A framework for understanding and conceptualising smart local energy systems

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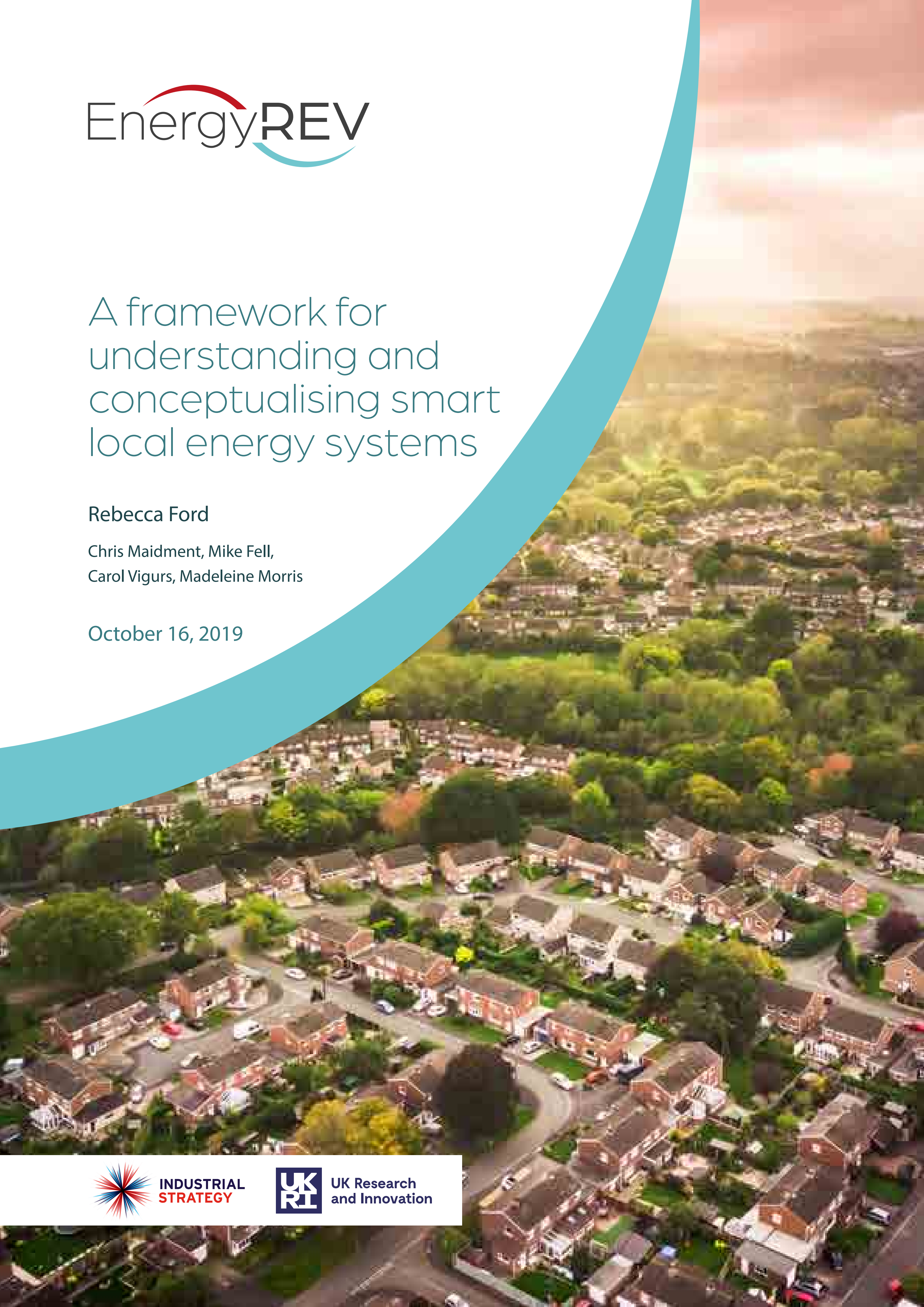

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Acronyms

BEIS – Department for Business, Energy & Industrial Strategy

DNO – Distribution Network Operators

DSO – Distribution Systems Operators

DSP – Distribution Service Providers

PFER – Prospering From the Energy Revolution

SLES – Smart Local Energy Systems

Contents

Introduction

As countries around the world embark on energy transitions to decarbonise their economies, decentralised and digitised solutions are an increasingly important part of the landscape – but what do these smart local energy systems (SLES) look like, and how will they deliver benefits? Understanding the delivery process for both system and societal benefits is critical to ensure the full value of SLES is unlocked.

