Developing a multi-criteria assessment framework for smart local energy systems

Christina Francis, Alessa Sierra Costa,
R. Camilla Thomson, David M. Ingram

June 2020

INDUSTRIAL STRATEGY

UK Research and Innovation

Acknowledgements

- Christina Francis | School of Engineering, University of Edinburgh
- Alessa Sierra Costa | School of Engineering, University of Edinburgh
- R. Camilla Thomson | School of Engineering, University of Edinburgh
- David M. Ingram | School of Engineering, University of Edinburgh

This report should be referenced as:

Francis, C., Costa, A.S., Thomson, R.C. and Ingram, D.M. 2020. Developing a multi-criteria assessment framework for smart local energy systems. EnergyREV, University of Strathclyde Publishing: Glasgow, UK. ISBN 978-1-909522-63-3

Contents

Introduction

Smart local energy systems (SLES) are being developed to exploit digital technology and the Internet of Things to connect various energy vectors such as transport, heat and power through flexible energy supply, demand, and storage. They are expected to contribute to efforts towards resolving the energy trilemma of producing cleaner energy, at an affordable price, with acceptable energy security.

SLES also have the potential to have wide ranging impacts that might exceed their initial goals. Many of these align to the UN Sustainable Development Goals (SDGs), demonstrating the potential for advanced technological changes such as SLES in a developed economy to have an impact on factors that are an aspiration for the whole world.

However, due to the innovative nature of these systems, no method for assessing their performance is yet in place. There are no known or universally accepted standards defining and measuring the performance of SLES. To ensure that their potential is realised, projects and funders need to be able to assess the performance of these projects and understand what works, for whom and in what context.

A multi-criteria assessment (MCA) tool for SLES is currently being developed to help identify how well an installation meets its aims for sustainability. It is being constructed as a tool for developers and other interested stakeholders including policymakers, end users and regulators to get a better understanding of the multiple benefits associated with these projects. It will allow the performance of a SLES to be analysed across a broad number of areas, extending beyond the key performance indicators (KPIs) of individual projects and the Prospering from the Energy Revolution (PFER) Challenge programme.

The creation of such a tool is a multi-faceted process that must include the expectations of different stakeholders. It must also be flexible enough to accommodate the diversity of projects and their specific goals, while at the same time providing a robust framework to assess the different stages of development and their level of alignment towards success.

This report describes the first stages in its development. It is based on an extensive literature review, an analysis of stakeholders and their roles and an initial consultation with stakeholders.

10 key factors for assessing SLES

The basis of the tool was initially created by considering 10 key factors or themes:

1. Data Security
2. Data Connectivity
3. Technical
4. Transport
5. Techno-Economic
6. Economic Market
7. Governance (Socio-Political)
8. People
9. Living
10. Environment

These themes are further divided into a total of 50 sub-themes, as shown in Figure 1 .

These key themes and sub-themes were compiled from literature and a preliminary stakeholder consultation. They were previously applied to the assessment of sustainable energy, smart cities, smart-grids, smart energy, and renewable energy (inclusive of tidal, wave and solar energy) products/services/systems.

Each theme and corresponding sub-themes applicable to SLES were classified in a taxonomy. The taxonomy will be used as a pathway to develop the MCA tool for SLES by reviewing the areas of strengths and weaknesses in their performance. The proposed taxonomy has a hierarchical structure, which will simplify the complex analysis of SLES through the identification of these themes and sub-themes of influence. These are expected to lead to a particular yield, objective(s) or consequence(s) of the development of the systems.

The methodology for the construction of the taxonomy and 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 (Figure 2).

At the end of the two-year duration of this research, the final version of the MCA tool will be made available to relevant stakeholders interested in planning, designing and conducting a comprehensive analysis of all the metrics of a SLES to ensure effective sustainable performance.

