EnergyREV

BRIEFING NOTE

Bristol: a case study on the training and skills needed for a smart local energy 'system of systems'

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Part 1: Overview

Summary

This briefing aims to inform all those engaged with the local energy system transition. Its intention is to help these engaged stakeholders see how the different parts of the local energy system are interrelated, and what skills and measures are needed to support an emerging smart local energy system (SLES).

This report presents an analysis of the smart local energy (SLE) case study undertaken within the city of Bristol. It argues that the SLES must be viewed as a **system of systems** (SoS), as it is comprised of a set of loosely interconnected, independently evolved, managed and operated subsystems. The *subsystems* considered in this study are: transport and mobility, traditional energy supply, building and retrofit, local government, community energy, information and communications technology (ICT) for energy services, local communities, and citizens. All of these play a part in the journey of a particular locality to meet its net zero ambitions. In this report, the findings for the city of Bristol at this SoS level are summarised, while considering the challenges and skills needed to bring the local subsystems together for a common goal of clean energy commitments and addressing the climate emergency.

In the context of **skills development**, 'skills needs' must be considered both within each subsystem, and also for the SoS as a whole, i.e. *across subsystems*. This briefing is focused on the cross-subsystem issues of a SLE SoS. (See full report for per subsystem details.)

Insights:

We have identified three key challenges and their respective required skills, which must be addressed while transitioning towards a well-established SLE system of systems:

1. **Lack of understanding of the SoS as a whole**, for which a variety of skills such as technological literacy, risk management, financial planning, partnership building, communication and engagement are critical.
2. **Subsystems integration**, for which skills such as hardware and software installation, networking and communications, data analysis and machine learning, data protection and standardisation are critical.
3. **SLE SoS operation**, for which skills such as large cross-institutional project management, supportive policy making, evaluation and assessment throughout operation, as well as regulation and standardisation are critical.

Recommendations:

Below are the key recommendations that subsystems can use to address the above challenges, and the areas where training provision is needed:

- Set a common and agreed upon goal;
- Set up a cross-subsystem SLES coordination body;

- Share an understanding of physical connection issues;
- Build a general understanding of renewable, clean energy technologies;
- Coordinate investment in data collection and control infrastructure;
- Develop a framework for conflict resolution.

These should be supported by training in specific aspects of the following generic skills areas:

- Managerial skills;
- Policy and regulation skills;
- Engineering skills;
- Trades skills;
- 'Soft' skills in communication and engagement.

Part 2: Smart Local Energy Systems of Systems

Assessing the skills needs for SLES

The UK's energy system is undergoing a rapid change, driven by both technological progress and policy goals of achieving carbon-neutrality by 2050. The UK must train the workforce that will deliver and operate this new system, as well as engage the citizens and communities into whose homes and environments this system will have to be integrated.

The key research questions addressed in this briefing are:

- **What challenges does the UK face in transitioning to SLES?**
- **What skills are needed for the UK's successful transition to SLES?**

To answer these questions, this report reviews a case study of the city of Bristol, one of the UK's energy champion localities where such a transition is already underway. This is a qualitative study, based on data obtained through documentary analysis, interviews and focus groups. Although the findings from this study are grounded on the evidence from the city of Bristol, they can also serve as 'food for thought' and trigger reflections on similar challenges within other localities.

What is a Smart Local Energy System?

A '**smart local energy system**' aims to manage and balance the supply, storage and use of local energy across all vectors, bringing efficiencies to energy supply and demand also social, environmental and economic benefits to the given locality. In line with the UK's commitments of a net zero carbon economy by 2050, all energy system assets should be carbon neutral or carbon reducing. Investment in assets other than these will either jeopardise the UK's national targets, or will lead to stranding these assets within the next 30 years. Therefore, this study focuses on green and renewable based energy initiatives.

