Starting to join the dots: An interim review of EnergyREV insights

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Introduction

The UK is committed to reaching net-zero carbon emissions by 2050. Many of the actions needed to achieve this are highly place-based – homes and offices will need to be retrofitted, with low-carbon heating systems installed, and electric vehicle charging infrastructure nearby. These activities can only be done in the place to which they apply, not elsewhere. This, combined with wider trends of digitalisation, decentralisation and democratisation in energy, has focused attention on the role local solutions could play in helping the UK achieve net zero carbon and other societal objectives.

Since 2018 the EnergyREV consortium has supported the UK Government's Prospering From the Energy Revolution (PFER) programme by investigating the ways and conditions in which integrated local energy systems can be accelerated and used to deliver services and benefits for individuals, communities, the energy sector and wider society. While the potential of such systems and technologies may be apparent, it is not sufficient to assume that they will deliver the required benefits. To be confident in their effectiveness it is important to understand the mechanisms of how smart local energy systems (SLES) work and under what circumstances they are successful.

As part of our team's objective to develop a whole systems understanding, we have carried out a review of the published outputs produced by EnergyREV up to the end of 2020. The aim was to give a snapshot of the project at this interim stage through understanding the scene that has been set by our researchers' initial investigations and to identify the issues that they are grappling with. We used systematic review methods to analyse findings from the outputs and draw out key themes that have been approached from different angles across the consortium.

Our researchers are studying a broad spectrum of topics related to SLES, with teams dedicated to cyber-physical systems; business and financial practices; policy, regulation, markets and governance; user engagement and to supporting scale up - alongside work looking at skills needs and impacts on industry and the environment. Analysing the interim findings from such a diverse range of perspectives on SLES necessarily produces a partial picture of the work of the consortium and of the wider PFER programme. For this reason, the review is not intended to be a comprehensive summary of EnergyREV to date. More forward facing or synthetic findings that have only been shared provisionally or in presentations have not been included in this review. We also realise that EnergyREV is far more than its collective outputs and that a great deal more knowledge, expertise and insight exist in both the interaction between consortium members and the ongoing work yet to be published. Our approach was to identify areas of alignment or tension and common themes or recommendations that can act as a starting point for further discussion and investigation.

In this context, this review serves as an introduction to EnergyREV for anyone involved in funding, planning or implementing SLES, including national and local policymakers, businesses, civil society and community organisations. It highlights themes and considerations that we believe are important and signposts our research for those interested in exploring certain topics in more depth, pointing to the practical implications and recommendations of this work. We also hope that this will help researchers, including those in the consortium, in directing their future research to address key gaps and questions. **The main themes that emerged from our review are summarised below**.

Following the publication of this report we will be looking to collaborate with the other work packages in EnergyREV to gain a better understanding of the implications of their work and how they connect with each other. By talking to researchers and analysing evidence as it is produced (by EnergyREV and others), we will continue to build and test our 'theory of change', developing a clearer picture of what is needed to bring about SLES that is effective in achieving its goals.

Key themes and findings

A central role for local authorities

For SLES to flourish there is likely to be a need for devolution of responsibility from central government to local authorities, albeit with continued central coordination. This should be combined with resources to increase local authorities' capacity to fulfil valuable roles such as providing technical assistance, project aggregation, and building on the trust they have locally to enhance engagement.

Driving investment

EnergyREV work has shown that public funding has had a key role in underpinning local energy projects -- but that if smartly directed (such as into technical assistance and project aggregation), such funding has the potential to leverage much larger external sums. There are also a range of regulatory barriers that will need to be addressed if substantial new entry into the SLES space by actors from other sectors is to be addressed, such as around licensing suppliers and the magnitude and predictability of income from providing flexibility services.

Connecting and coordinating technologies

A large part of EnergyREV's work has been examining how separate technologies and actors can interoperate and coordinate in a system that produces more value than the sum of its parts. EnergyREV supports existing initiatives to improve availability of energy data and standardisation and has proposed new microgrid computing architectures to support interoperability. There are, however, challenges around the uniformity that standardisation can lead to (especially in an area where local context is likely to be very important), and the privacy challenges associated with extreme data availability.

Flexibility, storage, and resilience

One of the main anticipated benefits from well-coordinated SLES is their potential to unlock energy system flexibility. Extensive work has been conducted in EnergyREV on how this might be delivered, mainly through a combination of energy storage and demand response, potentially mediated by local energy markets. EnergyREV modelling studies demonstrate the substantial value that such flexibility could have for the national energy system – value that should be taken into account in the design of SLES themselves (for example in the sizing of storage). However, it also points to complex dynamics whereby increased flexibility could provide sufficient benefit that it dampens investment in new decentralised generation because that is perceived to be less valuable. A range of regulatory barriers to realising the full value of flexibility from SLES are also highlighted.

Direct economic benefits for SLES participants

EnergyRev has looked at the conditions under which SLES can lead to financial savings or increased revenues for participants; for instance, how they are expected to benefit financially from participating in peer-to-peer trading. The main focus has been on how local electricity networks can be managed and charged for in order to minimise costs for users, while also avoiding challenges such as curtailing renewable generation.

Who's who: citizens, consumers, prosumers, market actors?

Benefits for participants are affected by the different ways they are treated or framed, for example as consumers, prosumers, citizens, owners, etc. A special focus is put on the distinction between local projects that are spatially defined, and community energy projects that engage the community – a distinction that is likely to be important as SLES continue to emerge across the UK.

The next section provides a brief background to EnergyREV and the PFER programme. We then provide an overview of the main consistent themes and recommendations emerging from our work so far. Finally, we present a list of the practical tools and resources we have developed that you can use in your work, along with a full list of EnergyREV outputs with links to the original documents so you can dig into the detail.

Background to EnergyREV

The Government launched the PFER programme at the end of 2018 with £100m in funding. It has the following objectives:

- Prove investable, scalable local business models by 2022, that
  - deliver cleaner, cheaper energy services
  - build more prosperous and resilient communities
  - benefit the whole energy system
  - use integrated, intelligent approaches
- Unlock 10x future private investment in local integrated energy systems in 2020s (vs business as usual)
- Accelerate new products and services to commercialisation, creating real world proving grounds
- Build UK leadership in integrated energy services provision

Figure 1: EnergyREV work packages

The programme is made up of a number of strands. EnergyREV contributes the academic research strand, with researchers investigating the ways and conditions under which the PFER objectives can be met. The EnergyREV consortium is made up of over 60 researchers from 22 institutions. These bring a broad array of disciplines and methodological approaches; see figure 1 showing the different work packages within the consortium. This wide coverage is suggested in the diagram of the structure of EnergyREV presented in appendix 1. A full list of participating researchers can be found on the team page of the EnergyREV website.

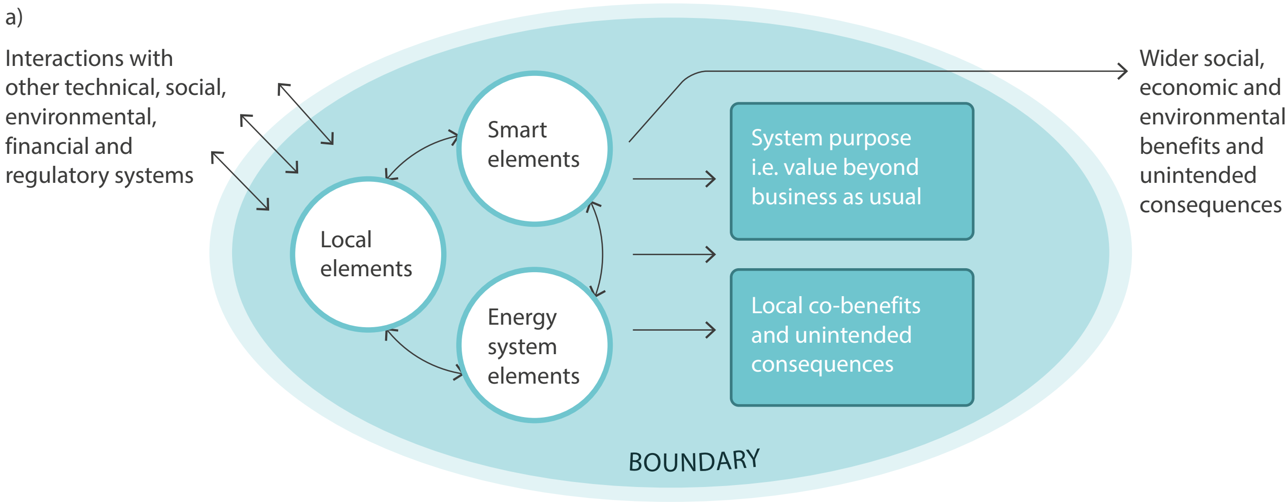
Smart, local energy is the subject of intense research interest around the world. The unique contribution that EnergyREV brings to this is a strong systemic focus – on the actors, technologies, institutions and so on that make up systems, the interactions between them, and the interactions between systems themselves.

Laying the groundwork

A foundational strand of EnergyREV work has been dedicated to understanding what SLES are, what success in a SLES might look like, and how this can measured. Figure 2(a) shows how SLES are made up of smart, local, and energy system elements working together for a purpose within a local boundary, and set within a wider context. Figure 2(b) shows the kinds of features that SLES might be expected to have – although the precise combinations will vary from context to context.

We cannot assume that simply introducing SLES elements such as better data or learning algorithms, or getting more local ownership, will automatically deliver benefits. Instead, it is important to be clear about the rationale underpinning the expectation that SLES can deliver specified outcomes. We have therefore created a provisional "theory of change" for how SLES could deliver on PFER objectives (Fell et al., 2020b).

a)



b)

Smart	Local	Energy system	To deliver
• More data • ICT • Automated / self-regulating • Learning / AI • Smarter decisions	• Local stakeholders / ownership / governance • Geographic proximity • Supply / demand / storage co-located • More self-sufficient • Deliver local value	• Multiple vectors • End-to-end (generation to consumption) • Integrated with other systems • Includes institutional infrastructure	• Energy services • Prosperous communities • Environmental benefits • Improved resilience

Figure 2: a) The "Smart local energy system framework" and b) the elements of SLES and areas of value creation; respectively extracted and adapted from Ford et al. (2019b)

What is a theory of change (ToC)? A ToC sets out the process by which an action is expected to lead to its intended outcomes. For example, we might expect a local electricity trading scheme to lead to lower bills for participants.

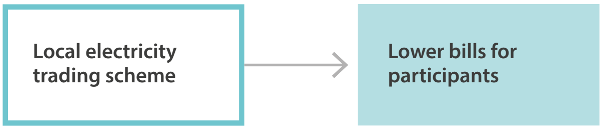


Figure 3: Example action and expected outcome.