Data Security	Data Connectivity	Technical	Transport
• Security • Privacy • Trust	• Digital technology enablers • ICT Infrastructure • ICT Management • ICT Accessibility	• Renewable fraction • Reliability, resilience • Flexibility, scalability • Efficiency • Maturity • Lifespan • Grid accessibility • Innovation	• Transportation Management • EV infrastructure
Techno-economic	**Economic-Market**	**Governance/ Socio-political**	**People**
• Benefits-to-Cost Ratio • Costs (capital, installation and O&M) • Rate of return • LCOE (levelised cost of energy) • Payback period	• Regulations • Compensation structures • Affordable or competitive cost • Investable • Job creation	• Transparency • Socio-economic impact • Integrated Management • Political and regulatory alignment	• Education & Gender equality • ICT Skills • Engaging/participation • Acceptance • User friendliness/ control • Inclusion/ Empowerment • Consumer protection
Living	**Environment**		
• Housing • Equity • Culture or behaviour • Livelihood • Convenience	• Water • Land • Air pollution • Noise pollution • Waste energy potential		

Figure 1: Taxonomy measuring criteria for SLES.

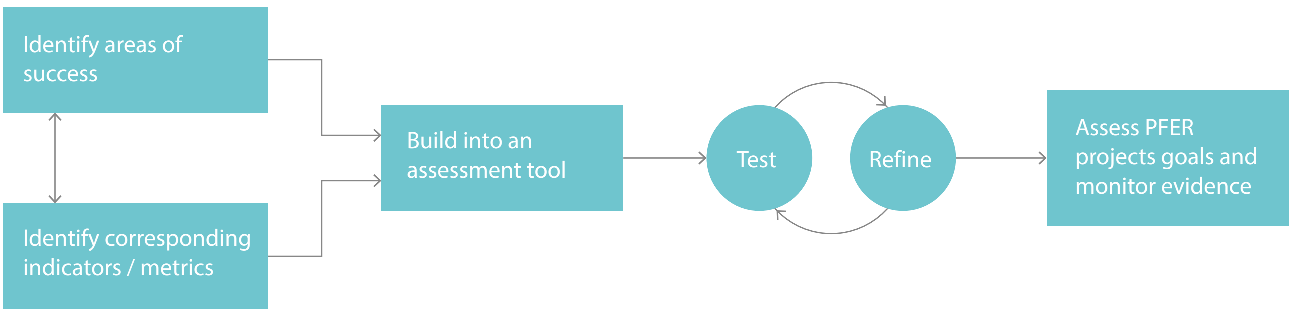

Figure 2: Iterative process for the development of the MCA tool for SLES.

Other key influences for SLES assessment

Other factors should be considered in addition to the key themes and sub-themes identified in the taxonomy for SLES assessment. The designs of SLES will vary depending on a number of aspects, such as geographical location, available resources, communities and people involved – this is clear from the PFER demonstrator and design projects.

It is important to understand and analyse 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. Factors such as the different spatial scales (e.g. urban, rural, remote area/islands, buildings) (Koirala et al, 2016; Ma, 2018); the existing energy landscape and infrastructure (e.g. domestic, industrial/commercial, generation, distribution network, Snodin, 2017); the varying actors, and changing roles (Koirala et al, 2016; Bush and Bale, 2019; Kumar et al, 2019) become equally as important in the design of overall framework of the MCA tool.

Progressing towards UN SDGs

Since SLES are being developed in the context of the energy transition towards a more sustainable future, it is desirable for them to align with the UN SDGs. In this way they can flourish within the international efforts dedicated to achieve these high-level objectives. Our analysis shows that eleven out of seventeen SDGs are directly applicable to SLES and could help alleviate global problems. This research considers that six SDGs (shown by a grey dot 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. Alignment of UN SDGs is summarised in Figure 3.

Figure 3: The UN Sustainable Development Goals. The ticks mark those that may be supported by the development of SLES (United Nations, 2015).

How UN SDGs align with key themes identified for SLES assessment

The SDGs below are aligned to multiple benefits from SLES, demonstrating that SLES can play a role in tackling global issues.