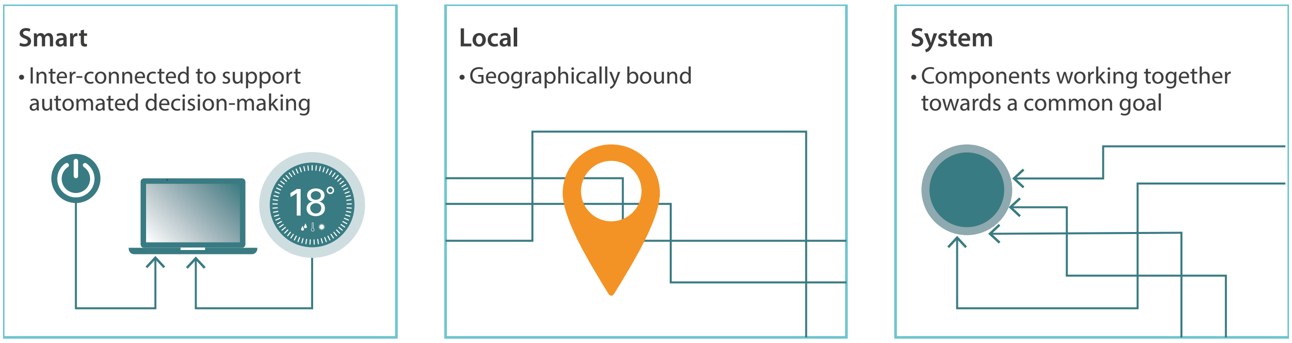

Figure 1: Terms of a smart local energy system.

Within this context (as shown in Figure 1):

Local refers to a defined geographical area where energy initiatives take place. This covers a range of organisations, including partnerships between public, private and non-profit sectors. Public authorities may take a coordinating role to leverage private sector investment in the provision of local energy. The **locally-based energy activities** include generation and storage, as well as consumption and its reduction through a variety of energy efficiency and behaviour change, energy management and balancing of supply and demand, and delivering non-financial societal value (such as, for example, health and educational improvement through warmer homes).

Each local geographic area is also endowed with its **locally distributed renewable energy sources**: e.g. sun, wind, tidal, waste recycling, etc. Therefore, **decentralisation** is a key part of the 'local' aspect of SLE. Most renewable energy technologies are dependent on locally distributed sources. For instance, tidal energy can only be generated in coastal locations, while solar generation can be secured locally through panels mounted on roofs and fields at a range of scales.

The **smart** aspect of energy implies a **digitally supported coordination of decision-making** *for (sub) systems* to optimise their resource use and waste reduction (both generation and consumption) and support for human decision-making for efficiency and comfort. However, the smart energy system will not fulfil its potential without **smart users**, thus household and business users will also need to acquire skills in the functioning and the use of digital energy systems.

SLES as a System of Systems (SoS)

A smart local energy system is itself a system of systems (SoS), the simplified overview of which (for Bristol's case study) is presented in Figure 2. Here, the set of individual (sectoral) subsystems are integrated through digital and physical infrastructure to create a SLE SoS. These individual subsystems have their own boundaries and behaviours, although they do collaborate for the *common goal of optimal use of local energy and carbon reduction*. For this to happen, they exchange data and exercise control over the energy exchange itself (e.g. drawing on, or storing into batteries, switching consumption equipment on/off, etc.).

The sectoral subsystems[1] which were identified and researched for Bristol are:

- **Building and retrofit**, which addresses energy efficiency and carbon neutrality of buildings. Buildings contribute to energy generation, (e.g. through solar PV panels) and consumption.
- **Transport and mobility**, which integrates battery storage through electric vehicles (EV), electricity drawn through EV charge points, use of alternative fuels (e.g. biofuels and hydrogen) for transportation, optimisation of travel routes and schedules, etc.
- **Energy supply**, which refers to the traditional energy sector and integration of the local energy assets and services with those of the UK's distribution and transmission grids.
- **ICT infrastructure for the delivery of digital energy services**, which includes the human, hardware and software assets (from networking infrastructure and servers to algorithms and data) that enable coordination and control of optimised energy generation, storage and consumption.
- **Community energy**, which refers to the community organisations that enable and engage local communities with energy generation, sharing, storage, consumption, (dis-)investment and other activities.