But why do we have this expectation? There are likely intermediate steps that need to be met if the ultimate outcome of lower bills is to be achieved. For example, this might be that locally generated electricity is available for sale within the scheme more cheaply. There may be other factors too. There may also be wider underpinning assumptions to consider, such as that the kind of trading scheme in question in permissible under the regulations. Finally, there may be unintended consequences it is important to recognise, such as higher bills for non-participants.

Developing a ToC like this helps ensure that the important aspects of delivering an outcome are carefully thought through. We can recognise where our assumptions that might need to be tested before doing the action. If different team members have different assumptions about how an outcome will result from an action, we are able to recognise this early in the ToC process.

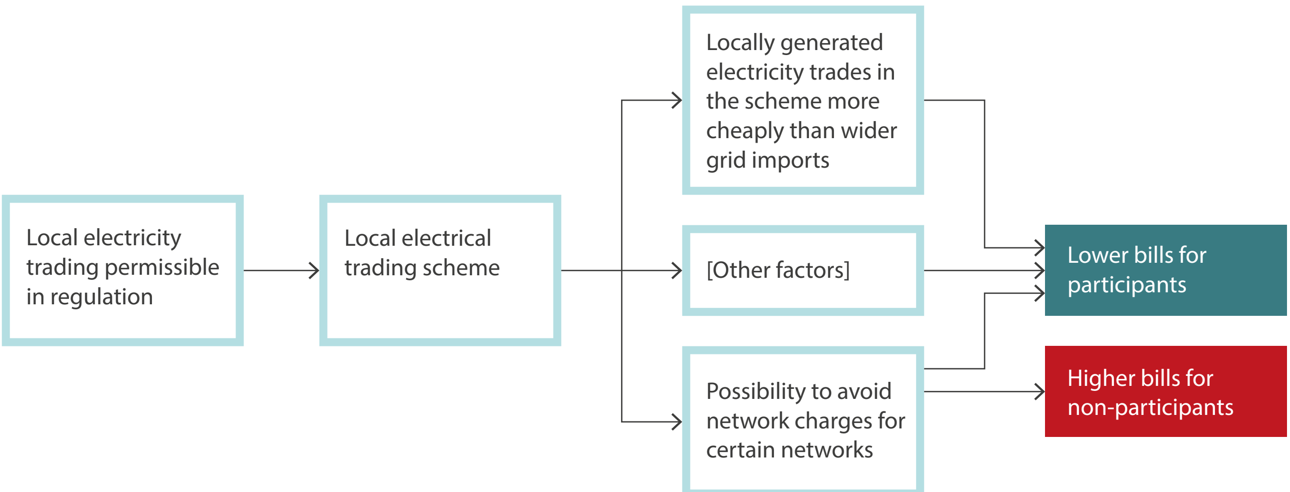
The ToC therefore helps establish a common understanding of how SLES work, their challenges, responses and assumptions, and can also inform measurement and evaluation. They are widely used in policy evaluation to help explicate why expenditure of public money and resources will lead to outcomes for the public good.

In the case of the EnergyREV ToC, researchers across the consortium were involved in a process of identifying the *necessary preconditions* for SLES to come about and for desired outcomes to be achieved. These are conditions which, if they are not created, we think would significantly limit the ability to develop SLES that lead to outcomes such as those summed up in the PFER objectives. These preconditions were then organised into eight interrelated "challenge areas", such as "data and digital" and "users".

The provisional version of the ToC is available in the report linked below. We also produced a set of worksheets to help SLES projects map out what action they are taking in each of the challenge areas, and think about whether these are in line with, or potentially challenge, the necessary enabling conditions.

Now that EnergyREV is producing evidence, analysis and recommendations, we have begun the process of mapping this onto the EnergyREV ToC. We are creating an interactive tool, which viewers can use to quickly identify the EnergyREV findings that are most relevant to them.

Figure 4: Simple ToC showing conditions and steps that are expected to lead to certain outcomes.



If you visit it, you will be able to:

- Show/hide all our main findings to see how they fit into the process of building successful SLES.
- Show/hide the key policy/regulatory inputs we suggest are necessary to help create the enabling conditions for SLES.
- Show/hide metrics which can be used to measure progress against creating the enabling conditions, activities, and outcomes.

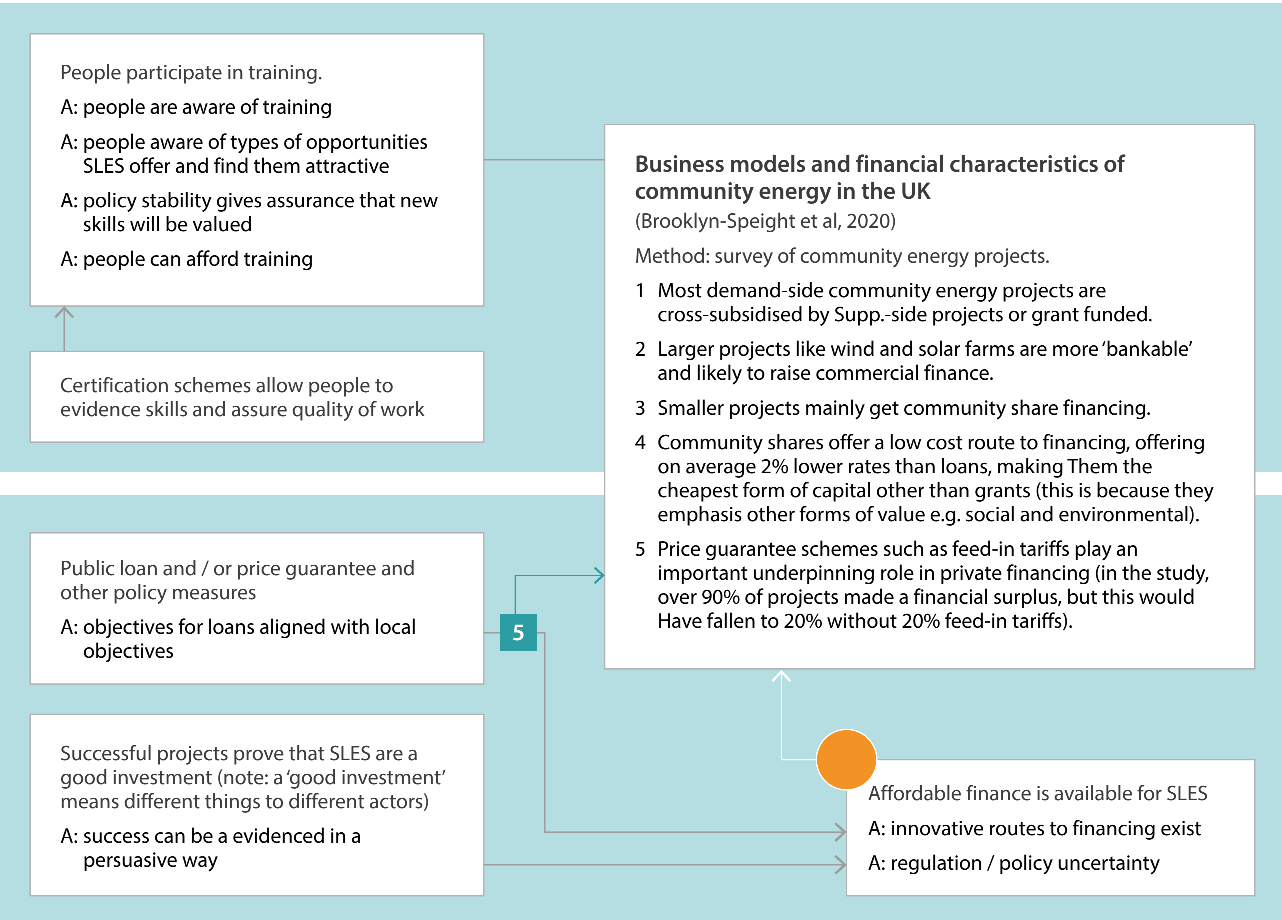
The interactive theory of change is a living document and will be updated continuously as more EnergyREV outputs are produced. Please visit it and explore our findings.

As highlighted above, EnergyREV researchers have developed a set of metrics to help measure progress against SLES enabling conditions, activities, and outcomes (Francis et al., 2020). If and when SLES become a more prominent part of the UK's energy landscape, being able to track this progress will play an important role in helping projects learn and adapt.

While recognising that what success looks like will vary from locality to locality, providing a common menu of metrics should make the process of selecting what to measure easier. And in due course it can also help build our general understanding of what works in creating effective SLES.

Before moving on, it is important to stress that work in the consortium is still ongoing. The nature and focus of each of the different projects influences both when they are able to produce outputs and the extent to which their activities have been affected by the Covid-19 pandemic. This is therefore very much an interim picture of where things stand, based on outputs that have been published so far (by the end of 2020). These are listed and described in Appendix 2, while Appendix 3 gives an overview of expected future outputs.

Figure 5: Excerpt from the EnergyREV Theory of Change, under ongoing development (Fell et al., 2020)



Key themes

We identified the following key themes running through EnergyREV outputs:

- A central role for local authorities
- Driving investment
- Connecting and coordinating technologies
- Flexibility, storage, and resilience
- Direct economic benefits for SLES participants
- Who's who: citizens, consumers, prosumers, market actors?

This section deals with each in turn, providing a brief introduction to the main findings and recommendations. Links to all the outputs are available in Appendix 2 so you can dig deeper into any areas of particular interest.

A central role for local authorities

EnergyREV outputs suggest that local authorities are expected to play a central and multifaceted role in SLES. This includes gatekeeping spatial aspects of decentralised energy systems through planning and regulation, and democratisation through citizen engagement and local accountability.

Local authorities have responsibilities and track records of action in many areas relevant to SLES and decarbonisation, such as energy efficiency, heat, and transport. Not only do they control planning and local policy, but they are also large purchasers of energy themselves as well as acting as a vital "connective tissue" between individuals and organisations working on the ground and regimes with wider policy and market interests (Tingey & Webb, 2020; González et al., 2020a).

They stand to benefit where they can reduce public spending on energy costs, generate new public revenues and achieve socially beneficial outcomes (Tingey & Webb, 2020).

Active community and public engagement were found to be necessary elements of take-up of smart local energy in several EnergyREV studies, and local authorities are found to have an important role to play here too. Community-led SLES were more likely to report user engagement. In Scotland, high levels of local authority engagement are associated with the prevalence of SLES (Tingey et al., 2017 in Gupta & Zahiri, 2020). In other regions of the UK with a high penetration of local renewable energy projects, actively engaged local authorities and community energy groups are all factors associated with the higher take up of SLES (Gupta & Zahiri, 2020). There is still progress to be made in this area as community, university and local authority-led SLES are in the minority compared to distribution network operators and private sector-led developments so far (Gupta & Zahiri, 2020).

However, a number of challenges to the ability of local authorities to take up this role have been identified. These include lack of formal responsibility and resources to address long-term net zero goals, team capacity to provide technical assistance to SLES projects, and a requirement to actually evaluate expenditure for consistency with net zero principles (Tingey & Webb, 2020). For these reasons, the involvement of local authorities in SLES and local energy business in general has been uneven and often small-scale (Wilson et al., 2020a; González et al., 2020a).

