

## 11 Skills Across SLE SoS Sub-Systems: Architecting through Interfaces

This chapter considers the cross-subsystem skills for the SLE system of systems, drawing on the case study of the Bristol City's SLE (as represented by the views of our study participants).

### 11.1 Challenges of SLE as a SoS

As discussed in section 1.2.1, SLE SoS comprises a number of semi-independent subsystems, each operated for its own purpose by a different managerial team, with different project time horizons, technological and professional heterogeneity and evolutionary paths. However, to act as a coherent SLE SoS, these subsystems must collaborate towards a common goal.

Given that these subsystems, due to their quite independent evolutionary developments, have relatively well established boundaries, the only way of creating a common SoS architecture is by integrating them through common interfaces.

Drawing on the case study of Bristol city through our documentary analysis and interview and focus-group based qualitative study (detailed in [48]), we observe that these interfaces are formulated through:

1. **Interfaces with the Energy Distribution and Transition Networks**, which refers to the hardware-level interlinking of generation and consumption equipment with the electricity and gas/heat networks;
2. **ICT interfaces** that integrate data collection, exchange, decision support and control over the various generation, consumption and storage devices located within the component subsystems;
3. **Policy and Regulation** that constrains and stimulates various activities within and across these subsystems;
4. **Education and Training provision**, which fosters the setting of - and working towards - the common SoS goals across the various stakeholders within and across the SLE subsystems.

We discuss the key challenges and their respective skills that the SLE SoS must face, upskill for and overcome in integrating the SLE subsystems through the above interfaces below:

#### 11.1.1 Challenge 1: Lack of a Holistic View (Understanding)

As discussed in [48], each subsystem within Bristol city SLE faces their own set of challenges; e.g. the Building and Retrofit subsystem suffers from a lack of professional esteem and public trust (in retrofit) and a lack of incentives to change their building practices (in building); the transport and mobility sector in Bristol is concerned about finding business models that are financially feasible for EV and biogas vehicle fleet operators and their supporting smart mobility service providers, etc. 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.

**A. Setting an agreed common goal is thus the first objective** to be tackled in fostering a SoS-level transition. Agreeing upon this common goal would require a wide set of **Education and Training activities** across all levels of the SoS and subsystems' stakeholders.

**Bristol City Council** has taken a **leadership** role in this area and, since 2019, has been supporting Bristol's One City Plan [35] which defines how the stakeholders within the city will work together to create a 'Fair, healthy and sustainable city'. This plan was developed through extensive **engagement and consultation with citizens and wider stakeholders** and provides a set of mutually agreed goals through a collective vision for organisations and individuals across the city, which stretches beyond just the city council. The City Leap [40] initiative is another development that has flourished alongside the One City Plan. Furthermore, given that Bristol City Council owns a significant amount of property (including schools, libraries, offices and depots) as well as approximately 40% of the land in the city, it **sets 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 the awareness of citizens about climate emergency and energy transition challenges.

**B. Building a Mutual Understanding and a Common Vocabulary** is another objective to be addressed through education and training, as the SLE subsystems may not acknowledge relevance of one or several of the other subsystems on the one hand (e.g. Building and Retrofit sector is disengaged from Transportation, as Transportation is from Community Energy, etc.). On the other hand, they will be using different terms to refer to the same subject and/or the same term to refer to different subjects (e.g. 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).

In order to address this, the **local authorities** can set up city-wide collaborations and bodies (e.g. a Committee for SLE Transition made up of representatives from a relevant business, the community and a training provider) where the cross-subsystem engagement and cooperation will help to build a mutual understanding and a common (or at least cross-referenced) vocabulary.

This cross-subsystem vocabulary sharing within the **Community Energy** sector often happens through collaboration and interaction between groups. For instance, in Bristol, the Cold Home Energy Efficiency Servery 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 the community's use. Thus, the community in the Laurence Weston area of Bristol is actively engaged with learning about retrofit as well as energy generation technologies.

Furthermore, all subsystems must interact with and learn about the **electricity (and/or gas) supply** distribution networks, as they must all connect their equipment with (at least) the distribution and (often also) transmission networks. This leads to a common understanding, e.g. of the network constraints that a distribution service operator would likely experience, and opportunities for new service delivery (e.g. by shifting away from peak time consumption through EV and/or battery storage/(dis-)charging, etc.

**C. General Understanding of Renewable and Clean Energy Technologies:** each SLE subsystem is experiencing a technological flux, as all renewable and clean energy technologies are evolving with an unprecedented speed. As a result, it is difficult for those already within the specific sector to keep up with the innovations, and even more difficult for those in other sectors to keep

up to date, as, for instance, new batteries and/or chargers are developed for EVs at the same time as new types of heat pump and natural/hydrogen gas-based fuels are emerging across heating and energy supply. Thus, general (and continuous) upskilling is required across all of the SLE subsystems on available technologies, risk management and financial planning for projects.

