Business Models and Financial Characteristics of Community Energy in the UK. Manuscript ref NENERGY-19050867

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Abstract

Community energy projects take a decentralised and participatory approach to low-carbon energy. We present a quantitative analysis of business models, financing mechanisms and financial performance of UK community energy projects, based on a new survey. We find that business models depend on technology, project size, and fine-tuning of operations to local contexts. While larger projects rely more on loans, community shares are the most common and cheapest financial instrument in the sector. Community energy has pioneered low-cost citizen finance for renewables, but its future is threatened by reductions, and instability, in policy support. Over 90% of the projects in our sample make a financial surplus during our single-year snapshot, but this falls to just 20% if we remove income from price guarantee mechanisms, such as the Feed-in Tariff. Renewed support and/or business model innovations are therefore needed for the sector to realise its potential contribution to the low-carbon energy transition.

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Main

Local energy projects delivered by community groups could potentially play a pivotal role in realising the transition to a low-carbon energy future. Community energy schemes offer an alternative to large-scale energy provision, with various forms of community energy already found across Europe, North America and elsewhere[1-5]. In the UK, the term "community energy" is generally associated with small civil society organisations and/or social enterprises running projects that encourage energy saving and efficiency, or that generate renewable electricity. These projects are typically grounded in the motivation to accelerate decarbonisation through both decentralisation *and* democratisation of the energy system, and address issues such as fuel poverty and energy justice[6-11].

The growth of the sector in the UK has been driven by a combination of the decreasing cost of renewable energy technologies and government policies (see Table 1)[1, 4]. However, more recently government support for small scale renewables has been substantially scaled back[1, 12]. Most notably, Feed-in Tariff rates fell more than 50% from 2015 to 2016 for many technologies (see Supplementary Table 2), and the scheme is now closed to new projects. In this challenging low-subsidy environment, project development and investment has slowed significantly[13].

TABLE 1 ABOUT HERE

These recent developments emphasise the importance of understanding how the community energy sector is financed. However, there is currently very limited empirical evidence on the financing of community energy activities [6, 14] Studies in Germany and Belgium note the mixture of motivations reported by citizens investing in community energy[15, 16];further studies in Germany note the substantial size of the renewable energy cooperative sector there[17], and its success in raising finance from cooperative members[18]. Much of the literature on the UK community energy sector focusses on the qualitative exploration of the definitions, motivations and challenges for projects, and how they engage with questions of justice and poverty[6-8, 10, 11, 19-27]. Nevertheless, some studies have examined the sector's finance and business models[9, 13, 28-33]. In particular, sector-wide surveys have played an important role in establishing the size and structure of the sector, gathering some data on finance; however, these surveys do not offer project-level analysis on financial performance[9, 13, 33]. A government-convened working group on Community Energy Finance offered insight into difficulties faced by community projects, but did not present an analysis of empirical data[29]. We are only aware of one previous quantitative study of community energy business models at project level, which compares the costs of community-owned and commercially-owned wind and hydro energy projects in Scotland[30, 31]. The study provides valuable detailed evidence on the distinctiveness of community energy, finding that community projects face additional risks and transaction costs compared to commercial projects. However, its scope does not include other aspects of business models (such as finance or revenue), other business model types, and projects in other parts of the UK.

In this paper, we fill an important gap in the community energy literature by providing a UK-wide analysis of the financing mechanisms and financial performance of individual community energy projects. We also systematically characterise community energy business models using quantitative methods. We perform our analysis using a dataset on the financial characteristics of community energy projects, collected in a survey of the UK community energy sector undertaken by the authors in 2017-18.

The Financing Community Energy survey

We use data from the new Financing Community Energy survey of the UK community energy sector conducted in 2017-18. The survey structure is based on the Business Model Canvas[34] which analyses organisations' value propositions and associated activities; customers; resources; and costs and revenues (see Supplementary Methods for the survey questions). For each project's energy generation and financial flows (costs and revenues), we collected data for only the most recent 12-month period for which it was available, to minimise the administrative burden on participants and maximise the number of projects included in the dataset. Our analysis of the community energy sector is therefore cross-sectional rather than longitudinal (see Methods for further discussion).

We received substantive responses to our survey on 145 projects from 48 organisations. To obtain more data on certain technologies, we supplemented the survey data with information on a further 8 projects from organisations' published financial statements and reports. This extra data gives a total of 153 projects and 56 organisations in our dataset. However, as published documents provide less extensive data than our survey, the data on the additional 8 projects is used only when we provide summary statistics on project characteristics by technology.

Of the 153 projects, the majority (139) are electricity generation projects, with a total capacity of about 41MW. A further 6 projects are heat generation projects, and 9 projects involve no direct energy generation. Other surveys of the sector found 228 community energy organisations in England, Wales and Northern Ireland in 2018, of which 204 were engaged in electricity generation, with a total of 168 MW operational capacity[13]. In Scotland, there was a total of 81MW of community-owned renewable electricity generating capacity in 2017[28]. Our survey dataset therefore captures approximately one-sixth of the UK community energy sector in terms of installed generation capacity.

Our analysis first provides a taxonomy of the project business models employed in the community energy sector. We then analyse the financial characteristics of community energy projects; the mechanisms by which they have been financed; the price they charge their customers; and the importance of the FITs, and other incentive schemes, to project revenues.

A taxonomy of community energy projects

To shed further light on the structure of the sector we applied cluster analysis to produce the first ever quantitative data-driven taxonomy of community energy business models in the UK. A cluster analysis of the survey results helps to identify similarities and differences between community energy projects, to complement case study research. The clusters also present a 'menu' of business models that can be used to inform the design of new projects.