1 Although this hasn't been discussed in this report, within each sectoral area, each subsystem can be viewed as a further set of sub-subsystems, with shared technological and infrastructural approaches.

- **Local government**, which refers to regional, city and area-scale policies, regulations and actions which foster or preclude energy-related activities (e.g. a local regulation in Bristol: any new build dwelling must have at least 20% of its energy needs met through its own renewable sources).
- **Citizens and communities**, who must be engaged in contributing to generation, storage and energy efficiency activities. Citizens and communities are the key players in all other energy activities. The more engaged the citizens and communities are, the more efficient the SLE SoS that they underpin will be.

A SLES therefore comprises a number of semi-independent subsystems, each operated for its own purpose by separate management structures, with different time horizons, technological and professional heterogeneity, and evolutionary paths.

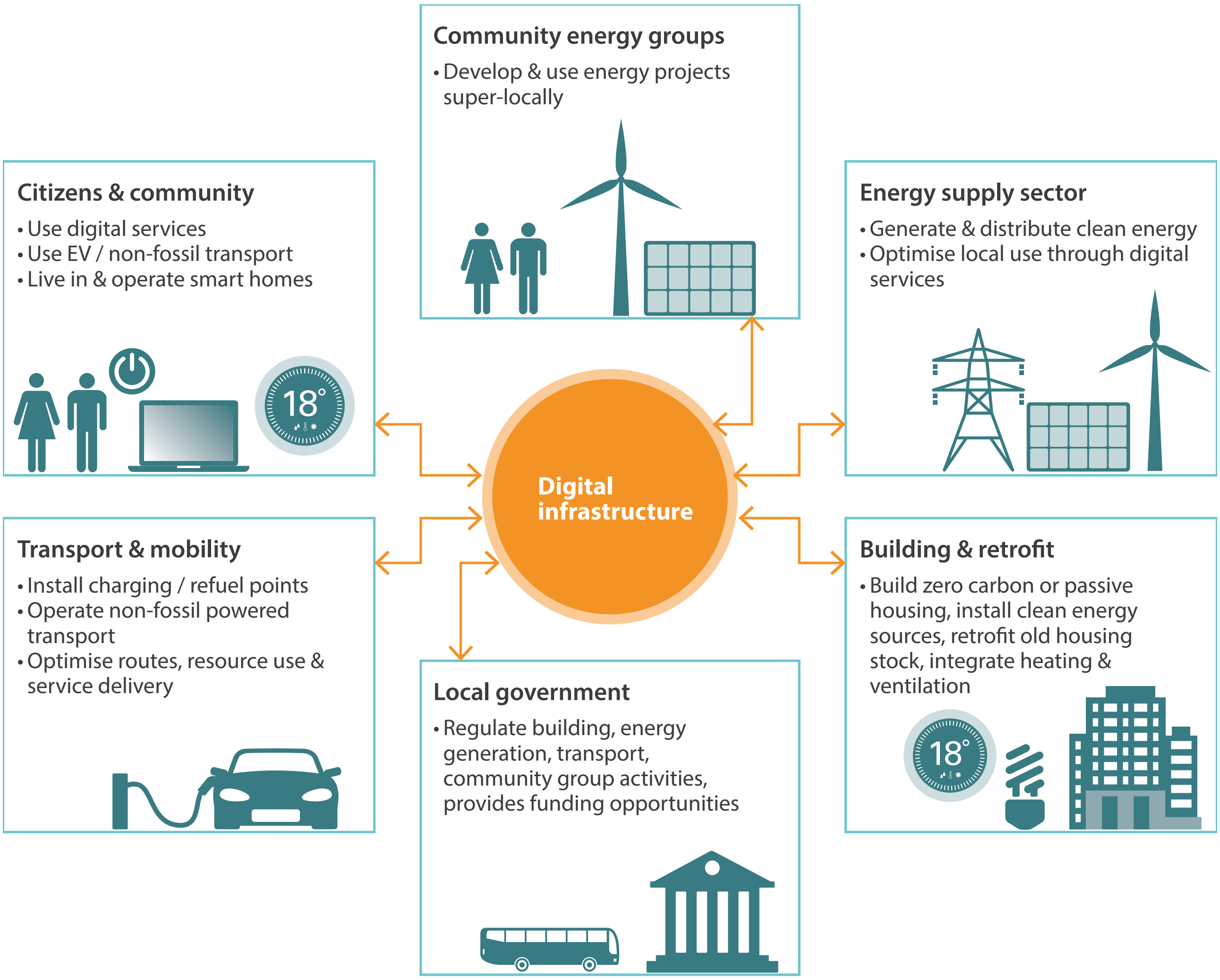

Figure 2: A simplified overview of a smart local energy system as a System of Systems.

Architecting SLES

In order to create a coherent SLES, the subsystems must be able to interact and collaborate towards a common goal, which, for the Bristol SLES, is achieving a net zero emissions local energy system by 2030. However, these subsystems, due to their independent evolutionary development (see Box 1), have well-established boundaries and operate largely independently of each other. The only way of creating a common SoS architecture for SLES is by integrating subsystems through common interfaces. Drawing on the case study of Bristol, we observe that these are:

1. **Interfaces with the energy distribution and transmission networks** that operate at the hardware level to interlink the generation, storage and consumption equipment with the electricity and gas/heat grids.
2. **ICT interfaces** that integrate data collection and exchange as well as decision support and control over the various generation, consumption and storage devices located within the component subsystems.
3. **Policies and regulations** that constrain and stimulate various activities within these subsystems.
4. **Education and training provision** that fosters knowledge and cooperation towards common goals across the various stakeholders within and across the SLE subsystems.

Given this independent development, one cannot expect to see a homogeneous set of skills, work practices or educational environments across the SLE subsystems. Thus, to ascertain skills needs for the SLE SoS, skills needs for each SLE subsystem are studied separately with the relevant cross-subsystem interfaces, and their skills needs are developed and overlaid for the SLES as a whole.