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 5. Achieve gender equality and empower all women and girls:

Aspects of goal 5 targets and indicators could be achieved through **Theme 8: People** (sub-themes – gender equality, empowerment).

Goal 7. Ensure access to affordable, reliable, sustainable and modern energy for all:

This is directly linked with SLES so most of the specified targets and indicators can be mapped onto the taxonomy of SLES assessment, For example, the target for substantially increasing the share of renewable energy in the global energy mix can be achieved through the **Theme 3: Technical** (sub-theme – renewable fraction).

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all:

This could possibly be realised through **Theme 6: Economic- market, taxonomy of SLES analysis** (sub-themes investable, employment/creation of jobs).

Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation:

This could be realised 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 by 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).

Goal 10. Reduce inequality within and among countries:

Goal 10 is indirectly linked to goal 5. Promoting the sustainable development target of empowering and encouraging the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status which could be achieved through **Theme 8: People** (sub-themes – gender equality, empowerment).

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable:

Particular sustainable development indicators, such as convenient access to transport, could be achieved through **Theme 4: Transport**. Affordable housing and basic services such as district heating for social housing communities could be achieved through **Theme 9: Living** (housing).

Goal 12. Ensure sustainable consumption and production patterns:

Goal 12 can be linked to SLES through the targets for reducing waste generation. Achieving environmentally sound management of chemicals and all wastes throughout their life cycle and significantly reduce their release to air, water and soil in order to minimise their adverse impacts on human health and the environment aligns to **Theme 10: Environment**.

Goal 13. Take urgent action to combat climate change and its impacts:

This goal to improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning can be aligned with **Theme 8: People** (education), 9: Living (culture or behaviour), and **Theme 10: Environment** (climate change mitigation – decarbonisation).

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development and Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss:

Goals 14 and 15 easily correspond to **Theme 10: Environment** and sub-theme ecosystem (land, freshwater, marine).

Table 1 shows the results of the above analysis.

Table 1: SDGs as related to SLES taxonomy

Sustainable Development Goals			SLES Taxonomy Themes		
4 QUALITY EDUCATION			Economic-Market	People	
5 GENDER EQUALITY	10 REDUCED INEQUALITIES		People		
7 AFFORDABLE AND CLEAN ENERGY			Technical		
8 DECENT WORK AND ECONOMIC GROWTH			Economic-Market		
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE			Technical	Environment	Transport
11 SUSTAINABLE CITIES AND COMMUNITIES			Transport	Living	
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	14 LIFE BELOW WATER	15 LIFE ON LAND	Environment		
13 CLIMATE ACTION			People	Living	Environment

Learning from existing assessment tools

This section describes the first stages in the development of MCA method for SLES. This effort began with a literature review of MCA methods in a broad range of areas; from renewable energy and sustainable accounting, through smart cities and defence technology. These existing MCA tools were divided into four categories, which include: 1) maturity or readiness level assessment, 2) planning and forecasting, 3) sustainability transition, and 4) other miscellaneous tools summarised in Figure 4.

Maturity or Readiness level
- Technology Readiness Level (TRL)
- Capability Readiness
- Technology Performance Level (TPL)
- Innovation Readiness
- Energy Transition Index

Planning and forecasting
- Techno-Economic Assessments
- Integrated Assessment Modelling (IAM)
- Techno-Ecological Synergy (TES)

Sustainability transition
- Multi-level perspective (MLP)
- Strategic Niche Management (SNM)

Others
- Integrated Community Energy System (ICES)
- Smart Cities
- Sustainable Accounting
- Waste Management
- Smart Energy Technology Landscape

Figure 4: Different types of assessment tools

From exploring the existing MCA protocols, several common assessment criteria and indicators emerged that were relevant to SLES. However, it became evident that no existing tool was capable of measuring and tracking the performance and benefits realisation of SLES adequately. SLESs are very complex and can be considered as a system of networked systems. In examining the existing body of MCA tools, it was found that a full assessment 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 MCA tool applied to SLES should also consider the different spatial scales, available resources and stakeholder opinions.