Our taxonomy has two parts, based on two runs of the cluster analysis. The first run used project-only variables, omitting the project location and all the variables that related to the organisation running the project. This analysis produced three broad clusters (Table 2) shaped largely by the type of energy activity undertaken (generation vs demand-side activities) and by the type of technology employed.

The second cluster analysis run used all variables, including those relating to the organisation as a whole (such as turnover, number of members, and legal structure), and the project location. Here, the three broad clusters splintered into many smaller ones producing twelve clusters in total (Table 3).

The two runs of cluster analysis map closely on to one another (Table 3). Taken together, they suggest that while technology and activity are important drivers of business models, within the three broad clusters, community energy organisations have fine-tuned their business models. This fine-tuning includes different means of accessing finance and other resources (such as varying reliance on community shares, loans and grants), and offering a range of value propositions to different customers (such as funding other local projects, providing educational opportunities, cutting CO_2 emissions, and reducing energy bills).

TABLE 2 ABOUT HERE

Of the twelve clusters, the 'Demand Side Services' and 'Energy as a Sideline' projects stand out as significantly different from the others, and they also form the third cluster in the project-level cluster analysis. The other ten clusters are differentiated partly by technology, with a clear divide between solar rooftop and other generation technologies – also reflected in the project-level cluster analysis.

Other variables, such as whether the organisation runs multiple projects, has paid staff or is entirely volunteer-run, the type of customers it deals with, and how it finances its projects, are part of the fine-tuning we note above.

TABLE 3 ABOUT HERE (will probably need separate page, landscape format)

We find that the most common aspects across the current business models in the community energy sector include: a predominance of electricity generation particularly through solar PV; not having charitable status and not being linked to a charitable 'parent' body; employing three full-time staff at most on average (although there are rare cases of employing up to ten staff); relying on at least some volunteers (and up to 90 in some projects); relying on FITs for revenue and community shares for finance; mainly working with one type of customer only; and typically emphasising environmental value propositions over social and economic value propositions.

Costs, revenues and performance of energy generation projects

Our sample includes 84 solar rooftop, 15 wind, 12 hydro, 4 solar ground-mount, and 2 biomass projects with sufficient data to calculate financial performance. Table 4 presents summary statistics on the average project characteristics by technology. (The table does not include data on the two biomass heat projects, due to the risk of compromising data confidentiality.)

We find there is substantial heterogeneity in the size, costs and revenues of community energy projects across the different technologies. Wind and solar ground-mount projects tend to be substantially larger than others in terms of generation capacity and performance, costs and revenues. The mean solar rooftop project is smaller, at 74kW capacity; but this size remains much larger than typical UK domestic solar rooftop (<4kW capacity)[35].

Table 4 also presents two measures of the financial performance of projects. Annual costs per unit generated are highest for wind projects and lowest for solar rooftop and biomass. In contrast, the return on capital expenditure (CAPEX) is higher for the average wind project than the average solar or hydro project. With the caveat that the sample is very small, biomass heat compares very favourably in terms of return on capital with other technologies (21p per £ CAPEX). The differences in performance observed across technologies may reflect various factors, including: project-specific characteristics such as age and size, both of which may have significant impact on original capital expenditure figures; organisation-specific characteristics, such as expertise of personnel and learning by doing; as well as the features of the technologies themselves.

We find that the average annual financing costs across all projects is £46,500 per annum (excluding projects with zero financing costs). The average total CAPEX across these projects are £865,900. Therefore, community energy projects on average face annual financing costs equal to about 5% of their initial total CAPEX.

TABLE 4 ABOUT HERE (will probably need separate page, portrait format)

Community energy project financing

Data on financing mechanisms are available for 136 projects (89% of the total). Around three quarters of projects (77%) use just one or two external financing instruments to fund their projects. Over one third (37%) of projects also use the organisation's pre-existing funds to undertake a project. Community shares[36] are the most frequently used instrument, with 102 issues of community shares in our dataset. In addition, there are 73 loans, 54 grants, and 9 'other' instruments, mostly bonds.

Focussing on operational energy generation projects (121 of the 136 with financing data), the size of capital expenditure (CAPEX) is related to how the finance is raised: larger projects rely more heavily on loans, and smaller projects rely more on community shares. There seems to be a threshold around a CAPEX of £200,000: 88% of generation projects above this threshold use some loan finance, but only 17% of projects below this threshold reported using loans. However, community shares still account for a significant proportion of total capital raised for all but the largest scales of project as Figure 1 shows. Community shares account for almost all the finance raised by projects with a CAPEX of less than £200,000 (the majority of projects); but a much smaller proportion of the total finance raised by projects costing over £1.5m. Grants, such as the Rural and Urban Community Energy Funds[37, 38], form a relatively small part of total capital at all project scales. However, they may play a significant role in de-risking projects[39], as they are often used to finance the earliest – and riskiest – stages of project development. They are also important sources of funding for projects in the Demand Side Services cluster.

We use regression analysis to consider whether there is a statistical relationship between the cost of finance and the instrument type (see Methods for details). We find that community shares charge an interest rate that is 2 percentage points lower than loans on average. (Community shares typically pay interest rather than dividends – see Supplementary Note 1.) To put this finding into perspective, the average size of the financing instruments in the regression sample is about £306,000; the first year's interest payments on this would be about £6,200 lower if financed by community shares rather than loans (see Methods section for details).

These findings are striking because, unlike conventional equity, community shares are neither saleable to third parties for profit, nor do they necessarily give the holder a claim to the proceeds of a sale of the issuing company's assets[36]. Therefore, the prospect of capital gains, that might encourage conventional shareholders to accept lower interest payments, is not available to community shareholders. Further, there do not appear to be many cases of community shares refinancing risky early-stage loans: most projects that issued community shares did not use loans at all. We explore alternative explanations for the interest rate difference in the Discussion.