While resource constraints have been exacerbated by the Covid-19 pandemic, it may also present an opportunity for change. An EnergyREV report has argued that viewing post-pandemic recovery through a "SLES prism" could unlock more, faster, better targeted and better value action towards a green economic recovery (Fell et al., 2020a, Figure 4). Local authorities are either central, or play an important role, in all facets of the prism.

There is an opportunity to utilise the post-Covid19 drive for local economic recovery through investments in clean energy industries by leveraging finance and development funding to citizen-led initiatives (Tingey & Webb, 2020), overcoming the barriers to community energy projects and addressing market failures (Hepburn et al., 2020).

Figure 6: The "SLES prism" (Fell et al., 2020a)

Local authority-led Green recovery plans could lead on retrofitting buildings for energy efficient homes and businesses, creating new full-time jobs and boosting the local economy (Green Alliance, 2020 in Fell, 2020a). Local Plans that push forward more ambitious net zero planning regulations on new buildings would support those businesses already investing in building lower carbon and accelerate the shift towards low carbon heating and cooling. Local transport strategies can prioritise healthier local journeys, encouraging walking, cycling and electric public transport and investing in electric vehicle charging infrastructure. Nationally, the benefit of a shift of just 1.7% of car kilometres to active travel is estimated to provide health benefits worth over £2.5 billion per year in 2030 (Green Alliance, 2020).

Evaluating the impacts of public funding and investment is an essential part of local authority accountability. Pless et al. (2020) recommend a number of ways to improve evaluation of publicly funded innovation which may be relevant to the role of local authorities in SLES.

These include considering embedding quasi experimental study design from the start, and developing and sharing learning in developing measures of impact. Impacts and outcomes would include associations between different funding mechanisms and outcomes, and measures of quality of innovation and environmental impacts. This would be done over a sufficient time period to examine effects after the programme or policy support. The set of metrics proposed as part of EnergyREV (Francis et al., 2020) is likely to be a useful starting point here.

Key recommendations

- Local authorities should follow a 5-point plan on government support for opening up the routes for locally led innovation (Tingey & Webb 2020):

  1. Establish long-term policy objectives and instruments for net zero carbon localities.
  2. Institutionalise local net zero carbon planning, strategy and implementation through statutory powers and devolved resources. Governments need to work with local authorities to move beyond the need to justify local energy investments as filling budget gaps for social care, to stimulate locally-led strategic net zero programmes.
  3. Build capacity for integrated local programmes through investing in local authority net zero teams. Local authorities should be offered opportunities to combine technical assistance resources. This should be backed up with regional and national coordination and support functions.
  4. Introduce net zero accountability across the public sector, including evaluating all public expenditure according to net zero principles.
  5. Use government economic and industrial strategy post-Covid to drive investment in net zero carbon localities. A concerted focus on investment in low carbon economic and industrial sectors would address market failures, drawing in more private finance.

- SLES projects should seek to involve already trusted parties – which often include local authorities – to help maximise participation and data sharing (Maidment et al. 2020b).
- Including local authorities (as well as other actors such as community groups and academic institutions) can help stimulate longitudinal engagement and evaluation in SLES initiatives, which should improve the likelihood of long-term success (Gupta & Zahiri 2020).

Driving investment

The conditions for maximising investment in SLES were examined in a number of EnergyREV outputs. Understanding this is essential if the PFER objective to "unlock 10x future private investment in local integrated energy systems in 2020s (vs business as usual)" is to be achieved. Financial barriers, such as access to finance, have been shown to be the main reported obstacle for community energy schemes (CEE, 2019).

A key component here is the role of public funding. A survey of community energy projects revealed that price guarantee schemes, such as feed-in tariffs, have played a core role in securing private financing (Braunholtz-Speight et al., 2020). Over 90% of the projects included in the study made a financial surplus, and it is calculated that this would have fallen to 20% in the absence of feed-in tariffs.

But EnergyREV reporting also highlights the significant potential of public funding to unlock investment beyond simple contribution to project finances. This includes avenues such as funding technical assistance. Tingey & Webb (2020) highlight the European-funded Elena project, which provided €150 million of funding to support local energy teams across Europe.

The activities undertaken by these teams are estimated to have contributed to generating €5.6 billion of further investment (EIB, 2019). In the UK, for every Euro invested through this scheme, €37 of additional investment is thought to have been generated.

Tingey & Webb (2020) highlight that improved technical assistance played a further important role in supporting wider investment: project aggregation. Often, individual local energy schemes are too small for large investors to invest in in isolation. Helping bundle schemes up into local programmes makes them a much more interesting prospect for larger investment. And because technical assistance improves the quality of projects, the energy and carbon savings delivered are thought to have been higher too.

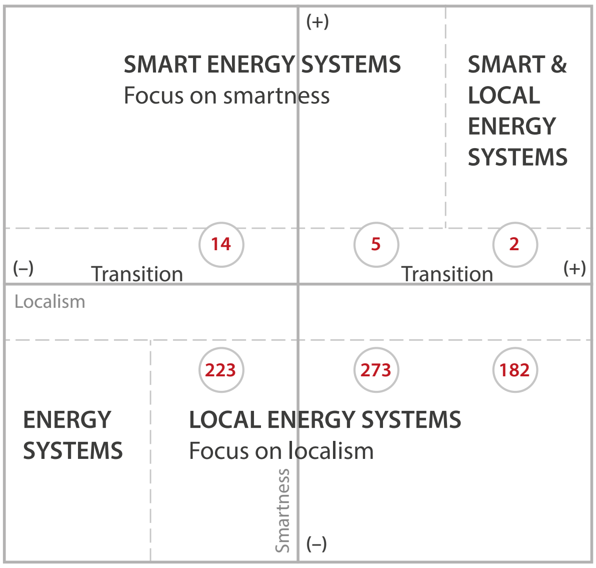


Figure 7: "Smart and local energy systems categorisation matrix" adapted from González et al. (2020b). 699 UK energy businesses are categorised into 6 groups (circled) based on localism and smartness degree estimates. Those towards the top of the matrix focusing on smartness and those to the right focusing on localism so, for example, the 182 businesses circled in the bottom right are focused highly on localism but not very highly on smartness. Only seven were assessed to be in the top right quadrant, potentially transitioning into true SLES, with the vast majority demonstrating a limited focus on smartness at present.

EnergyREV work has identified a number of other important factors which need to be addressed to unlock SLES-related investment. Mechanisms for funding storage and flexibility (such as the Capacity Market) are becoming less attractive sources of revenue to potential investors (Morris & Hardy, 2019).

This is accompanied by other important areas of policy/regulatory uncertainty, such as around the regulatory status and ownership of energy storage and the impact of network charging reviews on prospective revenues.

As well as encouraging new money into SLES, there is also a need to expand involvement beyond traditional incumbents. EnergyREV has noted the slow pace of development of a decentralised, integrated sector in the UK with many local energy businesses not integrated with digital or smart systems (González et al., 2020b, Figure 5).

There are a range of barriers to investment that are particularly relevant to new entrants, including:

- High capital costs that, for example, limit investment in power plants to a few incumbent investors. It is difficult to attract large investment for smaller scale projects (Li et al. 2020)
- Lack of public support schemes, e.g. the removal of the Feed-in Tariff (Rae et al., 2020)
- Insufficient intervention by government to allow or incentivise entry to the electricity market, and therefore low carbon investment, by third parties (Barazza & Strachan, 2020a)
- Perceived technical risks with new innovations compared to more mature technologies (Rae et al., 2020)
- Unattractive revenue streams from flexibility (changes in patterns of use or provision, principally of electricity, to balance supply and demand and maintain good system operation) and storage due to falling prices, rising costs, battery performance and uncertainty regarding future regulation (Morris & Hardy, 2019)
- Lack of technical or project management assistance to address gaps in local expertise is especially relevant for new entrants (Tingey & Webb, 2020)
- Flexibility and demand management measures. Balancing supply and demand reduces margins and therefore the financial appeal of local generation (Li et al. 2020)

Key recommendations

Recommendations relevant to supporting investment and new entrants include:

- Price support for exported electricity in the form of a price floor or Contract for Difference arrangement (Braunholtz-Speight et al., 2020)
- Mandated purchasing of community-generated energy by public bodies (Braunholtz-Speight et al., 2020)
- A stronger coordinating role for local authorities (Tingey & Webb, 2020; plus see specific recommendations in preceding section)
- Further research on the full range of investment models, types and sources which could finance net zero carbon localities, including joint ventures and private-sector-led investment (Tingey & Webb, 2020)
- Policy support for investment in local energy businesses and community benefit projects, such as through tax exemptions or other benefits, with increased transparency through a unified financial, business disclosure regime (González et al., 2020a)
- Local energy businesses are advised to consider ownership or partnerships with stakeholders, involving them in more decision making to strengthen ties and unlock non-monetary benefits (González et al., 2020b)
- New approaches such as multiple supplier models could encourage consumers to engage with local energy suppliers or other new entrants while allowing incumbent providers to explore new business models with less risk (Watson et al., 2020)
- More research is needed on how different organisations respond to different support mechanisms, and which mechanisms work best for whom, in which contexts (Pless et al., 2020)

Connecting and coordinating technologies

Much of EnergyREV's work so far has examined the connectivity of SLES, focusing on the technical and financial approaches that have been adopted, or could be. Traditionally, large energy projects have been a more attractive prospect for investors than smaller, distributed renewable energy schemes in terms of risk and reward (Wilson et al., 2020a). SLES could be key to addressing this imbalance in offering opportunities to connect granular technologies in ways that maximise their value to users, the network as a whole, and investors. For example, peer-to-peer (P2P) trading platforms can help prosumers generate profit while addressing network constraint issues (Morstyn et al., 2019), potentially driving readiness to invest in distributed energy resources. As smaller investments are needed, a wider range of investors and types of investors would have access to this market, which it is predicted could lead to an increase in aggregated investment in the UK (Barazza & Strachan, 2020a).