INDUSTRIAL STRATEGY UK Research and Innovation

A total of 50 relevant performance factors were identified from literature and aligned with expert views obtained from the first stakeholder consultation – "Defining Success of SLES". These common factors (sub-themes) were further clustered into 10 key themes to create the basic hierarchical structure for the taxonomy for SLES. This taxonomy forms a pathway to simplify the complex multi-criteria analysis of SLES performance and benefits.

Non-use of decision-making energy tools remain a common issue due to variety of reasons including being techno-economic centric as opposed to taking into account the wider social concerns; lack of trust or understanding due to complexity and/or underlying hidden agenda e.g. political motivated (Bush and Bale, 2019). As such it is important to develop a MCA tool that is useful and simple to use by the intended audience. Moreover, 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). To achieve this all, stakeholders need to be identified, sensitised and constructively engaged from the ground level upwards which will reduce any unintended consequences and maintain success. To facilitate the design of a functional, transparent and usable tool, a stakeholder identification and analysis was conducted to ensure that the needs of the target audience and users of the MCA tool are met. The next section outlines this process.

Taking stakeholders into account

As mentioned previously identification and analysis of the stakeholders' roles and interests is crucial to achieve the multiple potential benefits of SLES. Stakeholder identification and mapping is an often overlooked activity; however, its proper realisation is closely linked with the success of almost any type of project, and energy systems are no exception. For this study, a stakeholder map and two characterisations were created to help understand how actors interact with each other.

For the stakeholder map, five categories and 17 subcategories of stakeholders were identified from the literature for the UK energy system (Figure 5).

Within this categorisation, various stakeholder-types were identified, generating a comprehensive stakeholder map for the UK's current energy system (Figure 6).

- **1. Energy business**
  - Direct
  - Indirect
- **2. Regulation & control**
  - Regulation bodies
  - Law enforcement
  - Monitoring agencies
  - Certification bodies
- **3. End consumers**
  - Individual energy users
  - Medium energy users
  - Large energy users
- **4. Support**
  - Financial
  - Knowledge advancement
  - Network & advice
  - Other support groups
- **5. Influencers**
  - Interests promotion groups
  - Opinion leaders
  - Media
  - General opinion

Figure 5: Stakeholder categories for the UK energy system.

The nature of the evaluation of a socio-technical system will change as the design and the system processes evolve and, as a result, the expectations of the stakeholders change accordingly (Baxter and Sommerville, 2011). Similarly, for energy systems 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.

Two types of stakeholder characterisations were conducted which allowed grouping of several identities by a shared quality: 1) by role and 2) by level of engagement. In context of the MCA tool the objective of the stakeholder characterisation is to further ascertain a valuable stakeholder mix which represents the interests of all the involved parties for SLES, in order to create an assertive performance framework assessment.

