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Developing the framework for multi-criteria assessment of smart local energy systems

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ABSTRACT

In response to the climate emergency, energy landscapes are rapidly shifting to cleaner, decentralised smart local energy systems (SLESs). SLES will facilitate connection of transport, heat and power through flexible energy supply, demand and storage options supported by digital technology. SLESs are expected to contribute to tackling the energy trilemma (cost, security and sustainability), but there is also scope for them to offer many co-benefits aligned with the United Nations (UN) Sustainable Development Goals (SDGs). These benefits may drive for ongoing political and financial investment in SLES; therefore, there's a need to indicate how a SLES is performing over time relative to each of them. Currently, there is no standardised approach to evaluate SLES and most of the existing techno-socio-economic tools have limited scope to assess the complex multiple performance indices, scenarios and stakeholders.

The Innovate UK-funded EnergyREV research consortium is developing a multi-criteria assessment tool (MCA) for SLES. This paper describes the first step in this process – developing a simplified and standardised framework for assessing the performance of the system and the realization of benefits. It explores existing protocols and stakeholder opinion to identify 50 potential factors that are important in monitoring the system performance. These are clustered into 10 key themes to create a taxonomy for SLES performance that are aligned with relevant UN SDGs to track wider co-benefits. The resulting MCA tool will be instrumental to project stakeholders in providing evidence to support performance claims and identifying potential benefits beyond targeted key performance indicators.

Introduction

In response to the climate emergency, energy landscapes are rapidly shifting to cleaner, decentralised smart local energy systems (SLESs). SLES will facilitate connection of transport, heat and power through flexible energy supply, demand and storage options via the advances in digital technology. They are expected to help resolve the energy trilemma (producing cleaner energy, at an affordable price, with acceptable energy security level), but will also offer many co-benefits related to the United Nations (UN) Sustainable Development Goals (SDGs). These benefits (e.g. job creation, enhanced thermal comfort and living conditions) may be a key driver for ongoing political and financial investment in SLES, hence there is a need to indicate how an SLES is performing over time relative to each of them. Currently there is no standardised approach or framework for evaluating SLES, and most existing tools only give part of the story or are problematic for various reasons such as being techno-economic centric, complex and difficult to use. Therefore, there is a real need to develop a standardised assessment tool to measure the performance of SLES against multiple objectives. The design of this tool needs to take into consideration different elements and factors of the products, processes, people and overall system.

This paper presents the development of a simplified and standardised framework for an ongoing project to produce a multi-criteria assessment (MCA) tool for SLES, as part of the Innovate UK-funded EnergyREV project. This tool will allow project developers and other interested stakeholders to assess the performance of the system and the realization of potential benefits that may extend beyond identified key performance indicators.

This framework was developed through an exploration of existing multi-criteria assessment protocols used in related applications, augmented with a stakeholder mapping exercise (identifying current roles and responsibilities of the various actors in the energy sector), and stakeholder consultation. The resulting framework of SLES performance was also aligned with the UN SDGs to further illustrate the broader co-benefits that can be realized. The next steps in addressing the research questions and delivering a multi-criteria assessment tool are also discussed.

Methodology

A stakeholder mapping exercise of the UK energy sector and public consultation with experts identified were conducted. The data gathered was then supplemented with further information found through a literature review of a number of existing MCA tools used in different field applications. From exploring the existing MCA tools, several common assessment criteria and indicators emerged that were applicable to SLES. The outcome of this methodology resulted in a set of 10 common key performance factors and 50 sub-themes of interest which are proposed as a taxonomy to measure and track SLES performance and benefits. This section describes the stakeholder identification process and outlines the various tools examined in literature.

Stakeholder identification and analysis

It is widely acknowledged that adopting a socio-technical approach to system development leads to systems that are more acceptable to end users and hence delivers greater value for the interested parties (Baxter and Sommerville, 2011). Additionally, grassroots, bottom-up, community energy (CE) schemes developed by civil society groups and motivated by social and environmental issues have comprehensively informed best practice for policy and finance mechanisms, and have stood the test of time, leading to wider scale climate change mitigation (Devine-Wright, 2019; Sudmant et al., 2017). To achieve this all, stakeholders need to be identified, sensitised and constructively engaged from the ground level upwards. This will reduce any unintended consequences and maintain success; for example, government or local authority led initiatives are able to keep afloat after financial subsidies are removed.