We now turn to the marketing mechanisms employed to attract funds. Despite the growth of online alternative finance platforms, such as Ethex or Crowdfunder, that can reach potential investors across the UK, around half the community share issues in our dataset were made using local marketing only, e.g. through local newspapers and the organisation's own website. Many others were marketed nationally but via community energy networks, rather than general alternative finance online platforms. There is a clear gap between the scale of funds raised by these different mechanisms, with general large-scale marketing raising the largest sums (see Table 5). However, local marketing has the lowest mean interest rates in our data, with rates on average 0.8% lower than energy specific UK-wide marketing (a significant difference at the 1% significance level). It is also notable that locally-marketed community shares raised enough to cover project CAPEX for 32 of the 43 projects in the table (74% of these projects). This suggests that many community energy projects have succeeded in raising the capital they need through relatively cheap local finance.

TABLE 5 ABOUT HERE

Importance of price guarantee schemes to project finances

As the FITs and RO schemes are now closed to new projects, we examine the importance of revenue from these schemes to community energy business models. The overwhelming majority of generation projects in our dataset accessed FITs, RHI or RO revenues (only 2 projects did not). Of these, we used 110 projects with sufficient detail on annual costs and revenues to perform a simple calculation to examine their dependency on these schemes (note that existing projects are not affected by cuts to FITs rates and the closure of the FITs and RO schemes: see Methods for details). We find that 92% of these projects (101 projects) were in financial surplus (i.e. total annual revenues exceeded total annual costs) for the year for which data was provided; however, after removing the price scheme revenues, only a fifth of the projects (22 projects) were in surplus. As these projects were designed to draw on FITs or similar revenue streams, it is not surprising that removing those revenues would push many projects into deficit. Yet, it is notable that 22 projects do not suffer this fate in our exercise; and so in the rest of this section we examine their characteristics in more detail.

Of the 22 projects, 5 were commissioned in the two years prior to the survey date, and were financed primarily by community shares, but reported no financing costs. Quite often, community shares are issued with the stipulation that they pay no interest for the first year or two of generation[36], which may be the case with these projects. Subtracting community share interest payments, at the rate given for each project, from these projects revenues leaves three out of five of them making a loss without FITs revenue.

Four other projects had additional revenue that was not directly linked to levels of energy generation (e.g. environmental grant funding, or land rental to a commercial partner); 2 projects gained revenue in the form of savings on the organisation's own energy costs. The remaining 12 were all solar rooftop projects that sold electricity to the owners or occupiers of the building where the solar panels were located. For 10 out of these 12 projects, the customer used at least 80% of the electricity generated, at a price between wholesale and typical retail prices (see the next section).

This analysis suggests only a small number of existing projects – those selling most of the electricity they generate to on-site customers – could generate a financial surplus without price support. Further, the 22 projects highlighted above are mostly small scale (less than 50kW generation capacity), and 18 were left with an annual surplus of less than £3,000 without price support revenues. In the context of such small surpluses, year-on-year variation in weather conditions and operational costs can have a significant bearing on project financial performance. The long-term price guarantee offered by schemes such as the FITs plays a significant role in de-risking projects and attracting finance[40, 41].

Prices paid by community renewable energy customers

Community energy generation projects sell to a range of customers, including energy companies, other companies, community and third sector organisations, and public sector bodies. We find that energy companies pay the lowest rates on average, equal to just 5.03 pence per kWh in our sample (Table 6). This low rate is to be expected, as projects selling to energy companies are competing with wholesale rather than retail prices. Of community energy's retail customers, 6 out of 25 community or third sector customers in our dataset received energy for free ('zero rate' customers); the remaining 19 customers pay an average rate equal to 6.33 pence per kWh. Private sector companies that are not energy companies pay a slightly higher rate equal to 6.87 pence per kWh. Public sector organisations pay 2.28 pence per kWh or 45% more on average for their energy than energy companies (and 0.99 pence per kWh more than community or third sector customers). However, this rate may still represent a significant saving on retail market electricity prices: average non-domestic electricity prices were over 10 pence per kWh for most of the period (2015 – 2017) to which these data relate[42].

TABLE 6 ABOUT HERE

Discussion

This paper sheds light on how community energy organisations have developed small-scale energy projects, often with significant citizen-funding, in an energy system dominated by large-scale actors and commercial finance i.e. the UK energy system[32]. We find that, while organisations fine-tune the details of their business models to their context, the sector is dominated by renewable electricity generation, for which two basic project business models have been developed. First, larger projects have become increasingly professionalised and 'bankable', as shown by their ability to raise commercial loans alongside citizen finance. Second, many organisations run rooftop solar PV projects that supply an on-site customer as well as the grid, and are small enough to be mainly funded through community share issues. Whilst international comparisons are limited by the scarcity of literature, we note that these UK community solar projects appear to be similar to German renewable energy cooperatives in terms of financing structure and cost of capital, although

German cooperatives tend to be larger in terms of capital raised[17, 18]. We further find evidence that UK community energy projects benefit from a local discount in fundraising, with locally-marketed community share issues the cheapest category of finance in our dataset (other than grants).

Our analysis shows that bringing social finance approaches into the renewables sector has helped community energy to pioneer innovations that can make a significant contribution to the energy transition. In the field of social finance, innovations such as crowdfunding and community shares have emerged as a response to the difficulties that social enterprises have with accessing finance from traditional lenders[43, 44]. Meanwhile, in the energy sector, it is argued that progress towards a low carbon transition is hampered by dominant actors being 'locked-in' to the existing system by short term economic pressures[45-47]. However, expanding and diversifying the energy investor base can increase the flow of finance into renewables and other transition technologies[48], because different actors invest according to different criteria[49, 50].