In the UK, this shift toward decentralised solutions can be seen in:

- The energy industry, for example through the DNO-DSO transition;[1]
- Policy, for example in the Local Energy Teams across government; and
- Innovation, for example the UK Government Industrial Strategy[2] challenges and the Prospering from the Energy Revolution (PFER) programme.[3]

Four large-scale demonstration projects have been funded as part of the PFER programme which all illustrate how integrated smart local energy systems can deliver power, heat and mobility to users in new and more effective ways. However, they are very different in the vital local and contextual problems they address, the actors involved, and the solutions they deliver. This makes it difficult for policymakers, the wider industry, and private investors to understand how localised solutions align with the UK's broader energy vision, challenges, and opportunities.

Our smart local energy system framework allows stakeholders to explore how their projects might deliver value and in what context. It does not produce a single, fixed definition of what an SLES or project is or should do, but provides a consistent way to explore questions such as:

- What value or services does the system or project aim to deliver?
- How is "smartness" understood and delivered?
- What makes the system "local"?
- How are boundaries drawn?
- What aspects of the "energy system" are included? and
- How do these "smart", "local" and "energy system" elements help to create additional values and services beyond business-as-usual?

1 Energy Network Association. Open Networks Project – DSO Transition: Roadmap to 2030. Downloaded from www.energynetworks.org/assets/files/electricity/futures/Open_Networks/DSO%20Roadmap%20v6.0.pdf

2 HM Government, Industrial Strategy: Building a Britain fit for the future. Presented to Parliament by the Secretary of State for Business, Energy and Industrial Strategy, November 2019. Ref: ISBN 9781528601313, CCS1117470076 11/17, Cm 9528

3 www.ukri.org/innovation/industrial-strategy-challenge-fund/prospering-from-the-energy-revolution

The framework supports the design and development of SLES using a four-stage approach:

1. Identify the overarching purpose or added value(s) the system aims to deliver, as well as the co-benefits it hopes to realise;
2. Consider where and how to define the system boundary, and how hard or soft that boundary might be;
3. Identify the "smart" and "local" elements, and interconnections that are required to enable the SLES to deliver the expected benefits; and
4. Identify data needs and an evaluation strategy to determine the success of the SLES has been successful, and in what context.

We also outline where further work is needed, and identify some essential mechanisms to enable continued development of the smart local energy system framework. Our focus is not whether SLES are "better" than a centralised system – SLES development is already happening. Our goal is to clarify the possible benefits and consequences at local and national levels, and highlight how "smartness" and "localness" can contribute.