A stakeholder mapping exercise was conducted to identify all the individuals and interested parties in a SLES, understanding the roles they develop and outlining the relationships between them. For this purpose, a SLES can be viewed as a smaller version of the larger energy system; a transition from the current scheme to the future structure has the potential to affect all the actors involved in energy related activities.

Two larger UK energy system stakeholder maps were adapted to identify all the actors within the current structure: the first from the 'Energy System Transition through Stakeholder Activation, Education and Skills Development' project (ENTRUST) project (Dallamaggiore et al., 2016) and the second from the Scottish Power Energy Networks Accelerating Renewable Connections project (Scottish Power Energy Networks, 2014). Five stakeholder categories were identified: energy businesses (e.g. direct and indirect); regulators (e.g. regulation bodies, certification bodies); end consumers (e.g. individual, medium and large energy users); support (financial, knowledge advancement -researchers), and influencers (e.g. opinion leaders, media, general opinion). The stakeholder map developed for the UK current energy system as shown in Figure 1.

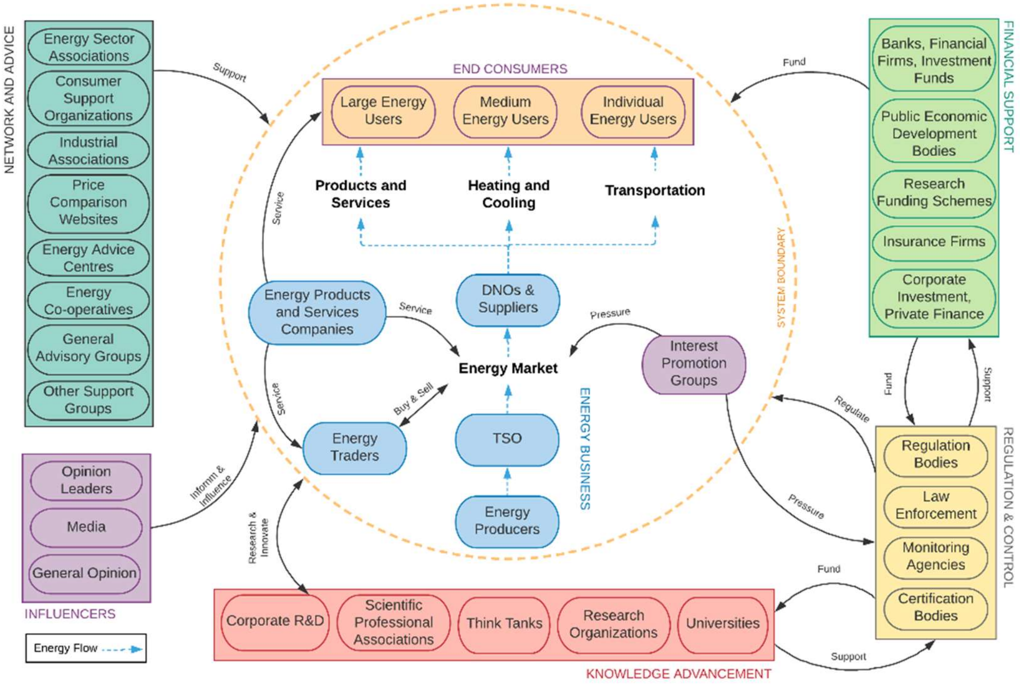

Figure 1. Stakeholder mapping for the UK larger energy system (developed from (Dallamaggiore et al., 2016))

The evaluation of a socio-technical system involves assessing the deployed scheme to understand how well it meets the expectations of its stakeholders. The nature of this evaluation changes as the design and the system processes evolve and, as a result, the expectations of the stakeholders change accordingly (Baxter and Sommerville, 2011). As traditional consumers start to become prosumers, new actors and roles will emerge and current actors will experience a change from their conventional activities (Koirala et al., 2016). As such these roles must be reconsidered. A characterisation by role allows the grouping of parties that may have similar objectives and methods, therefore when the actual engagement takes place in the context of group consultations, it can be ensured that all high-level perspectives on SLES performance are taken into account, contradictory as they may be. Successful stakeholder engagement is closely linked with the active management of stakeholders' roles, interests, and relationships within a flexible and agile environment. The constant review and update of these roles is of particular importance for SLES, because these types of system remain hand-in-hand with the energy transition and, as such, they will evolve at the same pace.

In conjunction with the stakeholder identification and analysis, an initial public consultation was held via a workshop to define the success criteria of SLES. The participants were comprised from academia, industry, non-profit organisations, community energy groups and the health sector. The results from the stakeholder feedback were then combined with relevant assessment criteria and indicators that emerged from literature to create a taxonomy for SLES. The next section discusses the characteristics of these MCA tools which were analyzed.