### Skills to Tackle Lack of Holistic View Challenge

To address this challenge, a number of so-called Soft and Managerial skills must be engaged:

- *Communication*, to explain to citizens and broader stakeholders what the said goals are and why are they relevant (e.g. via citizen assemblies, an energy champions' programme and business consultations used by BCC);
- *Engagement*, to ensure that all stakeholders are both generally supportive and also actively engaged with furthering the said goals (e.g. working with citizens and businesses to co-design solutions);
- *Partnership Building*, to guide the process of engagement towards productive solution delivery (e.g. partnership agreements signed by BCC with community groups, such as the Bristol Energy Network (BEN); tender programme launched for formal joint ventures with businesses for the City Leap).
- *SLE Technological Literacy* to avoid fears and unfounded concerns about new technologies (e.g. this can be done through workshops with community organisations, peer learning and conferences, such as BEN's annual conference in Bristol);
- *Risk Management and Financial Planning* with SLE technologies to assess the costs and benefits for business and household engagement for various technologies realistically. (This area is poorly addressed in Bristol presently, and can be integrated within the school curriculum and community/business training activities).

#### 11.1.2 Challenge 2: Interconnection and Communication between SubSystems (Integrating)

In order to operate in a coordinated way, the subsystems within the SLE system must support **physical interconnections** for energy (e.g. electricity, heat and gas) exchange and *data and information exchange* for decision support and control in the optimisation of operations.

**A. Infrastructure for physical integration**, in most cases, is developed along with the renewable technology installations (e.g. solar PVs are integrated with the electricity network at installation time, as are EV charge points and heating and ventilation equipment in building retrofit, etc.). 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 (e.g. if the materials of the pipework have a chemical reaction with the new types of gas fuels, such as hydrogen). While addressing these issues requires coordination and communication across and within the SoS subsystems, such dependencies are explicit, regulated and immediately apparent for any installation project.

### Skills to Tackle Physical Interconnection Issues

The skills needed across the SLE SoS subsystems in this respect are related to the Engineering disciplines as well as Energy Domain Regulation.

- *Installations Engineering / trades* (e.g. for charge point installations in T&M subsystem; smart meter for energy supply subsystem, heat pumps in B&R subsystem, and for local authorities subsystem as they undertake district heating and transition away from gas boiler schemes for BCC-owned dwellings) most (if not all) of which are directly linked up with the electricity supply subsystem as they are either drawing from or feeding into the distribution grid as part of their operation;
- *Regulate for Compatibility of Devices and Infrastructures* (e.g. on voltage and frequency use by all generation and consumption devices across all subsystems which are legally acceptable within the UK's interfacing with the electricity and gas grids; Energy Efficiency standards of all Building and Retrofit work; regulation of heat networks, etc.)

**B. The Communications needs for data and information exchange** are somewhat more implicit across the SLE SoS subsystems, yet poor communication for interactions between the subsystems will negatively affect the efficiency of the SoS operation and its evolution (e.g. grey-outs 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. However, it is primarily a requirement of the SoS as a whole. Thus, coordinated investment into the data collection and control infrastructure (such as installation of telecommunication networks, development of software platforms and APIs for data exchange and support for external control functionality) would be required at the SoS coordination level. In addition, policy and regulatory constraints around data and control must be defined, monitored and enforced.

### Skills to Tackle Communications and Information Exchange Needs

Thus, the list of relevant skills here includes:

- *Software Engineering and Algorithm Design*, as, for example, *smart buildings and controls* are expected to take a more central role with the automation of energy systems, because "...to guarantee the performance, you need much more detailed monitoring and controls than are typical" (P12). Energy trading platforms are required for accounting for the transactions from community- and citizen-owned generation equipment as well as for their consummation, and for the use by EV charging and returning stored excess electricity during peak demand times into the distribution grid, etc.
- *Data Analysis and Machine Learning* skills are relevant both within and across subsystems (e.g. in monitoring the state of the subsystems and SoS as a whole and supporting decision making for local authorities, energy supply subsystem, transport and mobility, ICT and smart energy, as well as for informing citizens and community groups).
- *Data Protection, Ethical Use and Security* skills within and across all subsystem of the SLE SoS, e.g. in ensuring compliance with GDPR, using encryption when sending data across networks, etc.