The Smart Local Energy System framework

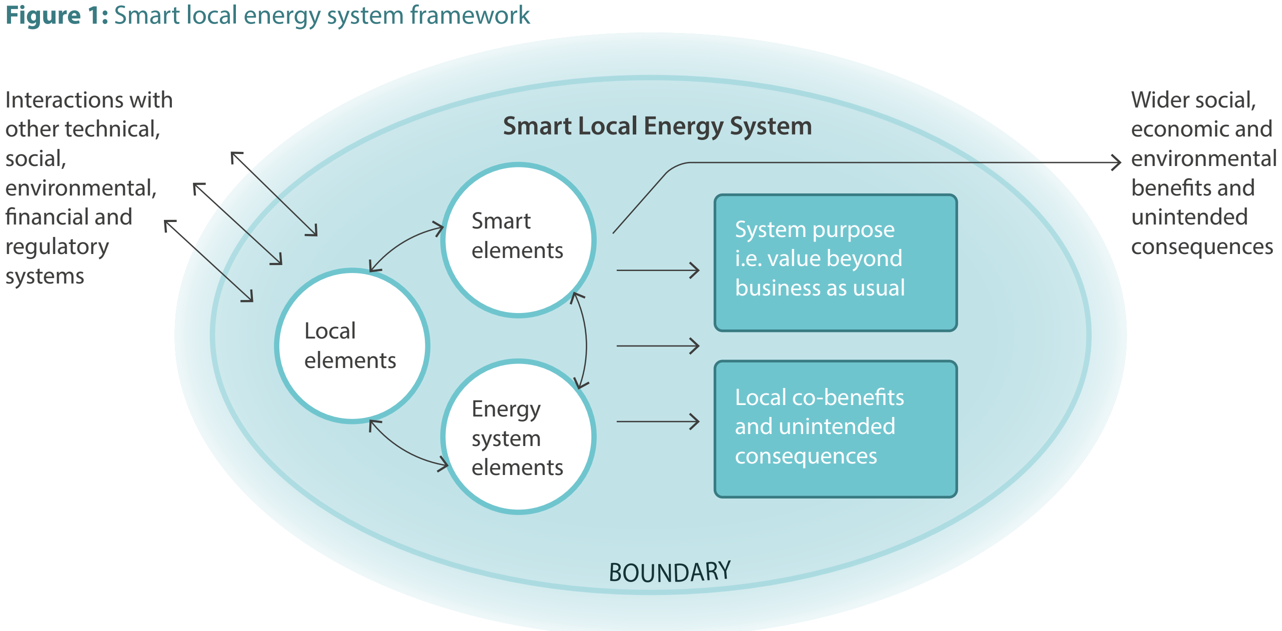
The smart local energy system framework (see Figure 1) provides a structure for stakeholders to develop a collective and shared understanding of how smart local energy systems can leverage "smart" and "local" elements in order to deliver value and benefits within a locality. It also helps to identify any potential unintended consequences, as well impacts on the wider system and interactions with other technical, social, environmental, financial, and regulatory systems.

System value, co-benefits and unintended consequences

This part of the framework helps users to think about the additional system value, benefits, and unintended consequences that could be created by SLES. Table 1 outlines some key areas where SLES can add value to the energy system or wider society. This is not an exhaustive list of value creation opportunities, and does not imply that all smart local energy systems will deliver value in each of these areas. However, the framework makes the consideration of system purpose and value explicit.

In addition, SLES could deliver broader co-benefits such as creating local jobs, strengthening local decision-making, demonstrating local leadership within the UK, increasing awareness of environmental issues, and building a sense of local community. There could also be unintended consequences, such as negative impacts on biodiversity due land use change for solar farms, or unequal distribution of financial benefits across homes in the region where the SLES is based.

Figure 1: Smart local energy system framework



It is also important to consider how the SLES could interact with the wider energy system, as well as other systems. This can help prevent national-scale negative impacts due to changes within the district, explore where regulatory or other barriers may exist, and also identify where additional wider system benefits could be delivered.

Table 1:	Example areas of smart local energy system value creation

Effective provision of energy services The ability of the system to deliver energy services to users in more effective and efficient ways that reduce system costs, and costs to users through reduced bills, for example, and improved comfort and quality of life through reduced fuel poverty, for example.
Enhancing environmental eco-system benefits Environmental benefits including and beyond carbon emissions reductions, for example, biodiversity and other ecosystem services that could be delivered alongside renewable energy provision.
Maximising local sufficiency and independence The ability to balance supply and demand locally is an important function of SLES, minimising energy requirements from the national grid and maximising the use of local and low carbon resources.
Enabling flexibility within and across energy vectors Flexibility across vectors and the ability to switch between different vectors to provide energy services is an essential benefit of SLES, and a fundamental component of energy system integration for greater efficiency and resilience.
Improved resilience and ability to cope with failure SLES could be better equipped to cope with both local generation failure as well as grid outages, for example, through better use of real time data, enhanced decision-making, or autonomous forms of control.
Social justice and energy equity By engaging stakeholders in new ways and carefully designing delivery methods, SLES have the potential to deliver greater energy equity and benefits to the local community.
Meets fundamental needs in a context-specific way SLES could better serve communities or neighbourhoods through delivering practical benefits, for example, making it easier for locals to access and take part in the system; community benefits, for example through boosting local employment; and wider values-based benefits from addressing the desire to reduce global environmental impacts, for example.

Energy system elements

The elements of an energy system that are needed to enable it to function appropriately include multiple components, including hardware, software, processes, procedures, governance structures, and people. Energy systems are thus inherently socio-technical in nature, and could incorporate technical energy infrastructure from generation to consumption including networks and storage, as well as institutional infrastructure including market structures, regulations, rules, industry codes, business models and so on, which are necessary for the system to operate and deliver energy services.