Learning from existing knowledge on different evaluation tools

An in-depth literature review was conducted on relevant evaluation tools for SLES. Existing protocols in various applications from renewable energy, through defence technology, sustainable accounting to smart cities were investigated. Although there were overlapping and combined methodologies, four main analytical tools were identified in literature and covered herein: maturity or readiness tools; planning and forecasting; sustainability transition; and other miscellaneous tools. These are summarised in Figure 2.

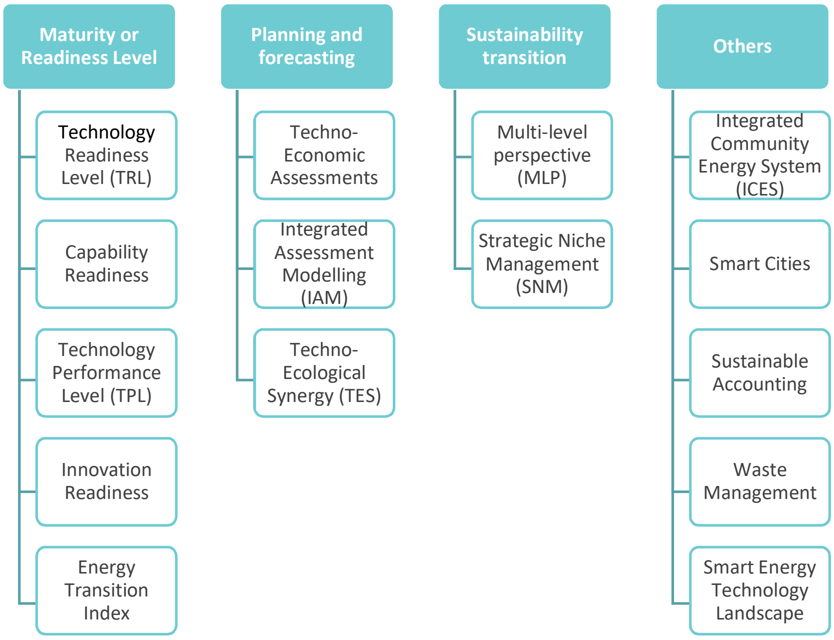

Figure 2. Different types of evaluation tools

SLESs are very complex and can be considered as a system of networked systems. In examining the existing body of MCA tools, as described in greater detail in the rest of this section, it was found that a full assessment of the performance and benefit realization of SLES projects must examine the socio-technical environment alongside an integrated assessment of the multiple factors which will drive the low carbon transition. In addition to the technical, economic, social, environmental and policy issues, any multi-criteria assessment tool applied to SLES should also consider the different spatial scales, available resources and stakeholder opinions should also be considered in. At this time, no existing tool adequately meet all these criteria at the same time.

a) Assessing maturity or readiness level

One of the first widely used assessment scales, now a de facto standard, is *Technology Readiness Level (TRL)*, used to assess the maturity or readiness of a product and/or service (Mankins, 1995). This measurement system originated from the military and aerospace industry (Altunok and Cakmak, 2010) and has since been adopted in many other fields, including renewable energy applications. There are, however, inherent draw backs to the TRL in that it is intended for the assessment of a particular technology and components. As components become interlinked with systems and sub-systems, and procedures and processes are put in place to interact and operate with people within an environment, the TRL becomes insufficient to assess the whole system. As such, the TRL scale has been modified and combined with other evaluation tools to analyze the overarching system or address a particular function.

The *Capability Readiness* was proposed for assessing the capacity requirements for a product-service-system (PSS) in engineering manufacture and involves analysing joint package of elements e.g. training, equipment and personnel (Tetlay, 2010).

The *Technology Performance Level (TPL)* was used to assess the benefits of wide range of wave energy converters based on their ability for reliable grid operations and energy security (Bull et al., 2017).

The *Innovation Readiness* explored other prerequisites indicators such as consumer behaviour to assess consumer knowledge level and their need for the technology under study (KIC InnoEnergy et al., 2017).