We suggest that, through its emphasis on environmental and social value propositions, community energy has developed alternative investment criteria that have successfully lowered financing costs for small scale renewables through diversifying the investor base. Previous research in the UK[51], Belgium[15] and Germany[16, 18] finds that people invest in community energy projects for a mix of financial and non-financial reasons, and local investors may invest larger sums[15]. Our analysis shows that, while it is clear from previous research that community projects can face additional costs and challenges[29-31], a community approach may also bring some financial advantages.

However, most of the business models in our data were built in an energy market where revenue was substantially de-risked by price guarantee schemes[40] such as the FITs. While citizens' investment motivations may be mixed, the financial security offered by such schemes were likely particularly important for people investing their own money[41]. What can our study say about future prospects for community energy in contexts like the UK (and also Germany[52, 53]), where FIT schemes are now closed?

First, we note that renewable heat and self-financing demand-side projects are currently a rarity in the UK sector[13]. Yet the projects of this type in our dataset show a financial surplus. The growing availability of technologies (e.g. LED lights for energy efficiency) and continued financial support for renewable heat (the RHI for heat generation), coupled with the reduction in support for renewable electricity, may lead to growth in these activities as community energy groups seek new business models[54].

Second, even discounting those with special circumstances, we find that 11% of renewable energy projects still showed an annual surplus without FITs (or other price scheme) revenues. This finding suggests that some new renewable electricity projects may be viable in a post-FITs world. Our analysis indicates key elements of post-FITs renewables business models to be: rooftop solar PV as the generation technology; a building with high energy demand as the site; and a customer willing to pay. Our data shows public sector bodies pay, on average, the highest prices for community-generated electricity; but we also find projects on private sector rooftops that show a surplus without FITs revenues.

However, without some form of price stabiliser it is hard to see the number of projects using community renewables business models returning to its previous rate of growth in the short term. One source of price stability could be a floor price for exported electricity, as suggested by community energy sector associations[55]. Another mechanism might be Contracts for Difference auctions. The UK already runs such auctions for large scale renewables and has opened them to remote island wind[56]. The auctions may benefit some future community projects using the Standalone Renewables business model, but could benefit many more if other technologies were also able to participate.

Third, policy could encourage, or even mandate, public sector bodies to purchase community-generated energy on long term contracts. Given the growth of the community energy sector to date, the low cost of community capital, and the wider social benefits it offers, these three measures would appear to be promising routes forward for both expanding renewable generation capacity, and supporting the delivery of positive social impacts through the energy transition.

Methods

Survey design and data collection

The survey formed part of the Financing Community Energy research project led by Professor McLachlan, which was funded as part of the UKERC research programme. In the early stages of this research project, Community Energy England (CEE) and Community Energy Wales (CEW) launched their State of the Sector Survey 2017 (SOTS 2017), which addressed some of the same topics. The Financing Community Energy project signed a Memorandum of Understanding with CEE to share survey data where possible, to maximise the benefit from the two data collection exercises.

The survey questionnaire covered characteristics of community energy organisations, and of the projects they run. With regard to organisations, it included legal structure, annual turnover, numbers of paid staff and volunteers, and numbers of members. In relation to each project, topics included: energy activities (including electricity or heat generation, and energy efficiency); ownership (sole or partnership type); financing (details of each instrument type, value, terms etc.); resources employed (including sites, technical, financial and legal services, general administration); costs (operating and financing); revenues (values and sources); value propositions (a range of economic, social and environmental propositions); customers (types, rates paid, etc.); and other beneficiaries.

These categories were based on the Business Model Canvas approach to analysing business models[34], adjusted to take account of the project's particular interest in financing mechanisms, and the characteristics of the community energy sector as the project team understood it.

The format of some of the questions was designed to complement the SOTS 2017 to facilitate data sharing. Pre-set multiple choice formats were used as far as possible to facilitate data coding and quantitative analysis. Some free text qualitative questions were also included, particularly in relation to organisations' future plans: responses to these questions have been fed into other parts of the overall research project and are not reported in this paper.

The survey sample was constructed with reference to the SOTS 2017 respondents list, data on community energy organisations in Scotland held by the social enterprise consultancy SCENE, and through internet searches, searching attendance lists at sector events, and through Local Energy Scotland sending a survey link to their members via their newsletter.

The survey received research ethics approval from the University of Manchester in October 2017. Informed consent was obtained in writing from all survey participants. The questionnaire was piloted in October – November 2017 with three community energy organisations. Only minor changes were made after the piloting process, and the pilot data forms part of the survey dataset analysed in this paper. The full survey was launched in November 2017 and closed in May 2018. During January and February 2018 it was suspended in England, Wales and Northern Ireland to avoid an overlap with the 2018 iteration of the SOTS.

The survey was available to complete online, or by telephone interview with the project team. Two methods of completing the survey were offered because the team were conscious that community energy is a heavily surveyed sector. Allowing research participants to choose the most convenient participation method ensured the survey achieved sufficient responses for a meaningful quantitative data analysis, while also reducing the administrative burden on research participants. Ideally, we would use only one method of data collection, because using different methods may affect the quality of the data. Although we attempt to minimise this concern by ensuring that the online and telephone data follow a standardised framework, we cannot rule out that inconsistent data collection methods has resulted in measurement error in our data. This is a limitation of the study.

In total the researchers contacted 280 organisations, of which 83 responded and 48 completed the survey, providing data on 145 projects. Not all projects are included in all the analysis presented here. Complete data was not available for some projects, limiting the kinds of analysis that could be performed. Further, some projects were classified as 'stalled or on hold', and so by their nature did not have complete data. Data were collected on an additional eight projects using published accounts and reports only. These data are used in Table 4, to provide greater coverage of the hydro, wind and solar ground-mount technologies, but are not otherwise used in the analysis.