The main findings from current work related to energy system elements cut across four themes:

- Multiple vectors
- From generation to consumption
- A socio-technical system
- Incorporates institutional infrastructure

Table 2 provides more information about each of these themes.

While these are important elements of energy systems, the way in which the local energy system boundary is drawn will have an impact on whether all the elements are part of the local system, or whether they represent interactions between the local and wider energy system. For example, the local energy system may not incorporate all generation assets, so depending on where the boundary is drawn there may be significant interaction, both technical and non-technical, with the wider system.

Table 2: Energy systems elements
Multiple vectors The energy system incorporates all energy vectors, and not just electricity. Discussion about purpose and services should include all the energy-related services delivered by the system, including heat and mobility.
Generation to consumption An energy system covers everything from production, conversion, transmission, storage, distribution, and consumption.
Socio-technical system The energy system is more than just its technical components – it includes social and human aspects such as political, economic and social dimensions. If non-technical elements were excluded, "energy infrastructure" would be a more accurate description.
Institutional elements Market structures, regulation, rules, industry codes, contracts, and other institutional elements are important aspects of any energy system. The interaction of the socio-technical with these institutional elements enables the energy system to meet its primary purpose of delivering energy services to end-users. Without these elements, the system would be incomplete and unable to function.

Smart elements

Smartness is layered into energy systems by collecting and using more and different forms of data, meeting SLES objectives in more effective ways. The data can be used to support autonomous management of the system, or coupled with data or boundary conditions input by users, and applying machine learning and artificial intelligence techniques to improve performance. All of this new data and learning can provide useful evidence-based information to help end-users, planners and those developing governance processes make more informed decisions about energy use.

Table 3: Four aspects of smartness
Information and communication technologies These technologies are layered onto energy systems, enabling data to be gathered and consumed in real or near real-time to optimise its performance against critical criteria, for example. to deliver greater energy security.
Automation and self-regulation This element refers to the ability of the system to respond to its environment, automatically adjusting its operation to optimise service provision.
Ability to learn system dynamics Some degree of machine learning or artificial intelligence embedded in the energy system allows it to regulate itself in accordance with wider dynamics and user-set preferences. This couples people with technology in defining the smartness; users set parameters, and technology learns and adapts based on the preferences that are revealed.
Smarter decision-making A broader discussion has emerged around the location of smartness, and the ability of SLES to engage people with more effective decision-making, planning, and governance processes.

Local elements

It's important to consider two main issues in local energy system elements: a) how processes, procedures, governance structures, and stakeholders – the energy system elements – make an energy system local, and b) where the boundary is drawn around those system elements.

a) There are three main ways in which energy system elements make that system "local":

- Local and community stakeholders
- Decision-making
- Asset ownership

Table 4:	"Local" energy system elements
Local and community stakeholders Community and other local stakeholders have a role to play in the delivery of SLES. Historically, community energy solutions have typically been about civic or grassroots organisations and citizen-driven change, while local energy tend to be more focused on local authorities working with the private sector, placing more emphasis on the role of existing public sector institutions. The lack of involvement of community or other local stakeholders could have an impact on the wider value realised from SLES. Further evidence is needed to gain a clear view of the potential value of local and community involvement, or what value could be lost by their lack of engagement.	
Decision-making processes Decision-making at a local level is likely to positively affect conditions for local energy systems. This can vary from one local authority to the next, though relationships between authorities can be forged due to shared energy needs. Recent recommendations from the IGov project suggest that a new entity, Distribution Service Providers (DSPs), become coordinators of local energy systems, market facilitators and balancers. This would encourage energy systems to focus on customers, and improve efficiency, flexibility and sustainability.	
Asset ownership Local ownership of assets can allow a degree of control of local energy systems, helping to foster engagement and enabling profits to be kept within communities, and potentially influencing greater and continued change. Such an approach can also support the delivery of local environmental and social benefits in line with local values.	

b) It is important to define the boundaries of a local energy system as that could have an impact on the resources or capacity available, and ultimately on achieving system or societal value.