Finding ways of connecting up granular technology to make it a more viable investment could also help produce other benefits. These include (Wilson et al., 2020b):

- Production scale leading to cheaper technologies, driving faster market diffusion and lowering investment risk and opportunity cost
- Simpler technologies to avoid or reduce interoperability issues
- The ability to upgrade and replace components more frequently to allow for rapid improvement cycles and so greater innovation

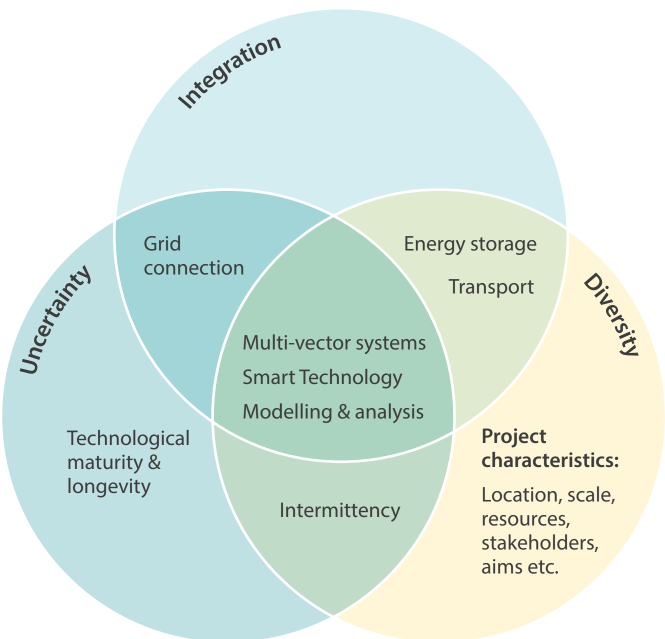
SLES approaches are not without risks and costs. The adoption of any technology takes time and effort so adopting multiple small-scale technologies will likely involve more time and money than larger, single schemes.

Incorporating and connecting these technologies also involves infrastructure expansion of the physical network, the computing needs (which may be complex) and the institutional networks that will enable the transfer of the necessary knowledge and skills. For this reason, intermediaries will have key roles in facilitating scale up or replication of SLES (Rae et al., 2020). The market response to the scaling up of SLES will be difficult to predict but more and more data is being collected that can help modellers address these uncertainties.

What works to integrate technologies and people?

Interoperability

Interoperability means that different parts of systems can work smoothly together, such as technologies which can exchange data in the same format. EnergyREV work has highlighted how important this is for the success and scale up of SLES. Interoperability is important for the user experience (Morris & Hardy, 2019) as it can improve ease of use, familiarity and choice, for example in electrical vehicle charge points. It also provides opportunities for businesses to develop more compatible, therefore more attractive, products (Verba et al., 2020a).



Beyond connecting to the heavily standardised existing electricity grid, issues for local and multi vector connection tend to be project or technology specific (Rae et al., 2020).

Technical and implementation barriers can be overcome through the use of simpler, interoperable components that can be easily integrated within larger systems, thereby stimulating rapid innovation cycles (Wilson et al. 2020b). Specific recommendations from EnergyREV include the application of a proposed smart microgrid computing architecture to overcome technical barriers and facilitate connection with peer systems and services (Verba et al., 2020b). Overlapping themes of integration of technology, combined with uncertainty and diversity, create the three main technical barriers to upscaling SLES identified in the literature (Rae et al., 2020).

Standardisation

In addition to emphasising the value of interoperability, some EnergyREV outputs have addressed how this might be achieved through standardisation and what implications such approaches might have. Standardisation means adopting common approaches to design, activity, operations, etc. Standards allow for greater economies of scale in production and offer opportunities for business to develop products that can be integrated more widely and therefore can achieve faster market diffusion (Wilson et al., 2020b). Standardisation can also provide a better user experience by reducing the number of technologies and approaches that a user needs to participate in to receive a range of services or by reducing the amount of time and effort needed to familiarise with these approaches (Morris & Hardy, 2019).

Figure 8: Technical barriers to upscaling SLES (Rae et al., 2020)

Challenges for integrating technologies

Uniformity

The risk of standardisation though, is that it can limit the ability to address local contexts through local approaches (Wilson et al., 2020b). Successful integration can lead to interdependence and standardisation that 'locks in' dominant designs, where the best tool for the job is overlooked in favour of the one that already connects with existing technologies and infrastructures, or is more familiar to users or practitioners. This issue can be exacerbated where local regulation and planning lags behind the development of new technologies, incentivising the use of tried and tested over novel approaches. A lack of local expertise can be eased by standardised components and connections but this potentially limits the innovation and approaches that can be taken to meet local needs. This aligns with how SLES tend to be used to address wider issues: most current SLES schemes are focused more on the 'smart' than the 'local' (Gupta & Zahiri, 2020), while the PFER demonstrators aim to encourage economic growth and energy transition at least as much as they tackle local issues (Devine-Wright, 2019).

Smart readiness

SLES presents challenges for implementing and integrating new technologies including:

- How interoperable they are with existing systems
- Whether the users of the system and the practitioners implementing it have the knowledge they need and, if not, how they can access it
- The uncertainty, risks and costs involved with adopting novel approaches
- The need for more or improved infrastructure to accommodate the technology

The use of smart technologies within SLES raises particular issues as increased amounts of data are gathered that need to be stored and used (Verba et al., 2020b).

In addition to increased storage capacity, computing systems will need to be more complex so that the data collected can be used innovatively for control in order to provide maximum efficiency and flexibility. Privacy is also a key issue as participants in SLES will want reassurance that their data is held securely and used fairly, for their benefit (Vigurs et al., 2021).

Opportunities provided by connected technologies

This digitalisation also presents opportunities as 'smart ready' systems and infrastructures have the potential to address issues such as rising energy demands that are occurring either naturally or as a direct result of SLES and decarbonisation efforts. One example is the uptake of electric vehicles which, despite a reduction in emissions, increases strain on the grid (Morris & Hardy, 2019). Digitalisation helps SLES providers tap into opportunities to provide flexibility, resilience and interconnectivity by automating or improving decision making with regards to balancing local energy supply and demand or shifting demand between times, technologies and vectors. The role that data-driven SLES approaches can play in decarbonisation is one focus of the ongoing EnergyREV work, alongside the issues and considerations such approaches raise.

Key recommendations

Recommendations from EnergyREV include:

- Using a combination of central and local solutions to maintain the robustness of existing industry protocols, while allowing the flexibility needed to scale up SLES (Verba et al., 2020a)
- Following Energy Data Taskforce recommendations including making data interoperable (Morris et al., 2020)
- Further research into how concentrated and dispersed versions of SLES may produce different impacts (Aunedi & Green, 2020) and new actors and projects that can produce a range of benefits and therefore accelerate decentralisation (González et al., 2020a)

Flexibility, storage, and resilience

Flexibility, storage and resilience are interdependent characteristics of SLES. They create flexibility by providing the capacity to adjust demand to mitigate transmission constraints and maximise the integration of intermittent renewables. This increases the security of supply. Storage is one of the key technologies with which SLES provide such flexibility by acting as either demand or supply as required. The two combine to increase the resilience of the broader energy system.

Flexibility in the context of energy can be broadly thought of as changes in patterns of use or provision, principally, of electricity, to balance supply and demand and maintain good system operation. It was a key theme in many EnergyREV studies, and consistently viewed as an important feature of SLES (Ford et al., 2019a; Aunedi & Green, 2020). Furthermore, modelling work has suggested that the potential of SLES to unlock increased flexibility locally, primarily through demand response and storage, could play a role in minimising overall system costs through reducing need for investment in low-carbon generation (Aunedi & Green, 2020).

Flexibility in SLES is expected to be unlocked through a combination of demand response and storage. Examples of how this can be achieved through the use of P2P trading and innovative network charging have already been highlighted in section on 'Connecting and coordinating technologies' above. There is also likely to be a role for switching between multiple energy vectors (Ford et al., 2019a).

In certain cases, it is likely to make sense to oversize local assets (such as thermal stores) because of the flexibility benefits this could bring to the wider system (Aunedi et al., 2020). However, there are anticipated to be challenges associated with meeting anticipated demand for storage, especially longer-term storage (Rae et al., 2020). It also needs to be made more attractive to investors, who are put off by price and planning uncertainty, high planning costs and lack of regulatory clarity (González et al., 2020b).

The system elements associated with providing flexibility, such as storage and automated control, provide a key benefit beyond those of balancing supply and demand or grid services – they help increase the overall resilience of the system. Resilience suggests an ability to quickly recover when things change or go wrong. Forms of resilience can range from the insulation that energy storage can bring from power or heat shortages when systems go down, through to new models of current and voltage control that could be used to improve the stability of future direct current (DC) microgrids (Braitor, 2020a, 2020b; Paspatis et al., 2019; Cao et al., 2020).

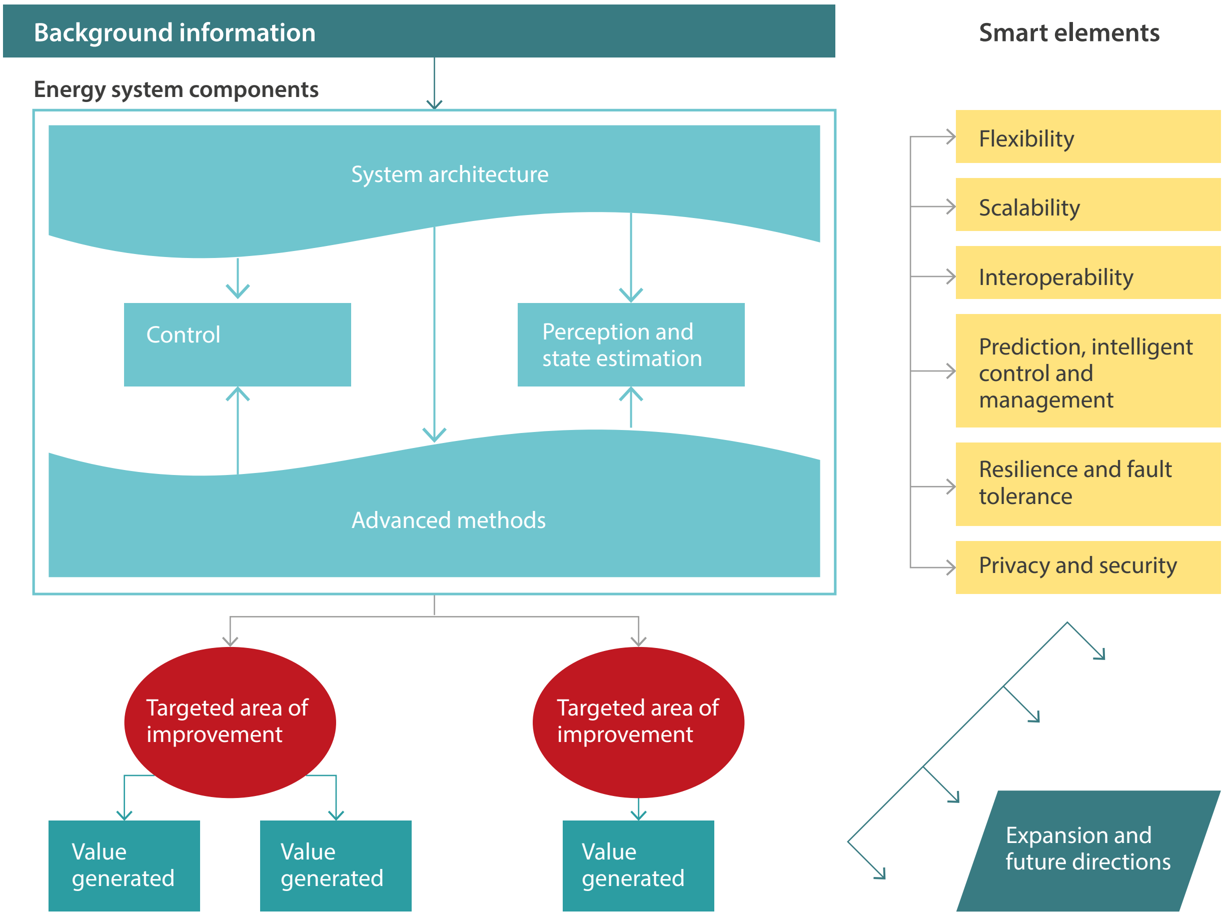
While increasing flexibility is seen as an essential component of future low-carbon energy systems, it may not always have the effects that we expect. Agent-based modelling work by Li et al. (2020), for example, indicates that under scenarios with high levels of flexibility, investment in low-carbon generation technologies could actually be delayed. This is because flexibility reduces the need for, and therefore the value of, such new generation assets. Nevertheless, this work suggests that overall a greater role for SLES will drive faster investment in renewable generation as the pool of potential investment expands beyond incumbents who are more likely to invest in large, centralised generation such as nuclear.