Cluster analysis

We used data on 119 projects for cluster analysis, as the projects that had missing values related to any of the business model aspects had to be excluded. Missing values were predominantly due to respondents not having access to some of the information required in the survey, for example because of lost paperwork or limited documenting.

Unlike in the performance and financial analysis (please see the next section), the two bioenergy projects were not excluded in the cluster analysis, as their anonymity would be preserved when aggregated into clusters. However, we did re-run the cluster analysis without these two projects to test whether the results would change. The exclusion of these two projects has not affected the composition of the clusters in any of the runs (i.e. either in the run with all variables, including those related to the organisational level and location, or in the run with only project-level variables). Excluding those two projects has also had little effect on the silhouette coefficients and the shapes of the clusters on the t-SNE plots. As the presence or otherwise of the bioenergy projects does not affect our cluster analysis results, we have kept those projects in the sample. The analysis runs with those projects excluded are available on request from the authors.

The cluster analysis was performed using R 3.6.1[57] and packages *dplyr*[58], *cluster*[59], *factoextra*[60], *ggplot2*[61], *Rtsne*[62], *dbscan*[63] *fpc*[64] and *clustMixType*[65]. Partitioning around medoids (PAM), hierarchical agglomerative clustering (HAC), density-based clustering and k-prototypes clustering were the four clustering methods applied to the dataset.

We included different combinations of organisation-level variables (e.g. legal structure of organisation) and project-level variables (e.g. type of energy activity, type of customer) in several analyses runs. The first run used all 48 variables; the second run omitted the variables for organisation turnover and project location; and the third run omitted all the organisation-level variables (such as turnover, number of members, number of volunteers, number of staff employed, ownership structure, charitable status, and year of foundation), and project location, and used only the 40 variables relating to the operation of individual projects.

Before running the analyses, we created a heatmap of the dissimilarity in the community energy dataset, using the daisy function with Gower distance that can handle mixed types of variables. The heatmap (Supplementary Fig. 1) demonstrated that the dataset did contain patterns, compared to a heatmap of random data. We then performed a sanity check on the dissimilarity matrix through outputting the most and the least similar pairs of projects, with expected results.

We used two key types of validation statistics to compare the results of the four clustering methods: the within-cluster sum of squares (WSS) and the average silhouette width (see Supplementary Table 1). The WSS was significantly better for PAM (1.8901) than for the next best method using this metric: HAC (4.5846). The average silhouette width for PAM (0.3058) was slightly lower than for HAC (0.3798), but significantly better than for the next best method using this metric: density-based clustering (0.1485). The validation results were similar for the analysis run that included only project variables i.e. with organisation and location variables excluded. In this run, density-based clustering showed somewhat better average silhouette width (0.2910) than PAM (0.2690). However, in this analysis run, the density-based clustering method only yielded one cluster of 68 projects, with the remaining 51 projects designated as outliers, which did not provide meaningful insights. On the basis of these validation statistics (reported in Supplementary Table 1), the PAM clustering results were not a statistical artefact, and hence we selected PAM as our main clustering method.

For PAM clustering, we calculated and plotted silhouette width (Supplementary Fig. 2) to select the optimal number of clusters. Twelve clusters corresponded to the highest silhouette width (0.4054) for the first analysis run where all variables were used, with thirteen and three clusters for the second and third runs respectively (with the highest silhouette widths of 0.4327 and 0.4026 respectively). Results of the first two analysis runs were very similar to each other; therefore we have omitted the second analysis run with thirteen clusters as it did not add any extra insights to the results.

We then visualised the clustering using the t-Distributed Stochastic Neighbour Embedding (t-SNE) technique. The t-SNE technique decreases the number of dimensions while preserving the structure of the dataset. The resulting figures are presented in the Supplementary Information file for both the twelve-cluster and three-cluster runs (Supplementary Fig. 3). The figures illustrate which business models are well-defined and distinct (for example, clusters 4, 11 and 12 in panel (a) of Supplementary Fig. 3) and which business models are more diffuse and might share similarities with other types (for example, clusters 6, 8 and 9 in panel (a) of Supplementary Fig. 3). Similar plots for other clustering methods (Supplementary Fig. 4, panels (a) and (b)) give a less clear-cut allocation of projects into clusters.

In relation to the variables present within the clusters, it is important to explain the value proposition variable. We constructed a list of value propositions potentially offered by community energy organisations to their customers, based on a review of the wider community energy literature. Survey participants were asked to say which of these value propositions they felt were important in their customers' decision to use their services (e.g. to buy electricity). In the cluster analysis, the value propositions were categorised as environmental, economic or social, and projects were coded according to whether participants selected environmental, economic or social propositions (or a mixture) as important. Environmental value propositions included providing renewable electricity, reducing CO_2 emissions, and tackling climate change. Economic value propositions included electricity generation regardless of origin, reducing energy bills, dealing with known trusted organisation, benefiting local economy, enabling customer to meet planning requirements, and enhancing customer reputation. Finally, social value propositions included bringing community together, generating community benefit, and providing educational benefits. Further research could investigate customer perspectives on the value propositions offered by community energy organisations.

Performance and financial analysis

This paper uses data collected for a single year of project operation. Therefore, we provide a cross-sectional analysis that involves looking at the sector at a moment in time, rather than assessing how it changes over time. It is particularly important to bear this in mind for the project performance characteristics presented in Table 4: because generation, revenue, and operating costs may vary considerably from one year to the next, these data may not be representative of project performance in other years. Future research may wish to address these issues by collecting survey data on project performance over a number of years to construct a panel dataset.