Local energy system projects vary from single building systems to just below national energy infrastructure level. The following ways of drawing boundaries might be useful in determining the scale:

- On a map
- By generation resource
- By network infrastructure
- Socially

These boundaries provide different ways of thinking about what and who is or isn't part of an SLES. If one of the main objectives of an SLES is to alleviate issues on the network, then following network infrastructure boundaries may be appropriate. To engage users and support new and innovative ways of delivering energy services, a social perspective that allows for more subjective ways of determining where the lines are drawn, and how soft or hard those lines may be, might be more suitable.

Table 5: Ways of drawing boundaries around smart local energy systems
On a map Local in this sense is based on physical, map-based geography, where a circle can be drawn around an energy system. This could reflect local authority areas or another delineation between different regions, for example Parish boundaries.
By generation resources Where supply is located close to demand it makes sense to take advantage of that. Proximity to energy generation can help to encourage interest in customers, even where the supply is not connected to the demand. A local energy system can be built around a single nucleus or a network of multiple energy sources.
By network infrastructure Local can also apply to the physical networks and infrastructure that enable energy to flow. As a main purpose of SLES is local energy balancing, boundaries are often defined by network segment; for example, all the customers connected to the low voltage network beneath a particular electricity substation or beneath a known supply bottleneck.
Socially The people who benefit from or participate in their local energy systems can constitute a boundary. It can also refer to the social context driven by place and identity, where the boundary can vary from a single street or estate up to a county or regional level, depending on the sense of engagement.

Using the framework

The SLES framework provides a structure to engagement with stakeholders in discussing and clearly identifying critical issues in smart local energy system development. Projects must be designed and developed with the right range of stakeholders in such a way as to deliver value and benefits in the context of the climate emergency.

The framework is designed to support cross stakeholder discussion, to address questions such as:

- What benefits will the smart local energy system deliver?
- How should boundaries be drawn around the system?
- How can "smart" and "local" elements help deliver the anticipated benefits?
- Within the locality? Beyond the locality?
- How can evidence be built to support and refine further development?

Step 1: Identify the purpose and co-benefits

Identify the overarching purpose or added value and co-benefits that the SLES aims to deliver. This likely to be context-specific; while many projects may have high-level goals focused on delivering cost, security, or carbon benefits, more specific issues will be at play within particular regions. For example, the primary focus of a project may be fuel poverty reduction in homes, and creating more equitable and affordable energy systems, while another may have a stronger focus on alleviating network constraints and enabling greater connectivity of renewables into the system.

In practice, it may be difficult to achieve the maximum potential benefit; for example, some outcomes may be linked in such a way that when one element sees increased benefits, the other decreases. In this first stage it is important to identify which outcomes are essential to the project, and which are "nice to have". This clarification helps bring together different stakeholders around a common set of goals, and help to develop an evaluation process for all potential outcomes (see Step 4).

Once the purpose and co-benefits are understood, the next step is to explore how smart and local elements can be brought together, within a specified system boundary, to realise this potential.

Step 2: Consider the system boundary

The boundary around an SLES is an important element in understanding how the system may deliver value beyond business-as-usual. For example, if the goal of the system is to deliver a zero-carbon local energy system, the boundary will be defined by the demand for clean energy within that area, which will have implications for the size and situation of the system. However, if the objectives focus on delivering flexibility to enable greater efficiency at a local level, the boundaries must take into account any network constraints, and may not need to include generation assets. Understanding the relationship between the system values and the system boundaries is a critical step in developing a successful SLES.