- *Networking and Telecommunications* skills, to ensure that the equipment and appliances are able to exchange data and control instructions, for which hard-wired or wireless communication infrastructure needs to be in place.
- *Regulations and Standardisation* skills are essential for the utility of the exchanged data and usability of the software platforms and services APIs (which is relevant to all subsystems).

### 11.1.3 Challenge 3: Governance of the SLE SoS in its Entirety (Operating)

While each subsystem will be managed by its respective management structures, there is a need for an additional governance mechanism that accounts for the holistic SLE SoS, along with the impacts that interactions between the subsystems could cause. These interactions may result in, for instance, *privacy impacts* from the cross-subsystem aggregation and the sharing of householders' data, *exacerbated inequalities* (e.g. if the well-off and so well-networked areas of the city can acquire new digital energy services, which are not accessible to less affluent areas). Another possible impact is *stifling of business opportunities*, for instance, if one subsystem, say the EV charge operators, refuses or lacks networking infrastructure to share its data with the others (e.g. energy suppliers) who therefore cannot deliver new services (such as demand response management), etc. These challenges could be addressed through the following:

**A. Set up of a Cross-Subsystem SLE SoS Coordination body to Identify and Address Emergent Properties.** While there is no such mechanism in place presently for the SLE SoS at Bristol, this is not entirely unfamiliar ground. For example, this cross-subsystem impact consideration is taken by BCC through the *Health and Wellbeing Board* in the Joint Strategic Needs Assessment [49] for identifying and addressing the impact of fuel poverty on health.

The task of this body would be to consider **inter-dependencies, and emerging impacts** that subsystem-specific-behaviours could cause in deviating from the agreed upon goals and vision (as discussed in Challenge 1) of the intended SLE SoS. For example, is optimising traffic flow for EVs acceptable for the Citizen's subsystem? Also, can community energy groups support their communities better by collaborating with local charge point providers for EVs?

**B. Develop a Framework for Conflict Resolution** as conflicts can emerge both from **incompatible goals and worldviews** between stakeholders (e.g. a goal to optimise traffic routes for smart mobility providers may conflict with a community group's goal to minimise through-traffic; wind turbine installations goals may conflict with biodiversity preservation, etc.).

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

#### Skills to Tackle SLE SoS Governance Issues

This challenge is centred around the need to align SLE SoS operation with its subsystems as well as the broader national frameworks. Thus, a variety of skills, inclining negotiation, communication, policy, regulation and standardisation, and processes would have to be employed, with the following list of relevant key skills:



- *Building Partnerships* skill is necessary to bring the stakeholders along and unite within and across subsystems to identify and address both emergent issues and conflicts (e.g. as noted with respect to partnership with a core trusted team of tradespeople in B&R, with Industry, Community and local government, etc.)
- Skills to *Integrate Evaluation and Assessment* into the SoS and subsystems operation is critically important as any emergence is to be observed relatively early and addressed to prevent systemic negative impacts. This could relate, for instance, to cross-subsystem regulations and standardisation, as well as coordinated actions to address cross-subsystem impacts. For instance, the poor retrofit practices in the B&R sector will undermine the Energy sector's efforts of shifting the consumers' energy demand away from peak time, as well as impede the fuel poverty resolution efforts of the local authorities. Thus, the SLE SoS coordination body could strongly recommend specific quality and qualifications regulations in the B&R subsystem, as well as agree that the local authorities will motivate retrofit quality improvements by only contracting qualified delivery tradespeople and maintaining a qualified traders' register for citizens to employ on their personal retrofit projects. (The last point has indeed been realised in Bristol through the Futureproof project [28]). This can be supported through both quantitative and qualitative means, e.g.:
  - *Modelling and Simulation skills* for use in SoS optimisation (e.g. system dynamics models)
  - *Qualitative methods of planning*, such as expert panels, Delphi studies, a “what-if” scenario walkthrough with stakeholders.
- *Risk Assessment and Management* both within and across subsystems, as risks will cross subsystem boundaries and amplify, if not handled, e.g. through 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*).
- *Large, Cross-Institutional Project Management* skills would play a particularly important role as the SoS needs to integrate and manage a large set of stakeholders, set up a set of common operating systems and processes, foster cross-team collaboration, preserve and utilise historical knowledge in a very dynamic SoS.
- *Regulation and Standardisation* skills were already noted with respect to the data and API standardisation, yet a broader effort will be relevant for cross-subsystem standardisation as well. For instance, Bristol's regulation in the Building and Retrofit sector stating that at least 20% renewable energy generation for all new built dwellings must be generated locally has a profound effect on the Energy supply subsystem as well as the citizens and community energy subsystems. Thus, standardising the types of generation equipment used across new-builds in Bristol would facilitate e.g. retrofit quality improvement as builders are familiar with the said type of renewable generation installations; citizens are also more familiar with this technology, and consider it to be less risky for their own use; digital energy suppliers have a homogeneous resource to deliver new services with, etc.
- *Stable supportive policy for SLE SoS as a whole* is necessary, as 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 the data sharing and privacy concerns; while data exchange is essential