As renewable energy generation is affected by weather conditions it is important to note that, although data were collected between November 2017 and May 2018, as noted above, the data do not relate to the project performance during the months the survey was open. Rather, organisations reported data that relate to a 12 month period – more specifically, the most recent financial year for which data on the project are available. As the data reflect project performance over a 12 month period, they will reflect project performance over a sustained period of time rather than during an individual month or season of the year. Furthermore, we do not typically expect that community energy projects will vary that much in terms of their performance from one year to the next, especially in a systematic way (such that variations over time would not average out across projects when performing statistical tests e.g. when performing t-tests of means). Nonetheless, we cannot be sure that information during one 12 month period is representative of a different 12 month period. This is an issue with any cross-sectional dataset.

The absence of data with a time-dimension means we also do not aim to assess performance over the lifetime of a project e.g. by measuring the Internal Rate of Return. Likewise, we analyse costs in terms of cost per unit of kWh of generation, rather than Levelised Cost of Energy (LCOE). Costs per kWh is a similar metric to a LCOE in that it involves dividing operating costs and a capital cost recovery component (in the form of an annual financing cost) by electricity generation. However, unlike the LCOE, it provides an annual snapshot rather than discounting the predicted costs and generation over a project's entire lifetime.

In order to better understand the importance of financing characteristics for community energy projects, we explore whether there is a statistical relationship between the interest rate (cost of finance) and the instrument type. We are particularly interested in comparing community shares with loans, because the majority of community energy projects are financed using these instruments. (Grants are also a common source of finance but do not charge interest.) To do this we first note the mean interest rates for community shares and loans in our sample are 4.58 and 5.58 respectively. Therefore, the difference in means is 1.01 percent points. Performing a *t* test on the equality of the mean rates, we find that the means are statistically different at the 1% significance level (t statistic of 3.03). Thus, community shares charge a statistically lower interest rate than loans on average.

A comparison of means may however be misleading because the size of the finance obtained and the financing term (duration) may also influence the interest rate. We therefore compare the difference in interest rate between community shares and loans while holding these other characteristics constant. We do this by estimating a linear regression model. We proceed by defining three dummy variables that capture the instrument type:

CommunityShare = 1 if the financing instrument is community shares, and = 0 if it is not community shares.

Bonds = 1 if the financing instrument is bonds, and = 0 if it is not bonds.

Loans = 1 if the financing instrument is loans, and = 0 if it is not loans.

Although all three instrument types are included in our model, we need to include only two of these three dummy variables in the regression equation (further explanation can be found in Wooldridge, 2014[66]). We choose to include the *CommunityShare* and *Bonds* dummy variables. Therefore, *Loans* is chosen to be the base group (or benchmark or omitted group) and are the group against which comparisons are made. We choose loans as the base group because we are especially interested in looking at the difference in interest rate between community shares and loans.

We then estimate the following linear regression model: $IR_i = \beta_1 + \beta_2 \mathrm{CommunityShare_i} + \beta_3 \mathrm{Bonds_i} + \beta_4 \mathrm{Size_i} + \beta_5 \mathrm{Duration_i} + \varepsilon_i \quad (1)$

where the dependent variable *IR* is the financing interest rate of financing source *i*. *IR* is a continuous variable that can take non-integer values. *CommunityShare* and *Bonds* are defined above. As explained above, we compare how these financing instruments are associated with the interest rate relative to the omitted category which is loans. In equation (1) we also include the variables *Size* and *Duration* to control for the size and duration of the financing instrument, respectively. *Size* is defined as the monetary value of the financing source (in £ millions) and *Duration* is a dummy variable equal to 1 if the finance term is 240 months or more, or indefinite/not specified, and 0 if a relatively short-term duration (less than 240 months). β_1 to β_5 are coefficients to be estimated. Finally, ε is an error term. We estimate equation (1) using Ordinary Least Squares.

Each observation on financing source *i* belongs to an organisation that may use one or more sources of finance for its community energy project(s). Outcomes for different financing sources within organisations are likely to be correlated. As we cannot assume that the error term is independently distributed within organisations, we cluster standard errors at the organisation level.

In specification (1) the continuous variables (*IR* and *Size*) enter in levels. An alternative approach that allows for a non-linear relationship between the dependent and explanatory variables is to enter the continuous variables in logarithms. We find our results are robust if we use a logarithmic functional form (results are available on request). However, here we present the results with variables in levels because in this case the coefficients have a percentage point interpretation.

We now report the results from the estimation of regression (1). Here we report the estimated coefficients with cluster robust standard errors in parentheses. We also report t-statistics from two-tailed tests that the corresponding population coefficient values are equal to zero.

$\hat{\beta}_1 = 5.124\ (0.585)$ and t-statistic = 8.76. $\hat{\beta}_2 = -2.016\ (0.706)$ and t-statistic = -2.85.

$\hat{\beta}_3 = -0.653\ (0.667)$ and t-statistic = -0.98. $\hat{\beta}_4 = 0.185\ (0.091)$ and t-statistic = 2.02.

$\hat{\beta}_5 = 1.452\ (0.777)$ and t-statistic = 1.87.

Finally, the R-squared from the regression is 0.2457 and there are 118 observations.

The estimated coefficient on the dummy variable *CommunityShare* (-2.016) indicates that there is a difference in the interest rate between community shares and loans of 2.016 percentage points on average in our sample, while holding constant the size and duration of the finance. The t-statistic indicates that this difference is statistically significant at the 1% level. To put this finding into perspective, the average size of an individual financial instrument (i.e. a single loan, or share issue) in the regression sample is about £306,000. Therefore, for the average project, the annual interest payment for the first year would be on average lower by £6168.96 (2.016% of £306,000) if financed by community shares rather than loans. This does not take into account compound interest and repayments in later years of a project; it is simply intended to illustrate what the interest rate differential between loans and community shares means in terms of actual amounts a community energy project might pay in interest on the initial principal sum. In the paper, the figures given are rounded for greater readability: thus we mention a "2 percentage points" difference in interest rates, and an average repayment differential of "about £6,200".