The ability of SLES to yield this flexibility may anyway be constrained by certain aspects of current policy and regulation. These include limitations around the classification and ownership of energy storage, the attractiveness of flexibility support mechanisms (such as the Capacity Market) and an uncertain environment around the future of network charging (Morris & Hardy, 2019). More focus is needed on making SLES infrastructure 'smart ready' to ensure that, for example, the potential flexibility from electric vehicle charging is able to be realised (Morris & Hardy, 2019). There is an evolving role for distribution network operators (DNOs) as distribution service operators (DSOs), to facilitate the procurement of ancillary services associated with flexibility (Morris et al., 2020).

A further constraint could come in the form of reluctance on behalf of users to share the data and access to technologies necessary to unlock flexibility. Privacy concerns can act as barriers to sharing, and it will be important for SLES providers to seek to mitigate this through means such as user involvement, collaboration with trusted local actors, and clear consent processes (Vigurs et al., 2021).

Flexibility also has another important meaning in the context of SLES – the capacity to adapt and be used in different ways. This might be through incorporation of new technologies, devices, and protocols; digital and physical extensions; changes in the system size and the variety of energy vectors; and changes in sources and consumers throughout its lifecycle (Verba et al.,2020a).

Figure 9: **Functional Analysis Framework** for evaluating SLES project components in order to develop a future-proof energy system with the capacity to adapt to new technologies, requirements and uses (Verba et al., 2020a)



Key recommendations

To increase the beneficial contributions that SLES-enabled flexibility can make, recommendations from EnergyREV research include opening up flexibility markets and support mechanisms to a wider range of players (Hall et al., 2020; Morris & Hardy, 2019; Morris et al., 2020), developing responses to regulatory barriers and working to create the conditions of trust and security which customers are willing to consent to access to necessary data (Vigurs et al., 2021). Efforts to build trust in residential customers can be informed by the following principles:

1. Recognise the mutual benefits of data sharing for smart local energy systems and work with customers as partners.
2. Involve people in the design of data sharing technologies from the start.
3. Give people a say on the third parties that they are happy to share data with.
4. Empower people to set the boundaries around the flow of information about themselves.
5. Ensure that the purpose and value of the data collected are transparent and fair.
6. Ensure that everyone affected by sharing of data are involved in giving their informed consent.
7. Recognise that technologies for revealing and monitoring behaviours in the home can be used in unexpected and unwanted ways.
8. Ensure there are channels of feedback and ongoing communication to continuously improve service delivery.

Recommendations from these studies suggested that future research should consider how interactions between different energy vectors within, or facilitated by, SLES could "further contribute to a cost-efficient operation and design of an integrated low-carbon energy system" (Aunedi & Green, 2020). They also noted a research gap around the "potential for SLES to coordinate flexibility provided by district heating systems through controlling power and heat sources and using thermal storage and the thermal inertia of pipes and buildings".

We expect further concrete recommendations to emerge during the remainder of the project.

Direct economic benefits for SLES participants

Substantial effort within EnergyREV has been dedicated to exploring the conditions under which SLES can lead to financial savings or increased revenues for participants. The main focus has been on how local electricity networks can be managed and charged for in order to minimise costs for users, while also avoiding challenges such as curtailing renewable generation.

A number of publications show how P2P energy trading can be used to achieve this aim (Morstyn et al., 2019; Savelli & Morstyn, 2020; Tushar et al., 2019, 2020; Zhou et al., 2020). The publications provide detail on how the trading schemes are designed, and we link to these in the sections on **Recommendations for future research** and **Practical tools and materials** at the end of this report. The solutions show how prosumer revenues and consumer savings can be increased where participants are able to buy and sell power directly between each other. (See Table 1, for example, from Tushar et al. 2019). This value comes because incentivising local use of local electricity reduces congestion on local network infrastructure, and in turn the need to curtail this generation (Morstyn et al., 2019). Importantly, as Savelli & Morstyn (2020) demonstrate, benefits can even accrue to participants without generation and who are unable to be flexible in their use of electricity. Similar welfare benefits can potentially be achieved through the use of dynamic network tariffs (Paola et al., 2020).

Looking more broadly, work by González et al. (2020a,b) explored the nature of businesses active in the local energy space. Their findings reveal that over a third (36%) declare some kind of community benefit aim, principally through providing community funds or through local ownership. However, the work highlights that little is still known about the overall extent and nature of the local benefits that are actually yielded.

Table 1: Economic benefits for prosumers participating in the peer-to-peer trading scheme proposed by Tushar et al. (2019)							
Number of prosumers	Total demand	Cost to CPS ($)		Total cost to participating prosumers ($)		Cost reduction for participating in P2P ($)	
		With P2P	Without P2P	With P2P	Without P2P	CPS	Per prosumer
10	24	0	3.28	4.76	108.00	3.28	10.32
15	46	0	53.12	9.34	529.00	53.12	34.64
20	63	0	234.36	12.05	1480.50	234.36	73.42
25	67	0	258.25	12.87	1507.00	258.25	59.78
30	92	0	877.24	16.78	3910	877.24	129.77
Average cost reduction						285.25	61.58

Key recommendations

While the modelled benefits of local trading mechanisms are clear, they have still only been tested on a limited basis in the real world. Some of the PFER demonstrator projects should help build this real world evidence. However, as highlighted by (Morris et al., 2020; Savelli & Morstyn 2020), significant regulatory barriers still exist to their wide implementation. Also, further research is needed to understand questions such as:

- How markets can be designed that achieve an optimum trade-off between overall economic efficiency, DSO profits and the probability of network constraint violations (Morstyn et al., 2020)
- How P2P trading might affect network voltages and losses (Tushar et al., 2019)
- The role of uncertainties around generation and load forecasting (Zhou et al., 2020)
- The role that the introduction of new actors, such as businesses from other sectors, could have in delivering local environmental, economic, and welfare benefits (González et al., 2020a)

Who's who: citizens, consumers, prosumers, market actors?

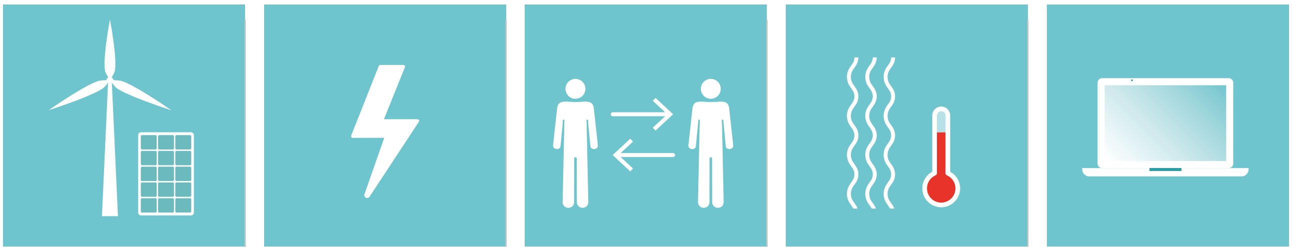
EnergyREV research has called attention to the different ways in which SLES and their participants are framed. Terms were sometimes used interchangeably but these stakeholder concepts had different roles, responsibilities and expectations as well as legal status and regulatory frameworks of protection.

Devine-Wright (2019) examines the distinction between 'local' and 'community'. 'Local energy' is usually spatially defined and often described in the literature as an aggregate of individual, self-interested market actors, with a focus on the role of technological innovation. This was compared to community energy projects which are more likely to be citizen-led, tending towards direct consumer or public participation as its aims and achieving non-profit/market outcomes, such as sense of belonging. Community-led initiatives could be more resilient to changes in policy priorities and specific investment opportunities than "local" energy projects (Devine-Wright, 2019).

This more engaged role for energy system users is captured in the concept of the prosumer, or those who both produce and consume energy, particularly electricity. Prosumers are seen as playing a key role in SLES; in them the spheres of local and community, cooperation and competition could come together, capturing both aspects of being a self-interested market actor and a socially minded citizen. However, while prosumers and community energy groups are encouraged to participate as active energy customers, producers and purchasers of energy (such as through P2P trading), there is a regulatory protection-gap between consumer protection laws and business regulations for these new forms of market actors, (individuals and collectives) in new business models (Hall et al., 2020). They are expected to take on financial risk but without the same protections as experienced and professional business and investors, and may be more vulnerable to changes in policy and investment priorities. These new "active energy citizens" may find it difficult to access funding and investment, the discontinuation of the feed-in tariff being cited as one barrier as well as a lack of access to finance and development funding (Tushar et al., 2020; Rae et al., 2020).

Modelling studies found that heterogeneity of market players could be an advantage in leading to higher aggregated investments in German and UK scenarios. Devine-Wright (2019) recommended that the inclusion of a range of different actors involved in energy should be strongly encouraged in policy and practice to ensure fast and wide transition to clean energy. It was suggested that large scale, high capital costs investment will still be needed, at a reduced scale, from the present incumbent investors (Barazza & Strachan, 2020a, Li 2020) but that barriers to entry for new third parties risk locking in the conventional generation by large utility companies (Barazza & Strachan, 2020a).

