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Spatio-temporal mapping of local areas for engaging communities in the planning of smart local energy initiatives

Rajat Gupta, Pablo Jimenez-Moreno, Angelines Donastorg Sosa
Low Carbon Building Research Group, School of Architecture
Oxford Institute for Sustainable Development, Oxford Brookes University
Oxford OX3 0BP, UK
Email: rgupta@brookes.ac.uk, pjimenez-moreno@brookes.ac.uk, adonastorg-sosa@brookes.ac.uk

Patrick Devine-Wright
College of Life and Environmental Sciences
University of Exeter
Exeter EX4 4RJ, UK
Email: P.G.Devine-Wright@exeter.ac.uk

Abstract

Community engagement in the planning and delivery of smart local energy initiatives is essential for their long-term success. Spatial and temporal visualisation of local energy flows can be used to engage communities in a more joined-up way. This paper describes the development and trial of an online and interactive smart local area energy mapping (LEMAP) tool for planning smart local energy neighbourhoods in Oxfordshire (UK). The spatial-temporal tool has been designed for community groups and residents.

The LEMAP tool brings together public, private and crowd-sourced data on energy demand, energy resources, building attributes, socio-demographics, fuel poverty and electricity networks within the ESRI ArcGIS platform. Postcode and dwelling level energy demand profiles are generated using the CREST energy demand model. The tool has been organised around three technical and three engagement elements that include ‘baselining’ local area energy flows in relation to socio-economic characteristics; ‘targeting’ suitable properties for low carbon technologies (LCT) such as rooftop solar, heat pumps, EV chargers; and ‘forecasting’ energy demand profiles at postcode level for different LCT scenarios. The engagement elements include: ‘Participatory mapping’ to allow residents to visualise their energy demand profiles, compare against the neighbourhood and see how the profile changes with LCTs; ‘Storymap’ for creating blogs on local energy flows; and ‘Forum’ to enable chats amongst users of LEMAP and project stakeholders.

The LEMAP tool was applied to a socially-deprived but data-rich neighbourhood in Oxford comprising over 2,500 households. A social enterprise organisation in Oxfordshire was trained online to use LEMAP to plan for energy management at neighbourhood level. Participatory mapping was found to enrich the tool and engage communities to provide local data through online surveys and highlight any discrepancies in the public and private data through local data interpretation.

Introduction

The UK has declared plans to decarbonise the built environment by 2050 at the latest, with a 78% reduction in carbon emissions by 2035 (Gummer *et al.*, 2020a; Gummer *et al.*, 2020b). Net-zero carbon presents a different challenge from the previous 2050 target of 80% reduction in emissions, which means that where zero-carbon options exist, these must be deployed (BEIS, 2018; DECC, 2011). In response, over the past ten years, energy systems have not only become decarbonised and decentralised (local or community energy) but have also developed in a smart way by becoming more digitised (Ford *et al.*, 2019). Termed as smart local energy systems (SLES), these systems can help overcome energy network constraints by allowing better control over local energy demand, distribution and energy supply (DECC, 2014; Gupta & Zahiri, 2020a). This is why the UK Government has launched the £102 million *Prospering from the Energy Revolution* (PFER) programme that has co-funded the development of three large SLES demonstrator projects and ten detailed design projects (UKRI, 2019; Hampton & Fawcett, 2020).

The growth in SLES is driven not only by achieving local energy management but also by local stakeholders desire to align the development of energy systems with their community objectives, including alleviating fuel poverty, community income generation, and improvements in local energy knowledge (Aunedi & Green, 2020).

Community-driven local energy projects have been playing a major role in achieving net-zero in the UK by contributing around 265 MW of renewable electricity generation and 13.1 MW renewable heat to the energy system (Regen, 2021). Alongside delivering renewable generation, community-based energy projects can facilitate SLES transition by ensuring that hard-to-reach areas are not left behind and supporting the economic returns of community-owned generation into the local area. However, a recent meta-study of SLES projects over the last 10 years showed that only 30% of SLES initiatives in the UK provided any evidence of user engagement (Gupta & Zahiri, 2020b) despite the fact that community engagement in local energy initiatives is essential for their long-term success.