We also find that projects financed by bonds do not have an interest rate that is significantly different from loans. In addition, we find that instruments that have a longer duration and larger value have higher interest rates on average.

We investigate whether these results are sensitive to outliers. We do not find any evidence of observations with large estimated residuals that may affect the estimates. We also investigate the distribution of the dependent and explanatory variables by inspecting the raw data and by using a leverage-versus-squared-residual plot. From this analysis we identify two observations with large leverage due to outlying values on the explanatory variables. However, our central findings on the difference in the interest rate between community shares and loans are robust to dropping these observations from the analysis. Therefore, they do not affect our conclusions.

The impact of the removal of price guarantee schemes is calculated by simply subtracting all price guarantee scheme revenue (FITs, RHI or RO) from total project revenue, project by project, for the single year of revenue data that we collected. It is important to note that, for the FITs, projects retain the tariff rate for which they initially qualified for the rest of their lifetime, including an inflation adjustment; unlike the RO, the FIT is not subject to annual variations in price due to market conditions. The RO scheme revenues are affected by year-to-year market variation, but this variation is not itself affected by the scheme being closed to new entrants. Therefore, the data do not only reflect the performance of community energy under the tariff rates available to new projects at the time of data collection.

The contribution of this analysis is to allow an appreciation of the extent to which actual projects are reliant on price scheme revenues. There is no consideration of how projects might have been designed if the schemes had not been available, which is a more complex question. Therefore, these results do not in themselves show that it would be impossible to design a future project to make a financial surplus without a price guarantee scheme; nor, given that we have just one year's data, do they test "viability" of a project over its lifetime.

To investigate whether different types of customers pay different rates for community-generated energy, we calculate mean rates paid by the four different types of customer (energy companies, other private sector, public sector, community and third sector). As noted in the main body (Table 5) we find the mean rates differ, with the mean rate lowest for energy companies and highest for public sector customers. Performing a *t* test on the equality of the mean rates paid by energy companies and public sector organisations, we find that the means are statistically different at the 1% significance level (t statistic of 3.69).

Data availability

The data gathered in the Financing Community Energy survey will be available via the UK Energy Research Centre's Energy Data Centre: https://ukerc.rl.ac.uk/

Due to the terms under which the data were collected, individual project records cannot be made public and will therefore not be available. However, aggregated records of small numbers of similar projects will be available.

No custom code was used in the analysis.

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Author contributions

C.M. led the research project. C.M., S.M., M.S., E.M., J.H., M.H. and T.B-S. contributed to the conception, framing and design of the survey research. T.B-S. conducted the survey, and supervised the work of C.B. and C.W.; he also conducted the analysis of the composition of project finances, and the impact of price support mechanisms. M.S. designed and conducted the cluster analysis. E.M.

conducted the econometric analyses of financing instrument interest rates, and provided descriptive statistical analysis. All authors jointly wrote the paper: T.B-S. led the writing; M.S., E.M. and C.M., M.H., J.H. and S.M. contributed text and extensive comments on the structure and content of several drafts of the paper.

Competing Interests

C.M. is Chair of the Trustees of the climate change charity Possible (formerly 10:10), and a director of Community Energy North. Both of these roles are unpaid.

M.H. is an unpaid Trustee of South Seeds, Glasgow, a community environmental charity with a focus on energy.

J.H. is a Non-Executive Director of Public Power Solutions Limited, a renewable energy developer that has worked with community groups.

TABLES

Table 1. Principal forms of government-mandated price support for small-scale low carbon energy provision referred to in this paper

Scheme	Dates open to new projects	Energy scope
Renewables Obligation (RO)	2002 – 2017	Electricity generation
Feed-in Tariff scheme (FITs)	2010 – 2019	Electricity generation
Renewable Heat Incentive (RHI)	2014 – 2021	Heat generation

Notes: These schemes offer eligible projects a guaranteed price for the electricity or heat they generate. In some cases the schemes operate differently across the UK's devolved nations, and each scheme involves a complex set of scale and technology bandings, and eligibility and administrative requirements. Further information on these schemes can be found on the Ofgem website[67], and in previous work by the authors[1].

Table 2. Taxonomy of UK community energy from cluster analysis of survey data using only project-level variables

Cluster name	Number of projects	Number of organisations	Key characteristics of clusters
Standalone renewables	20	16	Wind, hydro, and ground-mounted solar electricity generation projects, and one biomass heat network
On-site customer renewables	85	22	Almost entirely rooftop solar PV projects, but also one solar thermal, one hydro, one wind and one biomass boiler. Electricity sold to customer in building (solar rooftop) or via private wire.
Demand-side activities	14	10	A mixture of energy efficiency and fuel poverty advice projects, and renewable energy generated for own use (rather than selling)

Table 3. Taxonomy of UK community energy from cluster analysis of survey data using project, organisation and location variables