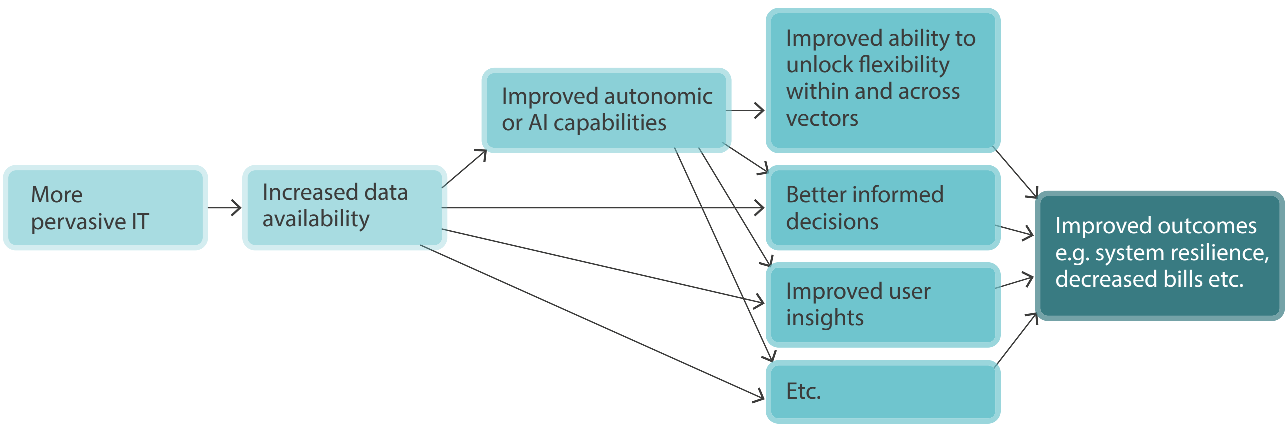
It is also useful to consider how hard or soft system boundaries should be. For example, network boundaries are very clearly defined, while others such as social boundaries are more subjective. Understanding the type of boundary is important to ensure the right set of stakeholders and users are engaged in the system development. Social identity and connection to place don't stop at the end of a road because that's where the local authority region ends, or how the network infrastructure is configured. Allowing people and communities to self-identify with a locale may be crucial to delivering a socially equitable system, raising a question of how and when other, more rigid boundaries should be crossed.

Step 3: Consider system elements and their interconnections

The relationship between system elements and outcomes can be formalised into a set of theories that explain how smart or local elements can be brought together to deliver system value. Figure 2 depicts how certain "smart" elements might be linked to each other, and to vital system outcomes (as identified in Step 1).

Historical data and evidence, together with data from expert elicitation, can be gathered to develop a causal model which outlines the expected relationships that may occur as the system is implemented, and highlights where additional evidence may be required.

Figure 2: Causal model illustrating how more widespread information and communication technology in an SLES might be expected to lead to certain outcomes (for illustrative purposes only)