Box 1: System of systems traits in smart local energy

How system-of-systems traits[2] apply to SLES

The common system-of-systems characteristics and their relation to SLES are explained below:

- **Operational independence**: subsystems can *usefully* operate independently so, for instance, the Energy Supply sector will deliver energy to its household or business customers with or without the Transport and Mobility or Building and Retrofit subsystems.
- **Managerial independence**: subsystems are delivered and operated by independent organisations which both belong to a wide set of different owners, and are also located within quite different sectors such as transport, energy, government, etc. While, as part of the SoS, the subsystems collaborate towards a common goal, each of the subsystems also continues to deliver its own goals. For example, a Transport and Mobility subsystem moves people and goods to the required destinations as its primary goal, irrespective of also storing and resupplying electricity to the grid via EV batteries.
- **Evolutionary development**: the SoS will be able to deliver useful services even before the complete deployment of all its components. Similarly, the SoS will still be operational even if some subsystems are removed. Thus, a reduced form of SLE SoS can start to optimise use of local energy and reduce carbon impact, even if, for instance, Community Energy generation is not present, and Transport and Mobility sector is fully fossil-fuel based. As the subsystems are, at least partially, independent in their development and operation, there can be no guarantee of their availability.

2 Vargas, G. and Braga, R.T.V. 2020. Understanding system of systems management: A systematic review and key concepts. *IEEE Systems Journal*, pp 1–10.

- **Emergent behaviour**: by working as a SoS, the subsystems deliver more than the simple sum of their services. They are able to provide new (levels) of services, for example flexibility to the grid via EVs from the Transport sector, and demand side response (DSR) services over Citizens' household appliances.
- **Geographical distribution** leads to looser coupling between the subsystems.
- **Heterogeneity**: the components of each subsystem are different. For example, each subsystem has hardware components – from wind turbines to EV charge points and washing machines – and software systems to monitor and control them. They pursue different goals, serve different stakeholders and operate different economic models. To create a SoS, interfaces between the subsystems must be developed and integrated.

Part 3: Findings and recommendations

Key findings: the three main challenges of SLES

Integrating the SLES subsystems through the identified interfaces poses three key challenges that local authorities (or other stakeholders leading SLE SoS development) must address.