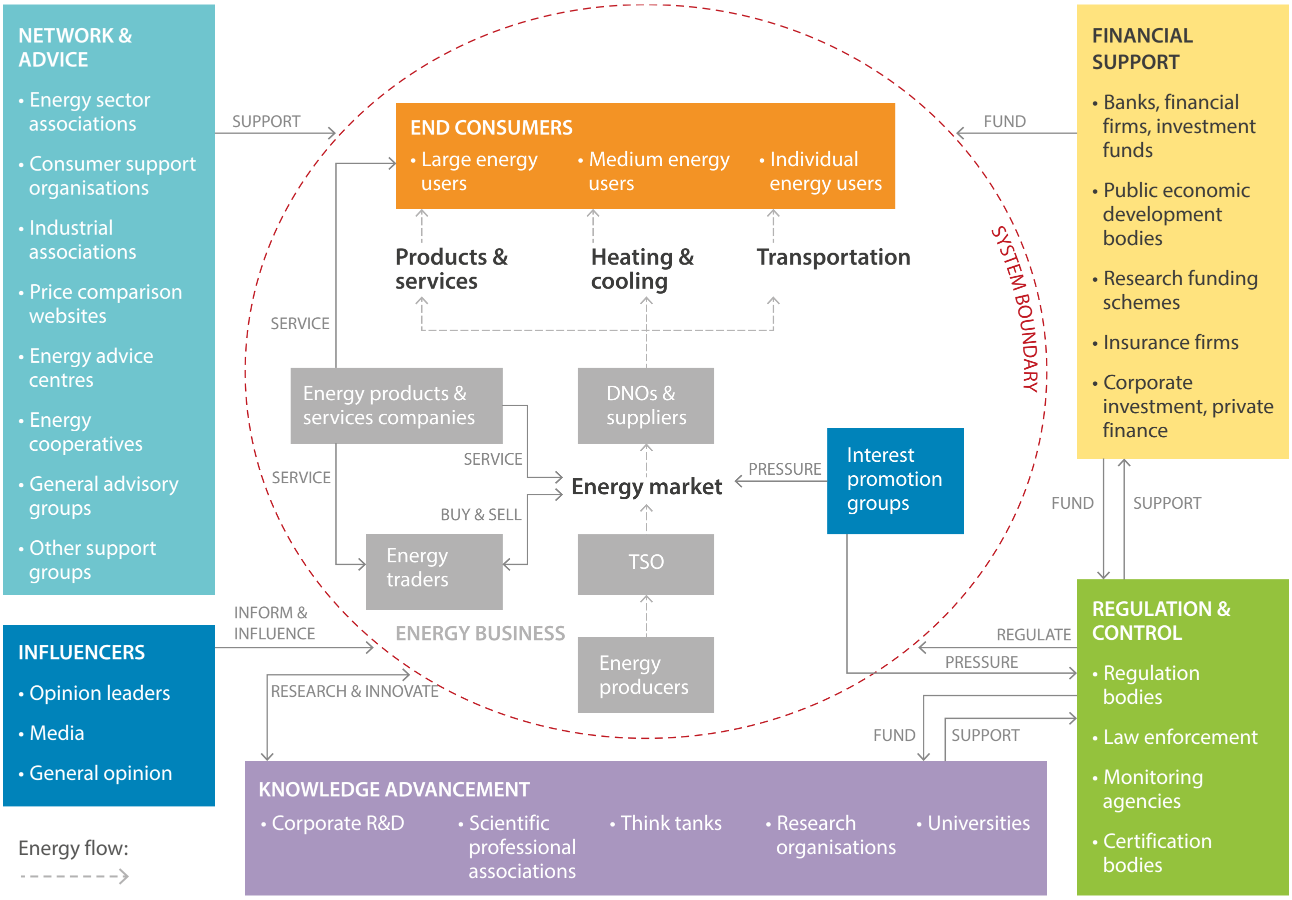

Figure 6: Stakeholder mapping for the wider UK energy system (developed from Dallamaggiore et al, 2016).

The first characterisation refers to the role of the actor within the system, in which eight categories were identified (energy business, regulation and control, end consumers, financial support, knowledge advancement, network and advice, influencers, and other support groups). Different roles create different objectives, different expectations, and different success metrics. These can be contradictory in of themselves hence the importance of accounting for them.

The second characterisation relates to the level of importance for stakeholder engagement on successful renewable projects and follows the Technology Performance Levels (TPL) assessment. A systems engineering technique was used in the TPL to identify and specify stakeholders' requirements for commercially successful wave energy farms (Babarit et al, 2017). For this study 26 stakeholders were identified and grouped into four categories (highest-level, core, first-tier suppliers and second-tier suppliers). Stakeholders were arranged by means of their participation in different life cycle stages (i.e. planning, construction, installation, operations and disposal) of a SLES whether active or passive, was examined and recorded.

The constant review and update of these roles is of particular importance for SLES, because these types of systems remain hand-in-hand with the energy transition and, as such, are expected to evolve at the same pace. Adequate representation of the stakeholder mix during the agile development of the MCA tool will essentially promote transparency, functionality and usability by the intended target audience.