Figure 10: Low carbon business models analysed by Hall et al. (2020)



Pure low-carbon generator	New electrifier	Peer-to-peer	Energy Service Company	Third party control
Producing low-carbon power and selling directly to large customers or wholesale market	Traditional utility that is helping consumers switch to electric hear and mobility, including installing equipment and automating DSR	P2P customers directly buy, sell or swap electricity with each other	An ESCo delivers energy services to customers, such as comfort, and illumination, rather than units of energy like a traditional supplier	A their party, such as a price comparison website, takes decisions on consumers' behalf, like automatically switching energy supplier

Key recommendations

There was general consensus in the included studies that increasing the diversity of participants in the new electricity markets was necessary to make the transition to clean, renewable energy and meet net zero targets. However, there remain some barriers to new entrants, often related to their definition and legal status. EnergyREV recommends that:

- SLES providers harness grassroots support where possible as community-led initiatives tend to endure longer and produce greater local co-benefits than company-led investment in local energy schemes (Devine Wright, 2019)
- The development of new flexibility markets is accelerated and steps are taken to simplify the increasingly complex regulatory framework, addressing any unintended consequences (Hall et al., 2020)
- Further research is needed on technical barriers which, while often context-specific, may have contributing factors common to new entrants and those looking to upscale SLES (Rae et al., 2020)
- Diverse market players and their realistic, adaptive behaviours are represented in energy system models to ensure that policy design for decarbonisation is effective (Barazza & Strachan, 2020a)

Aligning recommendations across EnergyREV

EnergyREV researchers have produced advice and guidance on a wide range of topics: please see Appendix 2 for links to the outputs published so far by each work package. From these findings we have found some initial areas of alignment (below) where similar or related recommendations have arisen from different work packages. Further areas of overlap and support are being identified across the consortium as members collaborate and discuss their work, and we expect to see more alignment as new evidence is published by the work packages. Over the remainder of the project, EnergyREV will work to draw out the key messages arising from both the outputs and the interactions between researchers.

Recommendations for policy and practice

Many of the recommendations that EnergyREV has produced so far for policymakers concern engagement strategies to promote local involvement in, and acceptance of, SLES:

- Harnessing grassroots support to effect change (Devine-Wright, 2019)
- Building engagement and evaluation, using local actors and trusted organisations, into SLES development (Gupta & Zahiri, 2020)
- Improving local planning to encourage the development of smarter infrastructure (Fell et al., 2020a)
- Using flexible, scalable system architectures that can adapt to future needs (Verba et al., 2020a)

These issues are mirrored in the EnergyREV recommendations for SLES providers. These include engaging with communities via local actors to ensure that SLES address local priorities (Gupta & Zahiri, 2020) and building on this engagement and trust to promote these benefits alongside providing support, transparency and control to energy users (Vigurs et al., 2021).

Various EnergyREV authors propose approaches to assist the design or implementation of SLES, from Deep Reinforcement Learning methods in energy storage markets (Cao et al., 2020) to a wide-ranging suite of measures that utilise SLES to boost economic recovery following the pandemic (Fell et al., 2020a). A set of practical tools developed by EnergyREV for SLES providers is included at the end of this document.

Recommendations for future research

EnergyREV has also produced a range of methodologies and suggested approaches to improve research on SLES. These include:

- A transparent and easily replicable methodology using aggregated data to estimate the effect of electricity generation technologies on employment (Arvanitopoulos & Agnolucci 2020)
- A framework for energy innovation policy and programme evaluation highlighting common challenges and recommending solutions (Pless et al., 2020)
- Discussion of how scenario modelling can be improved by the inclusion of extremes (McCollum et al., 2020)
- A novel framework to analyse and track Covid19 mitigation progress in the aviation, shipping, road freight transport, and industry sectors (Sharmina et al., 2020)
- A framework for compatible fixed and nodal structures to increase efficiency, addressing emerging economic problems in a local distribution area (Savelli & Morstyn 2020)
- A framework for ancillary service provision from a P2P energy trading community (Zhou et al., 2020)
- A framework for identifying cost-efficient solutions for supplying district heating systems, considering local and national-level interactions between heat and electricity infrastructures (Aunedi et al., 2020)
- The recommendation that all stakeholders are included in evaluation. For example, participants in this kind of research are often required to be familiar with the technology in question or volunteer because of their interest, so may respond differently to those who have less interest or experience (Vigurs et al., 2021). Success should be measured through an "equity lens" by considering differential impacts for different groups, e.g. by using a framework like the PROGRESS-plus determinants of health and wellbeing (O'Neill et al., 2014).

Beyond advice to adopt specific approaches, the majority of EnergyREV's calls for future research were to develop a better understanding of how the authors' findings fit into the bigger picture of SLES. We recommend further research into the interaction between the systems, practices and actors involved in SLES, particularly:

- How new elements can be introduced effectively, e.g. incorporating prosumers (Tushar et al., 2019)
- What synergies exist to enable them to complement and support each other (Tingey & Webb, 2020)
- How organisations respond to certain mechanisms and policies (Pless et al., 2020)
- The real-world impacts of SLES have, for whom and in what circumstances, to help quantify the value added and identify potential unintended consequences (Aunedi & Green, 2020; Ford et al., 2019b; Wilson et al., 2020c).

Practical tools and resources produced by EnergyREV

Work packages across EnergyREV have developed new frameworks, guidelines and tools for those involved in SLES, including SLES planning and provision:

- A framework for understanding and conceptualising SLES to support design and development (Ford et al., 2019b). In this four-stage approach, the framework aims to provide a structure for SLES stakeholders to consider how and in what ways SLES projects could deliver value in their local context and within the wider technical, social, environmental, financial, and regulatory systems.
- Verba et al. (2020a) have designed a demonstrator design analysis framework, consisting of a two-stage, 10-step process to give organisations a method to analyse SLES projects based on their Cyber Physical System (CPS) components and develop a future-proof energy system.
- A research portal is being developed to provide access to the range of existing research evidence on SLES (Maidment et al., 2020a)
- From an in-depth literature review of evaluation tools and stakeholder analysis, Francis et al. (2020) propose a taxonomy to measure the performance of SLES which fall into 10 clusters of themes: Data Security, Data Connectivity, Technical, Transport, Economics, Business and Finance, Governance (Socio-Political), People, Living and Environment.
- Pattern-IT is a novel, co-created participatory method, using card sorting and sentence mapping (Devine-Wright, 2020) that aims to illuminate the relationships between people, technologies and concepts in complex systems. In this study, 13 steps in the process are described that correspond to the three research phases: preparation, implementation and interpretation.
- Morstyn and team present Open Platform for Energy Networks (OPEN), an open-source platform for developing SLES applications (Morstyn et al., 2020) addressing the current challenge of software tools to model, control and simulate distribution systems with embedded distributed energy resources being divided between multiple tools. OPEN is available for download.
- Insights and recommendations (Maidment et al., 2020b) draw from evidence of the guiding principles of services design that address customer privacy concerns about sharing energy use data into recommendations for action for SLES data using stakeholders.
- A theory of change is ongoing work, mapping the evidence for SLES, how they work and how SLES could support prosperous UK communities (Fell et al., 2020b). This includes a set of worksheets that SLES operators can use to think through the necessary conditions for SLES to come about; the necessary conditions for good outcomes to result; key assumptions that need to be tested; and key risks to watch out for.

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Appendix 1: Organisational chart of the EnergyREV Consortium

Programme Management, Execution and Facilitation

Executive Committee

Principal Investigator: Stephen McArthur. **Research Director**: Rebecca Ford

Internal: Jo Patterson, David Ingram, David Shipworth, Simon Sjenitzer

External: Eric Brown, Rob Saunders, Jim Fleming

Project Management

Stephen McArthur, Rebecca Ford, Jill Rymer

Knowledge Management, Engagement and Dissemination (KMED)

Lead: Jo Patterson. **Members**: Rebecca Ford, Jeff Hardy, Melanie Rohse, Simon Sjenitzer, Jill Rymer

Researchers: Richard Hoggett, Ifeoluwa Garba

↓↑	↓↑	↓↑	↓↑
Infrastructure	**Business**	**Institutions**	**Users**
Core/Plus projects delivering review of past work, gap analysis, new research, knowledge exchange			
WP 1.1 Cyber-physical advances Lead: Elena Gaura Co-Is: Zhong Fan, George Konstantopoulos, Stephen McArthur, Jianzhong Wu Researchers: Euan Morris, Nandor Verba, Lakshmi Srinivas Vedantham, Pable Rodolfo Baldivieso Monasterious, Mike Siyuan Dong, Andrei Braitor, Yue Zhou	**WP 2.1 Business & financial practices** Lead: Jan Webb Co-Is: Matt Hannon, Maria Sharmina Researchers: Fabián Fuentes Gonzalez, Dimitrios Pappas, Tim Braunholtz-Speight	**WP 3.1 Policy, regulation & market enablers** Lead: Jeff Hardy Co-Is: Matt Hannon, Cameron Hepburn, Jonathan Radcliffe, Rebecca Ford Researchers: Madeleine Morris, Rachel Bray **WP 3.2 PLUS market design for scaling up local clean energy systems** Co-leads: Cameron Hepburn, Thomas Morstyn.	**WP 4.1 User behaviour and preferences** Lead: Patrick Devine Wright Co-Is: Jillian Anable, Rajat Gupta, Melanie Rohse, Charlie Wilson, Rebecca Ford Researchers: Sahar Zahiri, Luke Gooding **WP 4.2 PLUS user influence tools** Lead: Rajat Gupta Co-Is: Patrick Devine-Wright, Sarah Darby Researcher: Sahar Zahir

<table>
<tr><th>Infrastructure</th><th>Business</th><th>Institutions</th><th>Users</th></tr>
<tr><td colspan="4">Core/Plus projects delivering review of past work, gap analysis, new research, knowledge exchange</td></tr>
<tr><td></td><td></td><td>WP 3.2 continued…
Co-Is: Jeff Hardy, Jonathan Radcliffe. Associate: Alex Teytelboym.
Researchers: Iacopo Savelli, Chiamaa Essayeh</td><td></td></tr>
<tr><td>↓↑</td><td>↓↑</td><td>↓↑</td><td>↓↑</td></tr>
<tr><td colspan="4">Developing a whole system understanding</td></tr>
<tr><td colspan="4">WP 5.1 Synthesis
Co-leads: David Shipworth & Mike Fell. Researchers: Chris Maidment, Carol Vigurs</td></tr>
<tr><td colspan="4">WP 5.2 Multi-criteria
Lead: David Ingram. Co-I: Camilla Thomson. Researcher: Christina Francis</td></tr>
<tr><td colspan="4">WP 5.3 Next wave of energy systems in a whole system context +
Co-Leads: Tim Green, Neil Strachan. Co-Is: Charlie Wilson, Jianzhong Wu. Researchers: Marko Aunedi, Pei-Hao Li, Elsa Barazza, Enrique Ortega, Theo Arvanitopoulos, Alexandre Canet, Muditha Abeysekera, Meysam Qadrdan</td></tr>
<tr><td colspan="4">Supporting scale-up</td></tr>
<tr><td colspan="4">WP 6.1 New tools and framework
Lead: Walter Wehrmeyer. Co-I: Rajat Gupta. Researchers: Damiete Emmanuel-Yusuf, Sahar Zahiri</td></tr>
<tr><td colspan="4">WP 6.2 System integration
Lead: Mercedes Maroto-Valer. Stephen McArthur leading Tasks 3 and 4. Co-I: Sandy Kerr. Researcher: Callum Rae</td></tr>
<tr><td colspan="4">WP 6.3 New skills and training
Lead: Ruzanna Chitchyan. Co-I: Roberto Ferrero. Researchers: Caroline Bird, Helene Turon</td></tr>
<tr><td colspan="2">↓↑</td><td colspan="2">↓↑</td></tr>
<tr><td colspan="4">Roving Champions</td></tr>
<tr><td colspan="4">Jillian Anable (transport), Alona Armstrong (environment), David Elmes (heating & cooling), Simon Sjenitzer (industry). Cross-consortium Researchers –Sam Robinson (environment), Rachel Bray (institutions)</td></tr>
<tr><td colspan="4">International engagement</td></tr>
<tr><td colspan="4">Lead: David Armstrong, Researcher: Alexandra Schneiders</td></tr>
</table>