The *Energy Transition Index (ETI)* examined factors such as market transactions costs to determine the status of electricity flexibility markets and the level of preparation to for the energy transformation (REA, 2019).

b) Planning and forecasting tools

The next group of tools discussed are commonly used for planning or forecasting, such as evaluating the techno-economic performance of a product and/or service. *Techno-economic assessments* have been widely used for feasibility studies to optimise the performance of a product, service, process or system. It traditionally involves analyzing and comparing technical and economic parameters such as the classic levelized cost of energy (LCOE), (de Andres et al., 2017). There are two main issues in techno-economic assessment of renewable energy resource: challenges in quantifying assessment indicators and lack of a general indicators for MCA (Liu et al., 2018). Techno-economic assessments have since evolved into more holistic analyzes and have expanded to assess other factors such as the environmental and social influences.

Integrated assessment modelling (IAM) of sustainable energy systems have become increasingly influential among decision makers and have been used in various reports such as policy impact assessments and environmental legislative analysis reports (Krey et al., 2019). Despite the advantages of IAM (inclusive of multi-criteria decision analysis (MCDA) tools), there are several weaknesses due to complexity in the design and evaluation of sustainable energy systems and involvement of multiple performance indices, scenarios, and stakeholders. Similarly, analysis of social and cultural characteristics are another factor which makes the problem multidimensional with multiple objectives (Kumar et al., 2019). Additionally, the assessment of different spatial scales requires different strategies with different considerations, otherwise complications may arise when certain specific concerns in the evaluation process are ignored (Ma et al., 2018)

In relation to the environment, a *techno–ecological synergy (TES)* framework was introduced as an approach to augment the sustainability of solar energy across four recipient environments: land, food, water, and built-up systems (Hernandez et al., 2019). This framework essentially can be applied to other systems to minimize unintended consequences on nature associated with a rapid energy transition (Hernandez et al., 2019) as in the case of this research SLES.

c) Sustainability transition

To adequately respond to the climate emergency, an effective sustainable transition is essential. Therefore, understanding the context of what works and how is also critical for a successful low-carbon transition. SLES are characterised as being socio-technical in nature (Ford et al., 2019); as such two common types of socio-technical transition frameworks, *strategic niche management (SNM)* and *multi-level perspective (MLP)*, can be used for the assessment of SLES.

The SNM approach suggests that sustainable innovation journeys can be facilitated by creating technological niches; i.e. protected spaces that allow the experimentation with the co-evolution of technology, user practices, and regulatory structures (Schot and Geels, 2008). To complement the SNM approach, ‘nurturing’ the innovation within a niche space (Smith and Raven, 2012) and delivering empowering processes for wider system change for designing energy planning tools for low carbon transitions (Bush and Bale, 2019) are also considered to be critical.

The MLP on socio-technical transition offers a big picture and addresses the interdependent social, political, cultural, and technical processes of transformation (Geels et al., 2017). It is recommended that techno-economic approaches are complemented with frameworks that address the socio-technical dynamics of low-carbon transitions (Geels et al., 2017). A new analytical method of transition narratives was introduced to bridge the gap between socio-technical transition studies and integrated assessment modelling (IAM) through analysis of niche momentum and actors for variety of low-carbon energy scenarios (i.e. electricity, transport and heat) in Europe (van Sluisveld et al., 2018). These transition narratives are applicable to SLES and can be used to better understand the context of how they will drive future change.

d) Other miscellaneous tools and indicators

There are number of other notable tools, frameworks and indicators analysis methods which can be applied to evaluation of SLES.

An *integrated community energy system* (ICES), is a combination of the distributed generation and micro-grid concepts. The assessment criteria for an energy system to qualify as an ICES should include (Koirala et al., 2016): locality, modularity, flexibility, intelligence, synergy, customer engagement and efficiency. These attributes readily correspond to an SLES framework wherein its multi-objectives support the development of smart cities.

The concept of a *smart city* varies according to the context (Sharifi, 2019a), however the Focus Group on Smart Sustainable Cities considered that the sustainable indicators should be able to assess the quality of life, efficiency of urban operation and services, and competitiveness across economic, social, environmental as well as cultural aspects (ITU, 2016). Common indicator themes which were recommended as a reference guide for evaluating the performance of smart cities and other similar schemes (Sharifi, 2019a, 2019b) were similar to that of another study exploring the context of smart grids (Hargreaves et al., 2015). These included issues and factors such as data, environment and governance. The design of SLES will vary depending on a number of factors such as geographical location, available resources, communities and people involved. As such, what may work for one local area may not necessarily suit another. This was evident in the customized solutions for evaluating a smart city model for a developing regions where there was a clear distinction made between primary services and sustainable services to enhance the quality of life for the population (Marchetti et al., 2019) which can be readily applied to SLES. It is implied that if the basic needs of the population were not met, it is unlikely that the sustainable services offered would have a huge impact on improving the quality of life, thus the core objectives and co-benefits may not be realized. The same can be assumed for the city's assets: if the relative infrastructure is not there, rapid adoption of the technology and information systems may not occur. For example, the uptake of electric vehicles (EV), would require the fundamental EV infrastructure and charging points.