Next steps

The next steps in the development of the MCA tool for SLES will be to further refine the taxonomy and key themes, identify relevant metrics or assessment criteria for these, and build these into a tool that can be applied to the PFER Demonstrator and Design projects. The development of this assessment protocol will be an iterative process. In order to properly capture a whole systems understanding it will be necessary to test and refine the tool with experts and stakeholders within the field.

In the near term the focus will be on refining the proposed taxonomy of SLES assessment through surveys and semi-structured interviews with a range of stakeholders. Subsequently, metrics and assessment criteria will be identified through discussion with experts within the wider EnergyREV Research Consortium and PFER Programme.

For example, a semi-structured interview will be conducted with experts within "User Behaviour and Preferences" to develop the assessment criteria for the SLES Theme 8: People and Theme 9: Living. Similarly, expertise within areas of Theme 1. Data Security and Theme 2. Data Connectivity can be gained from experts within "Cyber-physical advances".

In this way the final multi-criteria assessment will be informed by the outputs of other EnergyREV work packages, and the independent evaluations being carried out by the Energy Systems Catapult and Ipsos Mori.

At the end of the two-year duration of this research, the final version of the assessment tool will be made available to relevant stakeholders interested in planning, designing and/or conducting a comprehensive analysis of the areas a SLES must cover to ensure effective sustainable performance.

References

- Babarit, A., Bull, D., Dykes, K., Malins, R., Nielsen, K., Costello, R., Roberts, J., Ferreira, C.B., Kennedy, B. and Weber, J. 2017. Stakeholder requirements for commercially successful wave energy converter farms. Renewable Energy, 113: 742–755. doi: 10.1016/j.renene.2017.06.040
- Baxter, G. and Sommerville, I. 2011. Socio-technical systems: From design methods to systems engineering. Interact Comput, 23 (1): 4–17. doi: 10.1016/j.intcom.2010.07.003
- Bush, R.E. and Bale, C.S.E. 2019. Energy planning tools for low carbon transitions: an example of a multicriteria spatial planning tool for district heating. Journal of Environmental Planning and Management, 62 (12): 2186–2209. doi: 10.1080/09640568.2018.1536605
- Dallamaggiore, E., Boo, E., Aze, F., Lennon, B., MacSweeney, R., Gaffney, C., Dunphy, N., Landini, A. and Otal, J. 2016. Energy System Stakeholder Characterisation. Cork, Ireland: ENTRUST project. doi: 10.5281/zenodo.3479257
- Koirala, B.P., Koliou, E., Friege, J., Hakvoort, R.A. and Herder, P.M. 2016. Energetic communities for community energy: A review of key issues and trends shaping integrated community energy systems. Renewable and Sustainable Energy Reviews, 56: 722–744. doi: 10.1016/j.rser.2015.11.080
- Kumar, A., Singh, A.R., Deng, Y., He, X., Kumar, P. and Bansal, R.C. 2019. Integrated assessment of a sustainable microgrid for a remote village in hilly region. Energy Conversion and Management, 180: 442–472. doi: 10.1016/j.enconman.2018.10.084
- Ma, W., Xue, X. and Liu, G. 2018. Techno-economic evaluation for hybrid renewable energy system: Application and merits. Energy, 159: 385–409. doi: 10.1016/j.energy.2018.06.101
- Snodin, H. 2017. Smart energy – technology landscaping, Scotland's Energy Efficiency Programme. Edinburgh: ClimateXChange.
- United Nations, 2015. Transforming our world: the 2030 Agenda for Sustainable Development. New York: United Nations.

Want to know more?

www.energyrev.org.uk

@EnergyREV_UK

info@energyrev.org.uk

Sign up to receive our newsletter and keep up to date with our research, or get in touch directly by emailing info@energyrev.org.uk

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.

EnergyREV is funded by UK Research and Innovation, grant number EP/S031863/1

INDUSTRIAL STRATEGY

UK Research and Innovation