Challenge 1: Lack of SLES understanding and holistic view

Individual sectoral challenges: Each subsystem within the Bristol city SLES faces a set of its own challenges. For example, the Building and Retrofit subsystem suffers from a lack of professional esteem and public trust in retrofit and a lack of incentives to change building practices. At the same time, the Transport and Mobility sector in Bristol is concerned with finding business models that are financially feasible for EV and biogas vehicle fleet operators and their supporting smart mobility service providers. While all subsystems interact through energy supply and demand, none of them has the optimisation of local clean energy production and consumption as its key goal.

Cross-sectoral understanding: The subsystems may not acknowledge the relevance of one or several of the other subsystems. For example, the Building and Retrofit sector is disengaged from Transportation, as is Transportation from Community Energy, etc. They may use different terms to refer to the same subject and/or use the same term to refer to different subjects. For instance, citizens 'optimise consumption' by using as much of their own solar energy as possible, while electricity suppliers 'optimise consumption' by shifting the electricity use away from peak demand time.

Challenge 2: Integration, interconnection and communication between subsystems

Physical connection: In order to operate in a coordinated way, the subsystems within the SLES system must support physical interconnections for energy exchange, as well as data and information exchange for decision support and control in optimisation of operations.

The infrastructure for physical integration, in most cases, is developed along with technology installations. For example, solar PVs are integrated with the electricity network at installation time, as are EV charge points and heating and ventilation equipment in building retrofits. However, challenges remain, for instance, where the existing electricity distribution infrastructure requires reinforcement for new EV charge point connections, or the gas distribution network cannot handle the chemical components of the new gas fuels, such as hydrogen.

Communications needs for data and information exchange are implicit across the SLE SoS subsystems, although poor communication for interactions between the subsystems negatively affects the efficiency of the SoS operation and its evolution (e.g. greyouts or blackouts due to poor coordination of peak time electricity demand and EV fleet charging, etc.). Notably, the collection and interchange of such data may not be a key requirement for the subsystems themselves, even though it will primarily be a requirement of the SoS as a whole.

Challenge 3: Governance and operation of the whole SLES

While each subsystem will be managed by its respective structures, there is a need for an additional governance mechanism for the holistic SLES, along with the impacts that interactions between the subsystems could cause. Examples of the impacts of these interactions include:

- **Privacy impacts** from the aggregation and sharing of householders' data across subsystems.
- **Exacerbated inequalities** if, for example, the well-off and well networked areas of the city can acquire new digital energy services which are not accessible to less affluent areas.
- **Stifling of business opportunities** if, for example, one subsystem, such as the EV charge operators refuses (or lacks the networking infrastructure) to share its data with others such as energy suppliers. The latter cannot deliver new services, such as demand response management, as a result.

Recommendations: addressing the challenges

A. Setting a common, agreed upon goal: This would require broad collaborations across all levels of the SLES and subsystems stakeholders. Bristol City Council (BCC) has taken leadership in this area since 2019 by supporting the development of Bristol's One City Plan in collaboration with a broad group of city stakeholders. This defines how city stakeholders will work together to create a 'Fair, healthy and sustainable city' with a set of agreed upon goals and a collective vision for organisations and individuals across the city.

EXAMPLE: Focusing particularly on energy, Bristol City Leap is a city council initiative to develop an energy joint venture to bring investment into the city. In addition, BCC owns a significant amount of property (including schools, libraries, offices and depots) as well as approximately 40% of the land in the city, so it can set a strong trend in defining the essential set of goals that its property operators must address.

The Community and Energy Groups across Bristol have also taken an active role in raising awareness about climate emergency and energy transition challenges.

B. Setting up a cross-subsystem SLES coordination body: An example of this would be a 'Committee for SLES Transition'. This could be made up of relevant business, community and training provider representatives to facilitate cross-subsystem engagement and cooperation and help to build mutual understanding and common vocabularies, as well as identifying and addressing emerging issues. While there is presently no such mechanism in place for the Bristol SLES, this is not entirely unfamiliar ground.