Another element which is relevant to SLES is the influence of *waste–to-energy* resources. Rodrigues et al. (2018) considered that municipal solid waste management entails multiple visions of sustainability not only focusing on environmental issues but social factors.

Assessment tools developed for Scotland's Energy Efficiency Program, which analyzed the *smart energy technology landscape* (Snodin, 2017), can also be employed with SLES to ensure that all aspects of the energy sector are incorporated.

Similarly, Six Capitals, the method for *sustainable accounting* that assesses long-term viability and value creation over time for an organization and utilizes integrated reporting can be easily applied in the assessment of SLES. It examines financial, manufactured, intellectual, human, social and relationship, and natural impacts (ACCA and NBA, 2013).

In reviewing the four main analytical tools discussed, it became clear, that common evaluation criteria applicable to SLES emerged from all four areas. The common factors identified through literature and expert views were then incorporated into a taxonomy (or classification) for SLES assessment. Details of this are further elaborated in Table 1. The taxonomy employs a hierarchical structure to simplify the complex multi-criteria analysis of SLES performance. The methodology for the construction of the MCA tool for SLES is an iterative process that allows for adjustment and refinement through the findings received from an ongoing series of stakeholder consultations which will be held throughout the remainder of the two year project. The next section presents the preliminary results of the taxonomy, key performance factors and sub-themes which are then aligned with the UN SDGs to track the co-benefits that may be realized through SLES.

Proposing a Taxonomy to Measure the Performance of SLES

In the context of this research, a taxonomy is defined as the classification or naming of each factor or theme applicable to SLES. It will be used as a pathway to develop the MCA tool for SLES by reviewing the areas of strengths and weaknesses, as well as administering the multiple performance indices, scenarios, and stakeholders. The taxonomy has a hierarchical structure, which will simplify the complex analysis of SLES through the identification of key themes and sub-themes that are of influence. The theme(s) and sub-theme(s) generated in the taxonomy will principally lead to a particular yield, objective(s) or consequence(s) from the development of SLES.

Classifying key themes for SLES analysis

A total of 50 relevant performance factors were identified which were clustered into 10 key themes, which are described as follows:

1. **Data security** – SLES are going to deal with a lot of information and perhaps even some sensible data, this theme aims at measuring how is this data being protected and the integrity of its owners entrusted.
2. **Data connectivity**– The present theme will assess data management and infrastructure in terms of how SLES might impact aspects such as ICT accessibility and penetration.
3. **Technical** – This theme will evaluate the technical aspects of the technology in areas of importance for the energy sector, such as flexibility, resilience, efficiency, innovation and renewable fraction.
4. **Transport** – The transport section aims at evaluating how transport management is being impacted by the system, as well as what is the level of deployment of EV technology.
5. **Economics** – This theme deals with the economic outputs of the technology, typical measures for such performance are considered, such as internal rate of return, payback period and benefits to cost ratio.
6. **Business and finance** – Looking into the financial aspect of the SLES, the present section will evaluate how this fits into the market as a whole, with indicators such as compensation structures and job creation.
7. **Governance (socio-political)** – This theme aims at assessing the political and regulatory alignment of the SLES, as well as its socio-economic impact.
8. **People** – This section will evaluate the impact the SLES has on its final users. Aspects such as education/ICT skills, engagement and acceptance are going to be considered.
9. **Living** – SLES are expected to have benefits on the communities and their social interactions, sub-themes to measure this have to do with housing conditions, equity and culture or behaviour.
10. **Environment** – Probably the main driver for the introduction of SLES, environmental performance can be assessed with indicators such as decarbonisation, human health, resource availability and waste energy potential.

The list of key performance factors itemize both core outcomes (primary benefits) and support solutions that are critical for the delivery of SLES objectives. Supporting solutions such as Data security and Governance are factors that will identify if certain boundary conditions are met in order to ensure that the SLES does not lead to negative impacts, dis-benefits or any unintended consequences. These key themes and sub-themes proposed for the taxonomy to measure the performance of SLES were previously applied for the assessment of sustainable energy, smart cities, smart-grids, smart energy, and renewable energy (inclusive of tidal, wave and solar energy) products/services/systems as shown in Table 1.