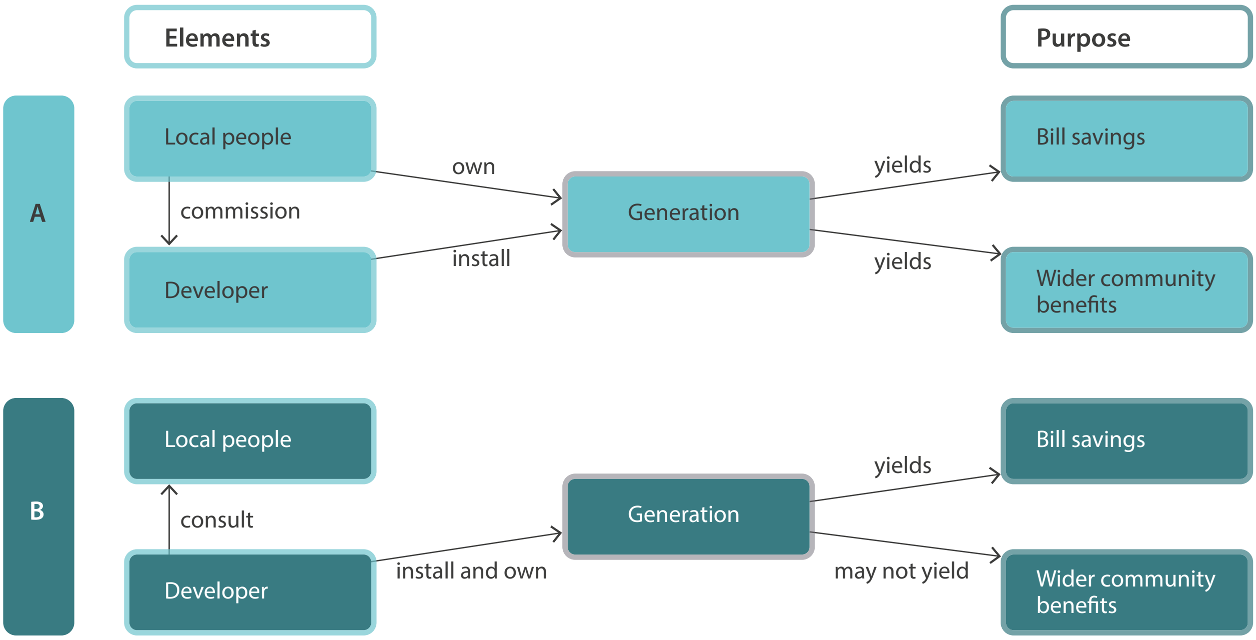


The importance of the way in which elements are interconnected is illustrated in Figure 3. This simplified schematic shows how different dynamics of ownership between the same elements might affect the outcomes of a local energy system. For illustrative purposes, the figure shows just one dynamic interaction: an SLES is likely to be a more complex picture with many more elements and interconnections.

Step 4: Generate evidence to test your model

The SLES development should identify the data collection required to test the causal model, and provide evidence to support or refute the links connecting smart and local elements to measures of success. Identifying data needs early and embedding these lessons into the project from the start allows for refinement of the causal model developed in Step 3, and improvement of the system outcomes in Step 1 during the project. This agile approach supports greater learning about how to drive success in SLES, and ultimately help to identify pathways for replicating or scaling successful solutions.

Figure 3: Different dynamics of ownership: The elements are interconnected (represented by arrows) differently in arrangement A and B, leading to potentially different viable outcomes viable (for illustrative purposes only)



Discussion and next steps

We recognise that further work is needed to support the full use of this framework – a discussion on the issues and next steps follows.

Although the SLES framework provides a structure for considering value creation in different contexts, currently there are no clear guidelines as to the types of value SLES could, or should, create. The opportunities we have identified in this report by no means represent a full list, nor is there consideration of the potential unintended consequences of SLES development. Further research is needed to provide a structure within which SLES value can be considered, allowing different projects to be compared consistently. Projects may not necessarily deliver value in all areas, but this structure could provide clarity about the areas they are addressing and those they are not. In addition, it would provide a way to benchmark these wider areas of value creation potential to ensure that no negative impacts occur due to a lack of consideration.

Future work should also focus on the objective, as well as subjective, importance of different SLES goals and benefits. If setting goals is left solely to those involved in developing the SLES, there is the potential for misaligned objectives between national and local targets. Understanding which stakeholders are or should be involved is critical, as the starting point for developing an SLES could have a significant impact on the validity of the solution, and on the outcomes achieved. In addition, in the context of the climate emergency there are questions about whether some benefits should be mandated goals, for example, carbon reductions in line with UK targets, while other benefits could be more context-specific with different areas of focus emerging in different projects.

Next steps:

We are working with researchers in the PFER projects, the wider sector, and sets of stakeholder groups to develop a structure to explore what SLES success looks like, and to identify which values or benefits are imperative, and which are considered "nice to have". This will form the basis of a set of metrics for reviewing and capturing value creation opportunities.

Developing a set of causal relationships between smart and local elements and system outcomes would be a useful but potentially time-consuming task. Given the existing body of evidence, development of an overarching theory of change (ToC) that brings together theories and evidence around these relationships with relation to potential areas of value creation is possible. The ToC could be reviewed and adapted or added to through additional data and evidence generated by individual projects.

Next steps:

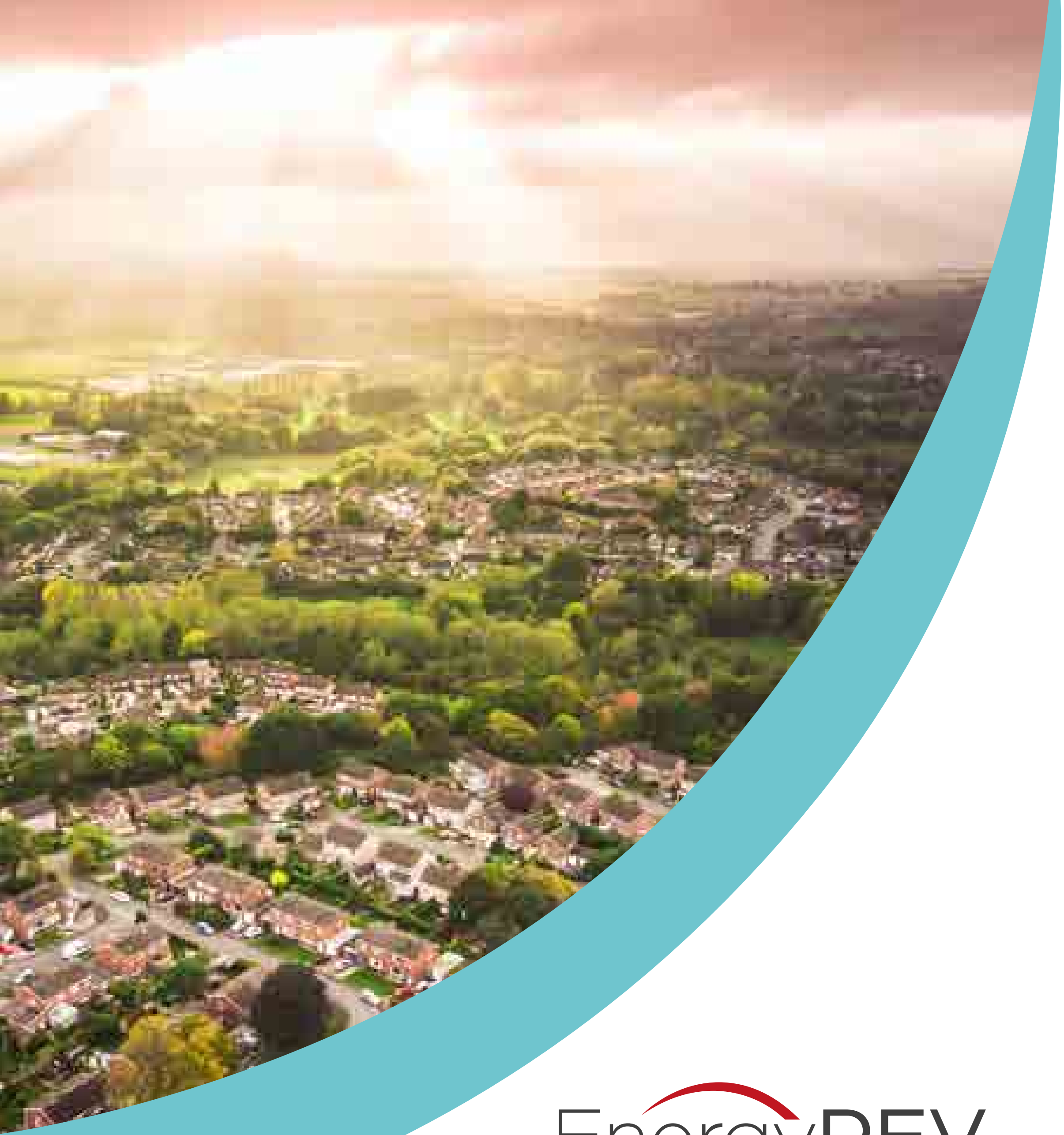
We are working with researchers within the consortium to develop an initial set of causal relationships, based on a series of expert interviews, that link smart and local elements to value creation opportunities. This overarching theory of change will be validated and refined using evidence from existing literature.

Finally, the framework could be used to explore the impact of SLES development on policy frameworks. There are a number of immediate implications, with others likely to emerge as SLES are developed and understood.

The first relates to the ability to realise value creation opportunities within current markets and regulatory models. The second is due to the new "smart" technologies that might be integrated into existing systems to support autonomous decision-making processes – there are no clear governance structures that define where or with whom responsibilities may lie under autonomous operation. Third, there remain questions around the data required to support enhanced decision-making, autonomous or otherwise. This data could come from multiple sources, and it is not clear whether it is available to those who require it to make decisions, if it is in an understandable or useable format, and whether additional protocols or processes might be needed to ensure its security. In addition, there are no clear guidelines on how this data, or evidence emerging from the many SLES developments, could be used by stakeholders to support more effective and evidence-based planning processes.

Next steps:

We are conducting a series of policy and regulatory reviews to consider different critical aspects of policy and regulation in an SLES context. Findings will be available via the EnergyREV website, and any important issues arising will be presented to a Policy Contact Group, convened by EnergyREV with membership including representatives from BEIS, Scottish and Welsh governments, and Ofgem. EnergyREV researchers are also exploring cyber-security and data standardisation issues, building on the work done by the Energy Data Task Force.



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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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