Appendix 2: Table of EnergyREV outputs published or submitted prior to the end of 2020

Output	WP	Study aims	Methods	Secondary Challenge Areas
Challenge Area: Data and digital				
		Models		
Gavin, H., & Morstyn, T. (2019) How can P2P energy trading platforms be designed to create value for both prosumers and system operators?	3.2	To propose a peer-to-peer (P2P) energy trading scheme	**Discussion** • Trade association report	Users
Mendoza, F. G. et al. (2019, 2019) Online Pricing via Stackelberg and Incentive Games in a Micro-Grid.	1.1	To test pricing online pricing mechanisms in microgrids Stackelberg and Incentive Games	**Model** • Behavioural	Users
Morstyn, T. et al. (2019) Integrating P2P Energy Trading with Probabilistic Distribution Locational Marginal Pricing.	3.2	To propose a new local energy market design which integrates peer-to-peer energy trading and probabilistic distribution locational marginal prices (DLMPs).	**Model** • Economic	Users
Savelli, I., Morstyn, T. (2020) Electricity prices and tariffs to keep everyone happy: a framework for compatible fixed and nodal structures to increase efficiency.	3.2	To test a model for both fixed and nodal pricing A framework to "address emerging economic problems in a local distribution area related to the coexistence of traditional consumers, flexible prosumers, and a DSO."	**Model** • Economic	Users
Tushar, W. et al. (2019) Grid Influenced Peer-to-Peer Energy Trading.	3.2	To propose a peer-to-peer (P2P) energy trading scheme	**Model** • Economic	Users

Output	WP	Study aims	Methods	Secondary Challenge Areas
Tushar, W. et al. (2020) A coalition formation game framework for peer-to-peer energy trading.	3.2	To propose a peer-to-peer (P2P) energy trading scheme	**Model** • Behavioural	Users
Verba, N. et al. (2020b) Flexible Fog Computing Architecture for Smart Microgrids.	1.1	To propose a flexible fog computing-based, distributed deployment and virtualisation architecture that solves some of the integration challenges	**Observational** • Case study	Technology
Zhou, Y. et al. (2020) Framework design and optimal bidding strategy for ancillary service provision from a peer-to-peer energy trading community.	1.1	To design a framework for ancillary service provision from a P2P energy trading community	**Model** • Economic	Users
		Investigating barriers and facilitators		
Maidment, C. et al. (2020) Privacy and data sharing in smart local energy systems: Insights and recommendations.	5.1	To inform SLES providers on addressing privacy concerns "…how they can work with users to get the data they need to operate, while respecting and addressing users' privacy concerns."	**Review** • Rapid realist review	Users, Policy
McCollum David, L. et al. (2020) Energy modellers should explore extremes more.	5.3	To discuss how scenario modelling can be improved "Energy modellers can study extremes both by incorporating them directly within models and by using complementary off-model analyses."	**Discussion** • Comment	Users, Ecosystem, Technology, Policy, Evaluation
Morris, M. et al. (2020) Policy & Regulatory Landscape Review Series – Working Paper 2: Digital energy platforms.	1.1, 3.1, 3.2	To identify the role of, and how the current environment helps or hinders, digital energy platforms	**Review** • Map/Scoping	Skills, Policy

Output	WP	Study aims	Methods	Secondary Challenge Areas
Vigurs C et al. (2021) Customer Privacy Concerns as a Barrier to Sharing Data about Energy Use in Smart Local Energy Systems	5.1	To inform SLES providers on addressing privacy concerns "To provide evidence-informed guidance on how SLES providers can minimise both concern and cause for concern around privacy."	**Review** • Rapid realist review	Users, Policy
		Research and methodological development		
Morstyn, T. et al. (2020). OPEN : An open-source platform for developing smart local energy system applications.	3.2	To propose a testing platform for SLES applications	**Methods** • Modelling software	Technology
Verba, N. et al. (2020a) The energy revolution: cyber physical advances and opportunities for smart local energy systems.	1.1	A method to analyse SLES projects based on their cyberphysical components	**Observational** • Case study **Methods** • Analysis framework	Technology, Evaluation
Challenge Area: Users				
		Investigating barriers & facilitators		
Watson, N. et al. (2020) Two energy suppliers are better than one: Survey experiments on consumer engagement with local energy in GB.	5.1	To assess the attractiveness of a multiple-supplier model and to understand whether consumers would be more likely to engage with local energy suppliers in a multiple-supplier model.	**Experimental** • Quasi	Business
		Maps/ describes current state		
Gupta, R., & Zahiri, S. (2020) Evaluation of user engagement in smart local energy system projects in the UK.	4.1	To investigate user engagement and its evaluation "…a meta-study approach to investigate user engagement and its evaluation in SLES initiatives undertaken in the UK over the last 10 years."	**Review** • Systematic	Evaluation

Output	WP	Study aims	Methods	Secondary Challenge Areas
		Research and methodological development		
Devine-Wright, H. (2020) Pattern-IT: A method for mapping stakeholder engagement with complex systems.	4.1	A method for mapping stakeholder engagement with complex systems A novel co-created participatory method for use with individuals or groups.	**Methods** • How-to guide	
Challenge Area: Business and Finance				
		Models		
Arvanitopoulos, T., & Agnolucci, P. (2020) The long-term effect of renewable electricity on employment in the United Kingdom.	5.3	A methodology based on a transparent and easily reproducible econometric analysis using aggregated and widely available data. Provides evidence that the long-term employment impact of renewable technologies is much higher than nuclear or natural gas technologies.	**Model** • Economic	Skills
Paola Antonio, D. et al. (2020) • A novel ex-ante tariff scheme for cost recovery of transmission investments under elasticity of demand.	3.2	To propose a novel tariff scheme for the recovery of investment costs in transmission network planning To evaluate the performance of the mechanism [a novel ex-ante dynamic network tariff scheme] in a context of increasing demand elasticity.	**Model** • Economic	Data, Users
Barazza, E., & Strachan, N. (2020) The impact of heterogeneous market players with bounded-rationality on the electricity sector low-carbon transition.	5.3	To model bounded rationality behaviours towards low carbon investment Using BRAIN-Energy, a novel agent-based model, to explore impacts on the transition pathways of the UK, German and Italian electricity sectors.	**Model** • Behavioural	

Output	WP	Study aims	Methods	Secondary Challenge Areas
		Investigating barriers and facilitators		
Braunholtz-Speight, T. et al. (2020) Business models and financial characteristics of community energy in the UK.	2.1, 3.1	To survey business models and financing of community energy projects	**Observational** • Survey	
Hall, S. et al. (2020) Prioritising business model innovation: What needs to change in the United Kingdom energy system to grow low carbon entrepreneurship?	3.1	To understand the key change requirements that will enable utilities to capture new value and deliver low-carbon energy systems. 'What needs to change in the United Kingdom energy system, to allow low carbon business models to thrive?'	**Observational** • Focus group	Users, Technology, Policy
Pei-Hao, L. et al. (2020) Early insights into the non optimal investment outcomes in the scale-up of smart local energy systems.	5.3	How non-optimal decision making can influence the uptake of SLES and the UK electricity sector's long-term	**Model** • Economic	Policy
Tingey, M., & Webb, J. (2020) Net zero localities: ambition & value in UK local authority investment.	2.1	To outline current local authority action on clean energy and energy saving, and consider changes needed for ramping up local scale activity.	**Observational** • Case study	Policy
		Maps/ describes current state		
Hepburn, C. et al. (2020) Will COVID-19 fiscal recovery packages accelerate or retard progress on climate change?	3.1	To catalogue different types of stimulus packages 700 stimulus policies proposed or enacted during and since the Global Financial Crisis (GFC) and develop a set of 25 policy archetypes	**Review** • Map/Scoping **Observational** • Interviews	Policy
González, F.F. et al. (2020) Characterising a local energy business sector in the United Kingdom: participants, revenue sources, and estimates of localism and smartness.	2.1	To describe the characteristics of the energy business sector	**Observational** • Case study	Data, Users

Output	WP	Study aims	Methods	Secondary Challenge Areas
González, F.G.F. et al. (2020) Describing a local energy business sector in the United Kingdom.	2.1	To describe the characteristics of the energy business sector: "..to support (future) innovations and coordinated strategies for a more decentralised, clean, affordable, resilient, and democratic energy system."	**Review** • Systematic **Observational** • Secondary data	Data, Technology, Policy
		Research and methodological development		
		To propose a framework for characterising businesses, using a matrix to assess their degree of localism and smartness		
Challenge Area: Ecosystem				
		Maps/ describes current state		
Wilson, C. et al. (2020c) Potential Climate Benefits of Digital Consumer Innovations.	4.1	To analyse the consumer appeal and potential emission-reduction benefits of digital consumer innovations Generaliable insights across different domains [mobility, food, homes, and energy]	**Review** • Directed	Data, Users, Technology, Policy
Challenge Area: Technology and system interactions				
		Models		
Aunedi, M. et al. (2020) Modelling of national and local interactions between heat and electricity networks in low-carbon energy systems.	5.3	To propose a framework for identifying cost-efficient solutions for supplying district heating systems, considering local and national-level interactions between heat and electricity infrastructures.	**Model** • Planning	Heating and cooling
Braitor, A. et al. (2020a) Current-Limiting Droop Control Design and Stability Analysis for Paralleled Boost Converters in DC Microgrids.	1.1	To propose a current-limiting droop controller for paralleled dc-dc boost converters	**Mode** • Technical	