Table 1. Taxonomy for SLES Assessment

No	Theme		Sub-theme	Previous Application
1	**Data Security**		Security	Smart-grid (Hargreaves et al., 2015), Smart city (Sharifi, 2019b)
			Privacy	Smart-grid (Hargreaves et al., 2015)
			Trust	Smart-grid (Hargreaves et al., 2015), Stakeholder consultation (1) (EnergyREV WP 5.2, 2019)
2	**Data Connectivity**		Digital technology enablers	Energy Transition (REA, 2019)
			ICT Infrastructure	Smart city (Sharifi, 2019a) (Sharifi, 2019b), Smart-grid (Hargreaves et al., 2015),
			ICT Management	Smart city (Sharifi, 2019a) (Sharifi, 2019b)
			ICT Accessibility	Smart city (Sharifi, 2019a) (Sharifi, 2019b)
3	**Technical**		Renewable fraction	RE (Liu et al., 2018), RE-Hybrid (Ma et al., 2018)
			Reliability	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Solar-energy (Hernandez et al., 2019), Smart energy (Snodin, 2017), Smart-grid (Hargreaves et al., 2015), Sustainable energy (Gallego Carrera and Mack, 2010), Wave & tidal energy (Bull et al., 2017)
			Resilience	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Solar-energy (Hernandez et al., 2019), Smart-grid (Hargreaves et al., 2015) , Sustainable micro-grid (Kumar et al., 2019)
			Flexibility	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Smart-grid (Hargreaves et al., 2015)
			Scalability	Smart-grid (Hargreaves et al., 2015), Sustainable micro-grid (Kumar et al., 2019)
			Efficiency	Energy (Krey et al., 2019), Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Energy storage (KIC InnoEnergy et al., 2017), Smart city (Sharifi, 2019b), Smart energy (Snodin, 2017), Smart-grid (Hargreaves et al., 2015), Solar-energy (Hernandez et al., 2019),
			Maturity	Energy storage (KIC InnoEnergy et al., 2017), Sustainable micro-grid (Kumar et al., 2019)
			Lifespan	Energy (Krey et al., 2019), Sustainable micro-grid (Kumar et al., 2019)
			Grid accessibility	Energy Transition (REA, 2019)
			Innovation adoption	Energy Transition (Association for Renewable Energy and Clean Technology (REA), 2019), Smart city (Sharifi, 2019b), Smart-grid (Hargreaves et al., 2015), Sustainable energy (Gallego Carrera and Mack, 2010)
4	**Transport**		Transportation management	Smart city (Sharifi, 2019a) (Sharifi, 2019b)
			EV infrastructure and EV charging	Energy Transition (REA, 2019), Smart city (Sharifi, 2019a) (Sharifi, 2019b)
5	**Economics**		Benefits to cost ratio	RE-Hybrid (Ma et al., 2018)
			Costs (capital, installation and O&M)	Energy (Krey et al., 2019), RE-Hybrid (Ma et al., 2018), Smart energy (Snodin, 2017), Sustainable micro-grid (Kumar et al., 2019), Waste management (Rodrigues et al., 2018), Wave & tidal energy (Bull et al., 2017),
			IRR	RE (Liu et al., 2018), RE-Hybrid (Ma et al., 2018)
			LCOE (levelized cost of energy)	RE (Liu et al., 2018), RE-Hybrid (Ma et al., 2018), Energy (Krey et al., 2019)
			PBP (payback period)	RE-Hybrid (Ma et al., 2018)
6	**Business and Finance**		Regulations	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Wave & tidal energy (Bull et al., 2017)
			Compensation structures	Energy Transition (REA, 2019)
			Affordable or competitive cost	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019)
			Investable	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Waste management (Rodrigues et al., 2018), Waste management (Rodrigues et al., 2018), Wave & tidal energy (Bull et al., 2017)
			Employment/Creation of Jobs	RE-Hybrid (Ma et al., 2018), Smart city (Sharifi, 2019b), Sustainable energy (Gallego Carrera and Mack, 2010), Sustainable micro-grid (Kumar et al., 2019)
7	**Governance**	**Socio-political**	Transparency on system needs and policy direction	Energy Transition (REA, 2019), Smart-grid (Hargreaves et al., 2015)
			Socio-economic impact	Energy Transition (REA, 2019)
			Integrated management	Smart city (Sharifi, 2019a)
			Political and regulatory alignment	Energy Transition (Association for Renewable Energy and Clean Technology (REA), 2019), Smart energy (Snodin, 2017), Sustainable energy (Gallego Carrera and Mack, 2010)
8	**People**		Education & Gender equality	Smart city (Sharifi, 2019a) (Sharifi, 2019b), Smart-grid (Hargreaves et al., 2015), Sustainable micro-grid (Kumar et al., 2019), Waste management (Rodrigues et al., 2018)
			ICT Skills	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Smart energy (Snodin, 2017)
			Engaging/participation	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Smart city (Sharifi, 2019a) (Sharifi, 2019b), Sustainable energy (Gallego Carrera and Mack, 2010)
			Acceptance	Wave & tidal energy (Bull et al., 2017), Energy storage (KIC InnoEnergy et al., 2017), Smart energy (Snodin, 2017), Sustainable micro-grid (Kumar et al., 2019)
			User friendliness/control	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Smart energy (Snodin, 2017), Smart-grid (Hargreaves et al., 2015)
			Inclusion/ Empowerment	Smart-grid (Hargreaves et al., 2015), Waste management (Rodrigues et al., 2018), Smart city (Sharifi, 2019b), Sustainable energy (Gallego Carrera and Mack, 2010)
			Consumer protection	Smart energy (Snodin, 2017), Smart-grid (Hargreaves et al., 2015)
9	**Living**		Housing	Smart city (Sharifi, 2019b)
			Equity	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019), Solar-energy (Hernandez et al., 2019), Smart city (Sharifi, 2019a), Smart-grid (Hargreaves et al., 2015), Sustainable energy (Gallego Carrera and Mack, 2010)
			Culture or behaviour	Smart city (Sharifi, 2019a) (Sharifi, 2019b), Smart-grid (Hargreaves et al., 2015), Energy storage (KIC InnoEnergy et al., 2017)
			Livelihood	Smart-grid (Hargreaves et al., 2015)
			Convenience	Smart city (Sharifi, 2019b)
10	**Environment**		Climate change - Decarbonisation	Stakeholder consultation (1) (EnergyREV WP 5.2, 2019)), RE (Liu et al., 2018), RE-Hybrid (Ma et al., 2018), Smart city (Sharifi, 2019a) (Sharifi, 2019b), Smart energy (Snodin, 2017), Smart-grid (Hargreaves et al., 2015), Solar-energy (Hernandez et al., 2019), Sustainable energy (Gallego Carrera and Mack, 2010), Sustainable micro-grid (Kumar et al., 2019), Waste management (Rodrigues et al., 2018), Wave & tidal energy (Bull et al., 2017), LCIA RECiPe model (LCIA: the ReCiPe model | RIVM, n.d.)
			Ecosystem (land, fresh water, marine)	
			Human health	
			Resource availability	
			Other e.g. waste energy potential	