for SoS optimisation (and the more data is shared, the better the optimisation algorithms which can be built), such total data availability undermines the fundamental human desire for privacy and security, which undermines the uptake of any of the potential solutions by citizens. Thus, policy making that supports the constituent subsystems, yet allows for optimisation of the SoS as a whole must be exercised.

## 11.2 Shaping the type of SLE SoS in Bristol

There are 4 general types of SoS, characterised by the levels of centralisation and autonomy that the constituent subsystems enjoy within a SoS: [8, 9]

1. *Virtual SoS*, have no centralised authority directly overseeing their interactions at all. The interaction of the subsystems and their emergent behaviours occur through indirect and invisible mechanisms (e.g. mechanisms such as interest rates and supply and demand regulate the national economy SoS, the sub-parts of the SoS do not formally agree to collaborate);
2. In *Collaborative SoS* the subsystems interact on a voluntary basis and collectively decide on how to provide a particular service (e.g. as the internet is composed from collaborating national networks);
3. In an *Acknowledged SoS* all subsystems acknowledge their common objectives and work through a designated management team to coordinate resource use and plans for achieving the agreed goals (e.g. as is done in disaster recovery SoS);
4. In a *Directed SoS*, the constituent subsystems are well integrated, are managed by a centralised team/authority, and operate as the subordinates of this central authority; the operation mode is subordinated to a central authority (e.g. as the centralised electricity system has been until recently).

Presently, the Bristol SLE SoS operates as a hybrid type, for instance:

- the community energy subsystem interacts through a virtual model with the transport and mobility and the local authority subsystems,
- building and retrofit subsystem interacts through a collaborative mode with the citizens and energy supply subsystem and through a virtual mode with the transport and mobility,
- the energy supply subsystem, however, interacts in directed-like fashion with the community energy subsystem, and in collaborative fashion with the citizens, yet virtually with the local authorities, etc.

As elicited both from our interview study and documents on the visions of the city of Bristol [35], the city envisions that its SLE should operate as an acknowledged SoS, with the goal of delivering a net-zero, liveable and prosperous city. For this vision to come to fruition, the challenges listed in the previous subsection must be addressed, and a well-integrated operational framework for the SLE SoS must be established. Such a framework 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 for all subsystems to contribute.

We note that the local authorities in Bristol are well-placed to take the leadership and serve as a core around which the SLE SoS governance would coalesce. They have good relationships with Bristol's citizens, supportive relationships with community energy, and partnership with community groups, as well as commercial partnerships and there has been a set of BCC-driven SLE projects over the past ten years which have developed knowledge and expertise internally.

Finally, Table 4 below presents the list of skills which, according to our study participants, cut across the subsystems and are also relevant at the SoS level itself.



Table 4: Skills Relevant across SubSystems and for the System of Systems as a Whole

Engineering	Skills		SubSystems							SoS	
	Building & Retrofit	Transport & Mobility	Energy Supply	ICT	Community Energy	Local Government	Citizens	SLE	SoS		
	Data Analytics and Machine Learning	X		X				X			X
	Algorithms Design and Monitoring	X		X							X
	Application Development/Programming	X		X							X
	Systems Engineering and Integration	X		X				X			X
	Connectivity, Networking and Telecoms	X		X				X			X
	Research and Simulation Skills	X		X				X			X
<b>Trades</b>	Gas boilers/network decommissioning	X						X			X
	Retrofit skills	X						X			
	Installation & Integration (heat, smart meters, charge points)	X		X				X			X
<b>Managerial</b>	Building Partnerships/Core Trusted Team	X		X				X			X
	Procurement (materials and services)	X						X			
	Cross-Institutional Project Management	X		X				X			X
<b>Energy</b>	Overview of Renewables/SLE Technology	X						X			
<b>Finance</b>	New Business and Finance Models with Renewables	X						X			X
<b>Policy</b>	Stable supportive policy	X						X			X
	Regulating Quality & Qualification (quality of work, heat, security, privacy)	X		X				X			X
<b>Legal</b>	Contract Reading/Writing for SLES projects							X			X
	Handling User Data (GDPRcompliant )	X		X				X			X
<b>Soft</b>	Educating and Engaging General Public	X		X				X			X