Output	WP	Study aims	Methods	Secondary Challenge Areas
Braitor, A. et al. (2020b) Stability analysis and nonlinear current-limiting control design for DC micro-grids with CPLs.	1.1	Control schemes are presented for each converter-interfaced unit to guarantee load voltage regulation, power sharing and closed-loop system stability.	**Model** • Technical	
Cao, J. et al. (2020) Deep Reinforcement Learning-Based Energy Storage Arbitrage With Accurate Lithium-Ion Battery Degradation Model.	1.1	Deep reinforcement learning model to optimise the battery energy arbitrage (price forecasting)	**Model** • Technical • Planning	Data, Business
Ford, R. et al. (2019b) A framework for understanding and conceptualising smart local energy systems.	3.1, 5.1	To propose a framework that supports the design and development of SLES Identifying the aims, boundaries, elements and success factors.	**Methods** • Analysis framework	Data, Policy, Evaluation
Paspatis, A. G. et al. (2019) Enhanced Current-Limiting Droop Controller for Grid-Connected Inverters to Guarantee Stability and Maximize Power Injection Under Grid Faults.	1.1, 3.2	To propose a novel structure of a current-limiting droop controller "..for the inverter-interfaced units that ensure the stability of any equilibrium point within a given operating range independently of the system parameters."	**Model** • Technical	
		Investigating barriers & facilitators		
Rae, C. et al. (2020) Upscaling smart local energy systems : A review of technical barriers.	6.2	To identify the main technical barriers to SLES	**Review** • Systematic	Data, Policy
Wilson, C. et al. (2020b) Granular technologies to accelerate decarbonisation.	5.3	To explore which technologies accelerate decarbonisation?	**Review** • Map/Scoping	Data, Users, Heating and cooling, Mobility
		Maps/ describes current state		
Wilson, C. et al. (2020a) Common types of local energy system projects in the UK.	4.1, 6.2	To describe the common types of local energy system projects in the UK	**Observational** • Case study	

Output	WP	Study aims	Methods	Secondary Challenge Areas
Challenge Area: Policy				
		Investigating barriers & facilitators		
Fell, M. (2020) Post-pandemic recovery: How smart local energy systems can contribute.	3.1, 5.1	SLES role in aiding economic recovery "…to draw together policy recommendations from previous EnergyREV outputs that would support [a SLES] approach."	**Review** • Rapid	Business
		Maps/ describes current state		
Devine-Wright, P. (2019) Community versus local energy in a context of climate emergency.	4.1	Examines the impact of the UK policy shift from community to local in a context of climate emergency	**Observational** • Case study	
Morris, M., & Hardy, J. (2019) Policy & Regulatory Landscape Review Series – Working Paper 1: Electricity storage & electric vehicles.	3.1, 5.1, RC	To review the policy and regulation related to electricity storage and electric vehicles.	**Review** • Map/Scoping	Mobility, Technology
Sharmina, M. et al. (2020) Decarbonising the critical sectors of aviation, shipping, road freight and industry to limit warming to 1.5–2°C.	2.1, 5.3	To develop and apply a novel framework to analyse and track mitigation progress	**Model** • Technical	Evaluation
Challenge Area: Evaluation				
		Investigating barriers & facilitators		
Fell, M. et al. (2020) Developing an organising framework: How do we create successful smart local energy systems?	5.1	To develop a theory of change of SLES To understand how smart local energy systems (SLES) could support prosperous communities across the United Kingdom	**Observational** • Interviews **Methods** • Analysis framework	Technology, Policy

Output	WP	Study aims	Methods	Secondary Challenge Areas
		Maps/ describes current state		
Ford, R. et al. (2019a) Smart Local Energy Systems (SLES): A conceptual review and exploration.	5.1	To describe the evolution of the terms used in SLES	**Review** • Meta narrative **Observational** • Interviews	
		Research and methodological development		
Aunedi, M. & Green, T. (2020) Early insights into system impacts of Smart Local Energy Systems.	5.3	To quantify the value added by SLES "with a particular focus on the whole-system benefits of local flexibility resources that might be unlocked and enhanced by SLES.	**Model** • Economic	Business, Technology, Policy
Francis, C. et al. (2020) Developing the framework for multi-criteria assessment of smart local energy systems.	5.2	To create framework for assessing the performance of the system and the realisation of benefits	**Review** • Map/Scoping **Observational** • Interviews • Stakeholder mapping	Policy
Maidment, C. et al. (2020) Developing a research portal on smart local energy systems.	5.1	To develop a research portal on smart local energy systems	**Methods development** • How-to guide	
Pless, J. et al. (2020) Bringing rigour to energy innovation policy evaluation.	3.1	To develop a framework for energy innovation policy and programme evaluation Discussing five challenges that researchers often face and recommending solutions.	**Methods** • Analysis framework	Business, Policy

Appendix 3: Recently published and planned EnergyREV outputs

The following is a list of outputs either published since the end of 2020 or currently planned for publication during the remainder of the project. The list is subject to change according to research priorities; outputs may be replaced and some work packages have further outputs planned where the focus is yet to be decided.

Work Package	Title and/or description	Publication type
1.1	MPC and Agent negotiation based energy trading for Smart Local Energy Systems	Journal Paper
	"On the effect of forecasting in peer-2-peer power networks with storage" This paper evaluates the effect of adding forecasting information to MPC controllers when coupled with market based negotiation mechanisms.	Journal Paper
2.1	UK Local Energy Businesses & Finances & implications for Innovations	White Paper
	Academic paper UK local energy businesses & finances & implications for innovation (Local energy businesses in the United Kingdom: clusters and localism determinants based on financial ratios)	Journal Paper
	Journal article on international SLES projects analysed through lens of the triple-layer Business Model Canvas (to be submitted)	Journal Paper
	Incorporating social and environmental indicators in business models for a smart local energy sector	Journal Paper
	Taxonomy of Business Models	White Paper
3.1	Summary paper of Policy & Regulatory Landscape Review Series	Working Paper
	SLES Benefits	White Paper
	Working Paper – Policy & Regulatory Landscape Review Series – heating and cooling	Working Paper
	Report on local energy governance	Report
	Academic paper on Energy Justice	Journal Paper
	"Skills Needed for SLES" Academic paper from study of workforce skills needed for the implementation of SLES – using the English LEPs as a case study and highlighting regional variations and policy implications	Journal Paper

Work Package	Title and/or description	Publication type
3.2	Inter-Market Coordination Mechanisms for Local Energy Systems	White Paper
	"A transmission and generation capacity market auction with externalities" Journal Paper – Proposes a mechanism showing how to integrate generation, network infrastructure and flexibility assets for system-level investment decision-making.	Journal Paper
	Local Energy Market Mechanisms for Managing Uncertainty	White Paper
	Mechanisms for Pricing Externalities within Local Energy Markets	White Paper
	System Level Energy Market	White Paper
4.1	Understanding what is Local about Smart Local Energy Systems	Journal Paper
	Understanding user engagement with SLES	Journal Paper
	Insights about Locality	Policy Briefing
	National survey of public perceptions of SLES	Policy Briefing
	A Longitudinal Comparative Analysis of User Engagements in Local Smart Energy System Demonstrator Projects	Report
	National survey of public perceptions of SLES	Journal Paper
	Walker et al. "What is 'local' about Smart Local Energy Systems? Project stakeholders' geographies of decentralised energy" Energy Research and Social Science	Journal Paper
4.2	Developing Smart User Influence Tools for Local Energy Management	Conference Paper
	Report on review of smart energy tools in local energy projects The report reviews what smart energy tools have been used in which type of local energy project and how effective they have been in enhancing user engagement.	Report
	User Influence Tools as an Effective Means of Engagement with Local Energy Systems	Conference Paper
	Role and Limits of Smart User Influence Tools in Enhancing User Participation in Local Energy Systems	Journal Paper
	Running Trials of Local Energy Management Tools with Local Actors	Briefing Paper
	Field Testing of User Influence Tools and Local Energy Management	Conference Paper
	Recommendations for Embedding User Influence Tools for Local Energy Management	Briefing Paper

Work Package	Title and/or description	Publication type
5.1	Interactive theory of change	Report
	Flexibility in SLES	Review
5.2	Review of Multi Criteria Evaluation Protocol	Report
	Second Test of Multi Criteria Evaluation Protocol	Report
	Multi Criteria Evaluation of Smart Local Energy Systems	Report
5.3	Characterisation of First Two SLES	Briefing Paper
	Characterisation of Further SLES	Briefing Paper
	Systems Impact of SLES	Briefing Paper
	Scenarios for SLES Diffusion	Briefing Paper
	Consequences of Heterogeneity of Investment Behaviour on SLES Diffusion	Briefing Paper
	Marko Aunedi et al. have submitted an abstract to the SDEWES conference titled "Multi-Model Assessment of Heat Decarbonisation Options in the UK Using Renewable Hydrogen and Learning Rates"	Conference Paper
	Synthesis Report on Next Wave SLES in Whole-System Context	Briefing Paper
	UKERC Review of Energy Policy 2019, "Heat Urgent Policy Action is Needed"	Report
	Arvanitopoulos, T., Monastiriotis, V. and T. Panagiotidis. "The determinants of convergence: The role of first and second nature geography."	Journal Paper
6.1	Papers on the Energy Revolution – Typologies and the challenge of putting theory into practical advice	Conference Paper
	Developing Energy Transition Pathways through Causal Links: a new way of engaging with the literature?	Conference Paper
	Identifying physical barriers to the upscaling of smart local energy systems	Conference Paper
	Scale Up Factors for Local Energy	Report
	Making sense of Upscaling: A new look at microgrid transition	Peer Reviewed Paper
6.2	Practical learnings from deployed Smart Local Energy Systems: technical barriers to scale-up	Conference Paper
	GIS visualisation with ESRU	Report
6.3	Self-Assessment Methodology Trial	Report
	Training Provision for SLES	Report

Work Package	Title and/or description	Publication type
	Skills for Transition to Smart Local Energy Systems in Community Energy: Case of Bristol City	Policy Briefing
	On Skills for Transition to Smart Local Energy Systems in Bristol: Bristol Policy Briefings	Policy Briefing
	Skills shortages in transition to Smart Local Energy Systems: Case of Bristol City	Case Study
	Skills shortages in transition to Smart Local Energy Systems: Case of Orkney	Case Study
	Recommendations on skills shortages in transition to Smart Local Energy Systems	Policy Briefing
	Skills shortages in transition to Smart Local Energy Systems: Case of Oxford	Case Study
8.2	EnergyREV Industry Engagement Workshop Report	Report
8.3	Literature review by GO-P2P sub-tasks Each sub-task is currently carrying out a literature review (of literature on P2P/TE/CSC models from their sub-task's perspective). They will all aim to publish their literature reviews.	Report
	GO-P2P concept definition paper (led by UCL) This paper will seek to define P2P/TE/CSC models; based on a literature review, interviews of experts in the field and overview of definitions in regulation.	White Paper
	Policy briefing with emerging findings Policy briefing on the results of an Interaction Matrix exercise we conducted during our September 2020 event, during which participants assessed the interaction between essential characteristics of P2P/TE/CSC models prioritised by each GO-P2P sub-task in July 2020 group interviews.	Policy Briefing

EnergyREV

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About EnergyREV

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

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