EXAMPLE 1: within the Community Energy sector, such cross-subsystem sharing often happens through collaboration and interaction between groups. For instance, in Bristol, the Cold Home Energy Efficiency Survey Experts (CHEESE) group has engaged with the Ambition Laurence Weston (ALW) community group to support energy efficiency improvements within local homes. ALW also operates a PV array and is currently deploying a wind turbine for community use. Thus, the community in the Lawrence Weston area of Bristol is actively engaged with learning about retrofit as well as energy generation technologies.

EXAMPLE 2: cross-subsystem impacts are considered through the Health and Wellbeing Board of the Joint Strategic Needs Assessment,[3] identifying and addressing the impact of fuel poverty on health.

3 Bristol JSNA, fuel poverty chapter, 2018.

The task of a coordination body would be to consider interdependencies and impacts that the behaviour specific to one subsystem could cause by deviating from the agreed upon goals and vision of the intended SLES. For example, is optimising traffic flow for EVs acceptable for the Citizens' subsystem, or could community energy groups support their communities better by collaborating with local EV charge point providers?

C. **Share understanding of physical connection issues**: All subsystems must interact with, and learn about, the electricity (and/or gas) supply distribution networks, as they all need to connect their appliances and equipment with the distribution networks, and often, with the transmission networks as well. This leads both to a common understanding of issues (such as network constraints that a distribution service operator would likely experience), and also to opportunities for a new service delivery (e.g. by shifting away from peak time consumption through EV and/or battery storage and (dis)-charging, etc.) Addressing the issues of interconnection requires coordination and communication from across and within the subsystems. The physical connection dependencies are often immediately apparent for new projects and must are regulated.

D. **Build a general understanding of renewable and clean energy technologies**: Each subsystem is evolving at an unprecedented speed. As a result, it is difficult for those already in a specific sector to keep up with innovations. It is even more difficult for those in other sectors to keep up-to-date with developments in neighbouring sectors. Therefore, general and continuous upskilling is required across all of the SLES subsystems on available technologies, risk management and financial planning for projects where these technologies are used.

E. **Coordinated investment in data collection and control infrastructure**: Poor interactions between the subsystems will negatively affect the efficiency of the SLES operation and its evolution. Coordinated investment into data collection and control infrastructure, such as the installation of telecommunication networks, development of software platforms and application programming interfaces (APIs) for data exchange and support for external control functionality is required at the SLES level. In addition, policy and regulatory constraints around data and control must be defined, monitored and enforced.

F. **Develop a framework for conflict resolution**: Conflicts can emerge from incompatible goals and worldviews between stakeholders. For example, optimising traffic routes for smart mobility providers may conflict with minimising the through traffic objectives of community groups, while wind turbine installations goals may conflict with biodiversity preservation or other land uses.

Similarly, technological solutions across various subsystems may lead to conflicting implementation requirements. For example, distribution network operators may wish to minimise network reinforcements, while EV charge point providers require such reinforcements for operating within a given locality. Likewise, data may need to be shared for the optimisation of electricity network management, although this may conflict with the privacy preferences of citizens.

Skills required to address the challenges of orchestrating a whole city SLES

1. Managerial skills:

- **Partnership building**, to guide the process of engagement towards the delivery of a productive solution and to unite actors within and across subsystems to work to address both emerging issues and conflicts.

  Examples: i) partnership agreements between BCC and community groups, e.g. Bristol Energy Network (BEN); ii) the tender programme for formal joint ventures with businesses for the City Leap).