In addition to the taxonomy for SLES assessment, other factors should be considered in the overall proposed framework. It is anticipated that the designs of SLES will vary depending on a number of aspects, such as geographical location, available resources, communities and people involved – this is evident from the Prospering from the Energy Revolution (PFER) Demonstrator Projects in the UK wherein two are located within a concentrated urban/sub-urban communities in Oxford and while another is formed through a group of small islands in Orkney. As such, it is important to understand and analyze what works, for whom and in what context, as what may work for one local area may not necessarily suit another. As the MCA tool evolves during the development phase, the characterisation of the varying types of SLES should be accounted for in the overall framework. Therefore factors such as the different spatial scales (e.g. urban, rural, remote area/islands, buildings) (Koirala et al., 2016; Ma et al., 2018); the existing energy landscape and infrastructure (e.g. domestic, industrial/commercial, generation, distribution network (Snodin, 2017)); the varying actors, and changing roles (Bush and Bale, 2019; Koirala et al., 2016; Kumar et al., 2019) become equally as important in the design of overall framework of the MCA tool.

Progressing towards UN SDGs

The evolution and benefits gained from SLES will directly extend to the development of smart sustainable cities and communities. This transformation is part of a bigger global plan of action for people, planet and prosperity to transform the world through peace and partnerships by achieving the United Nations (UN) Sustainable Development Goals (SDGs) (sustainabledevelopment.un.org, 2015). The UN SDGs seek to build on the Millennium Development Goals, realize the human rights of all, and achieve gender equality and empowerment. They span three dimensions of sustainable development: economic, social and environmental (sustainabledevelopment.un.org, 2015). The SDGs provide a shared blueprint for peace and prosperity for people and the planet, now and into the future (sustainabledevelopment.un.org, 2015) and applies to all member countries of the UN, including the UK. As such, this section seeks to align the objectives of the SLES to be delivered, with the SDGs in an effort to track the co-benefits that may be realized. The 17 UN SDGs were analyzed to filter out the applicable targets and indicators for SLES. Figure 3 illustrates and summarises the SDGs that align (or do not directly align) with the potential impacts and outcomes of the development of SLES.

