shrewsbury	1	Inverness	4	Stornoway	2
Dorchester	1	Sittingbourne	1	Inverurie	2	Strathpeffer	1
Driffield	1	Stafford	1	Isle Of Barra	1	Stromness	2
Durham	10	Staines	1	Isle Of Coll	1	Tarbert	1
Ely	1	Stockport	1	Isle Of Eigg	1	Taynuilt	1
Evesham	2	Stroud	19	Isle Of Gigha	2	Tighnabruaich	1
Exeter	4	Swanley	5	Isle of Harris	2	Turriff	4
Gateshead	1	Swindon	9	Isle Of Lewis	3		
Goole	1	Towcester	1				
Grange-Over-Sands	1	Truro	3				
Grimsby	1	Uxbridge	1				
Guildford	11	Wallingford	1				
Keighley	1	Warminster	1				
Kings Langley	2	Warwick	1				
Lancaster	1	Wolverhampton	1				
Leighton Buzzard	1	York	7				

Wales	**12**	**Northern Ireland**	**17**
Brecon	1	Belfast	12
Cardiff	1	Maghera	2
Colwyn Bay	1	Omagh	3
Crickhowell	2		
Haverfordwest	1		
Lampeter	1		
Mold	1		
Ruthin	2		
Swansea	2		

8. LEBs' registered offices per location considered in bottom-up approach – Run-1 (N = 316)

Cluster 1	**154**
England	142
Northern Ireland	5
Scotland	5
Wales	2
Cluster 2	**82**
England	77
Scotland	5
Cluster 3	**75**
England	56
Scotland	17
Wales	2
Cluster 4	**5**
England	5

Cluster 1	**154**
Bedford	1
Belfast	5
Birmingham	1
Chippenham	1
Christchurch	1
Colwyn Bay	1
Edinburgh	3
Glasgow	2
Guildford	11
Kings Langley	1
Liverpool	1
London	107
Milton Keynes	9
Reading	2
Ruthin	1
Sittingbourne	1
Swanley	3
Swindon	1
Towcester	1
Wallingford	1

Cluster 2	**82**
Alloa	1
Bedford	1
Blackburn	2
Bournemouth	1
Bridgend	1
Chippenham	2
Coventry	4
Durham	7
Edinburgh	2
Evesham	1
Exeter	3
Glasgow	1
Kings Langley	1
London	19
Maidenhead	1
Manchester	3
Milton Keynes	1
Penzance	4
Reading	1
Runcorn	1
Staines	1
Stockport	1
Stroud	17
Swindon	4
Truro	2

Cluster 3	**75**
Acharacle	1
Bowmore	1
Bristol	1
Corsham	1
Coventry	1
Crickhowell	2
Crook	1
Dundee	1
Edinburgh	3
Glasgow	2
Huntly	1
Inverness	1
Isle Of Eigg	1
Isle Of Lewis	1
Isle Of Mull	1
Lancaster	1
Lewes	1
Liverpool	1
Lochgelly	1
Lochgilphead	1
London	33
Manchester	1
Newport	1
Nottingham	2
Penryn	7
Port Glasgow	1
Scarborough	1
Swindon	1
Taynuilt	1
Truro	1
Warwick	1
York	1

Cluster 4	**5**
Bedford	4
Stroud	1

9. LEBs' registered offices per location considered in bottom-up approach – Run-4 (N = 287)

Cluster 1	**40**
England	27
Northern Ireland	5
Scotland	7
Wales	1
Cluster 2	**20**
England	19
Scotland	1
Cluster 3	**37**
England	36
Scotland	1
Cluster 4	**62**
England	50
Scotland	10
Wales	2
Cluster 5	**113**
England	110
Scotland	2
Wales	1
Cluster 6	**15**
England	15

Cluster 1	**40**	**Cluster 2**	**20**	**Cluster 3**	**37**	**Cluster 4**	**62**	**Cluster 5**	**113**	**Cluster 6**	**15**
Acharacle	1	Bedford	1	Bridgend	1	Corsham	1	Bedford	2	London	1
Belfast	5	Chippenham	1	Chippenham	1	Coventry	1	Birmingham	1	Manchester	1
Bowmore	1	Coventry	1	Coventry	3	Crickhowell	2	Christchurch	1	Penzance	1
Colwyn Bay	1	Edinburgh	1	Durham	7	Crook	1	Edinburgh	2	Stroud	10
Edinburgh	1	Exeter	3	Kings Langley	1	Dundee	1	Guildford	8	Swindon	2
Glasgow	2	London	6	London	10	Edinburgh	3	Kings Langley	1		
Guildford	3	Maidenhead	1	Manchester	2	Huntly	1	Liverpool	1		
Isle Of Mull	1	Penzance	2	Milton Keynes	1	Inverness	1	London	82		
London	20	Runcorn	1	Penzance	1	Isle Of Eigg	1	Milton Keynes	9		
Reading	1	Staines	1	Reading	1	Lewes	1	Reading	1		
Swanley	2	Swindon	2	Stockport	1	Liverpool	1	Ruthin	1		
Taynuilt	1			Stroud	6	Lochgelly	1	Sittingbourne	1		
Wallingford	1			Truro	2	Lochgilphead	1	Swanley	1		
						London	32	Swindon	1		
						Manchester	1	Towcester	1		
						Newport	1				
						Penryn	7				
						Port Glasgow	1				
						Scarborough	1				
						Swindon	1				
						Truro	1				
						York	1				