- **Risk management and financial planning**, to assess the realistic costs and benefits for business and household engagement for various technologies.
- **Negotiation and communication, as well as policy, regulation and standardisation skills**, to develop a co-ordination body and set up conflict resolution systems.
- **Risk assessment and management** both within and across subsystems, as risks will cross subsystem boundaries and will amplify, if not handled correctly. This might be done through an integration of responsibilities and mitigation plans into subsystem and SoS delivery contracts (which directly relates to the more generic and equally relevant contract writing skills).
- **Project management skills for large, cross-institutional collaboration**, to allow the SoS to integrate and manage a large set of stakeholders, set up common operating systems and processes, foster cross-team collaboration, and preserve and utilise historical knowledge.
- **Evaluation and assessment** of the SoS and subsystems operation, so that issues can be observed early on and addressed to prevent systemic negative impacts. This could relate to cross-subsystem regulations and standardisation, as well as coordinated actions to address cross-subsystem impacts. For instance, poor retrofit practices in the Building and Retrofit sector will undermine the demand for shifting efforts of the Energy sector and the fuel poverty resolution efforts of the Local Authorities. Evaluation can be supported through both quantitative and qualitative means:
    - **Modelling and simulation skills** for optimisation of, for example, system dynamics models.
    - **Qualitative methods**, such as expert panels, Delphi studies and "what if" scenario walk through with stakeholders.

2. Policy and regulation skills

- **Regulation** will be relevant for cross-subsystem interaction.

  Example: Bristol's regulation in the Building and Retrofit sector which states that at least 20% of the renewable energy generation for all new-build dwellings must be generated locally[4] has a profound effect on the Energy supply subsystem, as well as the Citizens and Community energy subsystems.

  The SLES coordination body could strongly recommend specific quality and qualifications regulations in the Building and Retrofit subsystem, as well as agreeing that the local authorities will motivate retrofit quality improvements by contracting only qualified tradesmen and maintaining a register of qualified tradesmen for citizens (as indeed is the case in Bristol through the Futureproof project).

- **Standardisation** for data, APIs and the types of generation equipment used, for example across new builds in Bristol, would facilitate retrofit quality improvement as builders and citizens become familiar with the renewable generation installations, and digital energy suppliers have a homogeneous resource to deliver new services.
- **Stable supportive policy for SLES as a whole**, since in many cases, the best policy for one subsystem could be less than optimal for the SoS as a whole. This is best exemplified with data sharing and privacy concerns: while data exchange is essential for SLES optimisation (and the better optimisation algorithms can be built when more data is shared), such total data availability undermines the fundamental human desire for privacy and security. This, in turn, undermines the uptake of any of the potential solutions by the citizens. Thus, policy making must be exercised so as to support the constituent subsystems, yet allow for optimisation of the SoS as a whole.

4 Bristol Development Framework core strategy, 2011.

- **Legislate compatibility of devices and infrastructures**, for instance, on voltage and frequency use by all generation and consumption devices across all subsystems which are legally acceptable within the UK.

3. Engineering skills

- **Software engineering and algorithms** are needed as energy systems become more automated, and smart buildings and controls take a more central role. This will require more detailed monitoring and controls to guarantee performance. Energy trading platforms are required for accounting for the transactions from community and citizen-owned generation equipment, as well as for consumption, and for use by EV charging and returning stored excess electricity during peak demand times into the distribution grid.
- **Data analysis and machine learning skills** are relevant both within and across subsystems. This could be for monitoring the state of the subsystems and SoS as a whole and supporting decision-making for Local Authorities, Energy supply subsystems, Transport and Mobility, ICT and Smart Energy, as well as for informing Citizens and community groups.
- **Data protection, ethical use and security skills** are needed within and across all subsystems of the SLE SoS, in order to ensure compliance with GDPR, and using encryption when sending data across networks, etc.
- **Networking and telecommunications skills** are needed to ensure that the equipment and appliances are able to exchange data and control instructions, for which hardwired or wireless communication infrastructure needs to be in place.
- **Regulations and standardisation skills** are essential for the usefulness of the exchanged data and usability of the software platforms and service APIs (relevant to all subsystems).
- **Infrastructure engineering (electrical and construction)** is necessary to ensure compatibility across different parts of the subsystems and allow for new connections and different uses of the energy system.

4. Trades skills

- **Installations trades are needed in different ways within the subsystems**, ranging from charge point installations in the Transport and Mobility subsystem to smart meters for the Energy supply subsystem, heat pumps in the Building and Retrofit subsystem, and for the Local authority's subsystem as they undertake district heating and transition away from gas boiler schemes for dwellings owned by BCC.