Figure 3. The UN Sustainable Development Goals (sustainabledevelopment.un.org, 2015). The ticks and crosses mark those that may be or may not be supported by the development of SLES

Inclusion. A total of 11 SDGs (shown by a green tick in Figure 3) were aligned to multiple benefits from SLES, thus demonstrating that SLES can play a role in tackling the global issues. A few examples of how they can be related to the themes detailed in (Table 1) are as follows:

Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all: Some of the targets for goal 4 such as substantially increasing the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship could be achieved through Theme 8: People (sub-themes – education, ICT skills) and Theme 6: Economic-market (sub-themes – employment/creation of jobs).

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all: This is directly linked with SLES, as such most of the specified targets and indicators can be mapped onto the taxonomy of SLES evaluation; for example, the target for substantially increasing the share of RE in the global energy mix can be achieved through the Theme 3: Technical (sub-theme – renewable fraction).

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation: May be realized through a number of themes and sub-themes; for example Theme 4: Transport (including management, EV infrastructure, and charging) can potentially add value through passenger and freight volumes in terms of the mode of transport sustainable development indicator. Similarly, the target for resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes can be aligned to Theme 3: Technical (efficiency, innovation adoption) and Theme 10: Environment (climate change mitigation - decarbonisation).

Exclusion - Although it may be perceived that each of the SDGs can be directly or indirectly linked to SLES, this research considers that six SDGs (shown by a red cross in Figure 3), don't directly align with the themes identified in the taxonomy, based on the UN SDGs specified targets and indicators. These targets typically relate to access of basic services to enhance the quality of life and it is unlikely that these targets will directly be achieved through the development of SLES; and if so it will be difficult to measure and prove. Notwithstanding, care will be taken to ensure that intuitive themes which may be linked will not be neglected but covered elsewhere under a more appropriate SDG target and indicators. The following are few examples where this has been executed:

Goal 1. End poverty in all forms everywhere: UN SDG indicators 1.1.1 (Code C010101) refers to the proportion of population below the international poverty line living on less than $1.25 a day. As this is a primary service required to enhance the quality of life, it is not anticipated that this service will be a direct outcome of SLES. Nevertheless, key concerns such as fuel and/or energy poverty which is a significant problem worldwide will be covered under Goal 7 *Ensure access to affordable, reliable, sustainable and modern energy for all*.

Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture: The UN SDG target 2.2. (Code C020201 -2) refers to end all forms of malnutrition, including stunting and wasting in children under 5 years of age, and addressing the nutritional needs of adolescent girls, pregnant and lactating women and older persons. For this research, it is not anticipated that this target relating to food security and improved nutrition will be directly met through the development of SLES, and if so it will be difficult to measure and prove. However, important issues such as enhancing the ecosystem and sustainable use of resources including promoting sustainable agriculture will be readily captured under Goal 12. 14. and 15., which directly relates to Theme 10: Environment.

Conclusion

The development of SLES is underway as part of the energy transition taking place in response to the climate emergency. Currently, there is no standardized approach to evaluate SLES and most of the existing evaluation tools have limited scope to assess multiple performance indices, scenarios and stakeholders. This paper presents the strategy and preliminary development of an MCA protocol for SLES. To understand the context of what does and does not work and for whom, an analysis of the socio-technical environment alongside an integrated assessment of multiple factors is recommended to facilitate the low carbon transition. Common factors, themes, and indicators appropriate for measuring the performance of SLES were identified from literature and aligned with expert views obtained from a stakeholder workshop. The information was subsequently used to create taxonomy from a total of 50 sub-themes which were clustered into 10 key themes. The key themes include: Data Security, Data Connectivity, Technical, Transport, Economics, Business and Finance, Governance (Socio-Political), People, Living and Environment. Finally, to track co-benefits which may be realized through SLES, an analysis of the UN SDGs was also conducted to filter out the applicable targets and indicators. This research considers that 11 SDGs (out of 17) could be directly supported through the outcomes of SLES. The next steps of the research will be aimed at refining the taxonomy and defining appropriate metrics and weightings for SLES. This will be conducted through an iterative process of stakeholder consultation and case studies of the PFER design and demonstrator projects.

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