Project-level cluster (Table 2)	Cluster name	No. of Projects	Energy activities	Organisation	Finance and Resources	Revenues and Customer Sectors
Standalone Renewables	Multi-Financed Hydro and Wind	4	Hydro and wind electricity generation at small-medium to large scale	Coops and other companies, single projects only	Mix of financing instruments; often pay for sites and other resources	FITs only
Standalone Renewables *and* On-site Customer Renewables	Large Wind Selling to Grid	5	Wind with mean capacity of >2MW	Coops and other companies with part-time staff	All use loans, some community shares	RO, energy sales to wholesalers or local grid
On-site Customer Renewables	Medium Scale Generation with Mixed Financing	9	Wind, hydro, solar ground-mount and biomass heat: mean capacity >1MW	Coops and other companies with some paid staff	All use loans, some community shares	FITs and sales to energy companies
	Small/ Medium Solar Rooftop	9	Solar rooftop PV – mix of scales	Volunteer-run coops	Community shares, most resources free	FITs and energy sales to mix of sectors
	Multi-Site Solar on Public Sector Roofs	35	Solar rooftop PV mostly <50kW capacity – sometimes with energy efficiency also	All coops with some paid employment, running multiple projects	Community shares; sites free, some resources free or in house (e.g. legal services)	FITs and energy sales, mostly to public sector
	Professionalised Solar Rooftop Coops	13	Solar rooftop PV – mix of scales	Coops with multiple projects and paid staff	Community shares main financing instrument; many resources paid for	FITs and energy sales to mix of sectors
	Small Multi-Project Generation for Third Sector Groups	12	Mostly solar rooftop PV (but some heat)	Volunteer coops running multiple projects	Mix of financing instruments	FITs and energy sales to third sector
	Small Solar Rooftop	9	Solar rooftop PV mostly <50kW capacity	Mostly volunteer-run coops	Finance mostly community shares; mix of free and paid resources	FITs and energy sales to mix of sectors
	Smaller Scale Multi-Project Coops	4	Multiple solar rooftop PV <50kW capacity	Volunteer-run coops	All using community shares, some loans and grants also.	Mix of public, private and third sector customers;
Demand-side Activities	Demand Side Services	6	Energy efficiency advice and installation, and fuel poverty reduction work.	Mostly coops, paid staff & volunteers	Grants, loans	Customer fees, energy services contracts, some work free of charge
	Energy as a Sideline	7	Rooftop solar PV, heat, and electricity storage	Small scale third sector sports and leisure clubs.	Grants and self-financing	FITs and savings on own energy bills
All three project-level clusters	Multi-Tech Generation including Partnerships	6	Hydro, wind and solar rooftop PV	Companies with paid staff	Grant and loan finance; sites free, other resources paid or in-house	Hydro and wind sold to grid, solar to local customer

Note: for further explanation of use of terms please see Methods section on data gathering.

Table 4. Energy generation project characteristics by technology

	Hydro	Wind	Solar ground	Solar roof
Number of projects in sample	12	15	4	84
Capacity (kW)	163	1,862	3,428	74
	(162)	(2,741)	(2,304)	(168)
Total capital expenditure (£ 000s)	1,097	3,255	5,992	87
	(979)	(4,187)	(6,387)	(170)
Annual operating costs (£ 000s)	25	136	172	3
	(32)	(182)	(205)	(13)
Annual financing costs (£ 000s)	29	161	318	4
	(37)	(219)	(370)	(9)
Annual generation (MWh)	472	4,317	3,385	56
	(458)	(7,512)	(2,289)	(111)
Annual revenue (£ 000s)	91	552	730	11
	(93)	(818)	(900)	(25)
Annual surplus (£ 000s)	37	256	240	4
	(39)	(489)	(328)	(7)
Capacity factor	0.36	0.27	0.11	0.09
	(0.15)	(0.14)	(0.01)	(0.03)
Annual cost per kWh (£)	0.12	0.15	0.12	0.11
	(0.05)	(0.18)	(0.10)	(0.09)
Return on capital costs (£)	0.11	0.18	0.10	0.12
	(0.05)	(0.10)	(0.03)	(0.05)

Notes: Table shows mean characteristics with standard deviations (the square root of the variance) in parentheses.
Only data from fully operational projects are included. Some projects for which revenue data is missing are excluded. Data for 8 projects taken directly from organisations' published financial statements and reports are only used in this table. The table does not include data on the two biomass heat projects, due to the risk of compromising data confidentiality.
Operating Costs refers to expenditure on running the project. Financing Costs include all repayments of borrowing and payments to shareholders. Operating Costs *do not include* Financing Costs.
Annual surplus = (annual revenue – annual operating costs – annual financing costs)
Capacity factor = (annual generation / (365 × 24 × capacity)).
Annual cost per kWh = (annual operating costs + annual financing costs) / annual generation. See Methods section for a discussion of this metric and a comparison with the LCOE metric.
Return on capital costs = (annual revenue / total capital costs).

Costs, revenues and generation figures are based on a single year of project data. See Methods section for further discussion of the implications.

Table 5. Community share issues analysed by marketing mechanism

	Number of share issues	% of total	Total amount raised (£)	Mean amount raised per share issue (£)	Mean interest rate on shares (%)
General online platforms – UK wide	9	10	6,362,856	706,984	4.33 (1.00)
Energy specific marketing – UK wide	38	42	7,881,930	207,419	5.06 (0.33)
Local marketing	43	48	4,248,498	98,802	4.26 (0.83)
Total	90	100	18,493,284	205,481	4.60 (0.79)

Notes: We find that the difference in mean interest rates between energy specific marketing and local marketing is statistically significant at the 1% level (t-statistic of 5.64). The difference in mean interest rates between energy specific marketing and general online platforms is statistically significant at the 10% level (t-statistic of 2.14). The difference in mean interest rates between local marketing and general online platforms is insignificant.

Table 6: Energy prices charged by community renewable generators by type of customer

Customer type	Average customer rate (pence per kWh)	Number of customers	Excluding recipients of free energy	
			Average customer rate (pence per kWh)	Number of customers
Energy Company	5.03 (0.66)	12	5.03 (0.66)	12
Other Private Sector Company	6.24 (3.48)	11	6.87 (2.95)	10
Community or Third Sector	4.81 (3.39)	25	6.33 (2.28)	19
Public Sector	7.32 (1.54)	51	7.32 (1.54)	51

Notes: Table shows mean customer rates by customer type, with standard deviations (the square root of the variance) in parentheses.

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