5. 'Soft' skills in communication and engagement

These are required across the SoS:

- To explain what the goals are and why are they relevant to citizens and broader stakeholders (*for example, via citizen assemblies, energy champions' programme and business consultations used by BCC.*)
- To develop technological literacy and avoid fears and unfounded concerns about new technologies. **Understanding** of technologies is not well addressed in Bristol presently and could be integrated within the schools' curriculum, and community and business training activities (*for example, via workshops with community organisations, peer learning and conferences, such as the BEN annual conference in Bristol.*)
- To ensure that all stakeholders are both generally supportive, and are also actively engaged with furthering goals, for example, working with citizens and businesses to design solutions together.

Shaping the type of SLES in Bristol

The city of Bristol, through its One City Plan, is developing a model for SLES, with the *shared goal of delivering a net-zero, liveable and prosperous city*. This is an 'acknowledged'[5] SoS model, i.e. a SoS structure which expects participating subsystems to share resources and coordinate management towards achieving an explicitly agreed upon goal.

However, the subsystems within the city do not yet have an explicit agreement on the goals, recourses and coordination processes.

For Bristol's SLES to be fully effective, it must address the challenges discussed above and establish a well-integrated operational framework. This must account for the goals and preferences of the subsystems, as well as the SoS as a whole and provide transparent governance and participation mechanisms to all subsystems.

The local authorities in Bristol are well placed to take leadership and serve as a core around which the SLES governance would coalesce. They already have supportive relationships with community energy and partnerships with community groups. Over the last 10 years, there has been a set of BCC-driven SLES projects which have, for instance, explored and installed EV charging, trialled smart homes, undertaken domestic retrofit, established heat networks and more, all supported by the Energy Service arm of the city council. City Leap might be a starting point for such a model, or the more collaborative One City Plan process could bring forward a group of stakeholders taking a lead in a more integrated SLES for Bristol.

Finally, Table 1 below presents the list of skills which, according to our study participants, cut across all SLE subsystems and are also relevant at the SoS level itself.

Table1: Bristol Smart Local Energy System: overview of the skills relevant across Subsystems and for the System-of-systems as a whole

Skills	Subsystems							SoS
	Building and Retrofit	Transport and Mobility	Energy Supply	ICT	Community Energy	Local Government	Citizens	SLE SoS
Engineering								
Data analytics and machine learning		x	x	x		x		x
Algorithms design and monitoring	x	x	x	x		x		x
Application development and programming		x	x	x				x
Systems engineering and integration	x	x	x	x	x	x		x
Connectivity, networking and telecoms		x	x	x		x		x
Research and simulation skills		x	x	x	x			x

5 Maier, M.W. 1998. Architecting principles for systems-of-systems. *Systems Engineering: The Journal of the International Council on Systems Engineering*, **1**(4):267–284.

Skills	Subsystems							SoS
	Building and Retrofit	Transport and Mobility	Energy Supply	ICT	Community Energy	Local Government	Citizens	SLE SoS
Trades								
Gas boilers and network decommissioning	x					x		x
Retrofit skills	x				x	x	x	
Installation and Integration (e.g. heat, smart meters and charge points)	x	x	x	x	x	x		x
Managerial								
Building partnerships and core trusted team	x	x	x	x	x	x	x	x
Procurement (materials and services)	x					x		
Cross-institutional project management		x	x	x	x	x		x
Energy								
Overview of renewables and SLE technology	x	x			x	x	x	
Finance								
New business and finance models (with renewables)		x	x		x	x		x
Policy								
Stable supportive policy	x	x	x			x		x
Regulating quality and qualifications (work, heat, security, privacy etc.)	x	x	x	x	x	x	x	x
Legal								
Contract reading and writing for SLE projects			x			x	x	x
Handling user data (GDPR-compliant)		x	x	x	x	x	x	x
Soft								
Educating and engaging general public	x	x	x	x	x	x	x	x

For full details on Bristol SoS skills case study see: Chitchyan, R. and Bird, C. Bristol as a smart local energy system of systems: skills case study. Research report, 26 Apr 2021, 124pp.

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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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