Geospatial energy mapping tools are emerging as essential tools for helping SLES planning and implementation given their ability to provide rapid and accurate spatial intelligence (Fonseca & Schueter, 2015, Amado *et al.*, 2018; Morstyn *et al.*, 2018; Camporeale & Mercader-Moyano, 2021). However, most of the current mapping tools are technical and have low engagement levels with the target community. These tools have been critiqued for having information-deficit assumptions about users as they focus on analytics and unidirectional dashboards (Owens & Driffill, 2008). Instead, energy mapping tools could help to engage communities if these move beyond a one-way flow of representing local energy flows (Buchanan *et al.*, 2018) to two-way interaction with local communities who can also offer a local interpretation of data underpinning these tools.

This paper describes the development and trial of an online and interactive smart local area energy mapping (LEMAP) tool for planning smart local energy neighbourhoods in Oxfordshire designed for community groups and residents. LEMAP brings together public, private and crowd-sourced data on energy demand, energy resources, building attributes, socio-demographics, fuel poverty and electricity networks within the ESRI ArcGIS platform. Postcode and dwelling level energy demand profiles are generated using the CREST energy demand model. The tool has been organised around three technical and three engagement elements. LEMAP was applied to a socially-deprived but data-rich neighbourhood in Oxford comprising over 2,500 households. A social enterprise organisation in Oxfordshire was trained online to use LEMAP to plan for energy management at the neighbourhood level. The study is part of two research and innovation projects on smart local energy systems - Project Local Energy Oxfordshire (LEO) and EnergyREV.

Review of local energy mapping tools

The growth in smart local energy initiatives has enabled the rise of spatially-based energy mapping tools and approaches to help with decision-making at a local scale. Over the last decade, several researchers have explored how online spatial energy visualisation can contribute to decision-making, design, planning, and implementation processes in local energy initiatives (Chiang *et al.*, 2012, D'Oca *et al.*, 2014, Wate & Coors, 2015, Flacke & De Boer, 2017; Camporeale & Mercader-Moyano, 2021). Given the current variety of online mapping tools, an extensive review of published and grey literature was conducted to identify 53 relevant local energy mapping tools (18 UK, 23 international, 12 global). These tools were characterised by key criteria that included spatial resolution, functionality, energy vector, data source, accessibility, form of communication, and target audience, as shown in Table 1. The review helped to identify any gaps that could be addressed by the proposed energy mapping approach.

Most of the tools identified in Table 1 had a single vector focus (electricity in 35 tools) and operated at sub-station level (n: 24), and were mainly focussed on visualisation of spatial data (n: 33), indicating one-way flow of information. About 20 tools had provision for user interaction to query and customise the visualisation of spatial energy data to extract spatial intelligence. For example, Amado's *et al.* (2018) 'E-City' web-based approach for the city of OEIRAS in Portugal presented digital visualisation of the existing municipal GIS system with statistical zoning and municipal energy demand for local government decision-making with limited opportunity for user interaction and customisation of results. Furthermore, Google supported project 'sunroof' provided a property-level 2D rooftop view of potential for rooftop solar, however, there was limited ability for spatial data customisation and multiple property selection, making it unsuitable for planning SLES projects (Castellanos *et al.*, 2017).

Furthermore, majority (n: 39) of the identified tools were accessibly publicly for visualisation of spatial energy data, such as the 'DNO's web-based tools. Other tools varied public access depending upon the granularity of spatial data, such as the 'Non-gas map' in the UK, which provided public access to off-gas properties at a local authority level; however, further information at a postcode scale was by registration.

Table 1. Key characteristics of the identified 53 local energy mapping tools

Criteria	**Categories**	**UK (n:18)**	**International (n:23)**	**Global (including UK) (n:12)**
Spatial resolution	Regional	1/18	-	-
	County	1/18	3/23	-
	City	-	5/23	-
	Neighbourhood	-	-	-
	Substation	**10/18**	**8/23**	**6/12**
	Postcode	3/18	3/23	-
	Property	3/18	4/23	6/12
Functionality	**Visualisation of spatial data**	**14/18**	**12/23**	**7/12**
	Visualisation, customisation and extraction of intelligence of spatial data	4/18	11/23	5/12
Energy vector	**Single vector (Electricity, heat or transport)**	**11/18**	**20/23**	**11/12**
	Multi-vector (Combination of two or more vectors)	7/18	3/23	1/12
Data source	**Publicly available**	**17/18**	**15/23**	**2/12**
	Privately available (purchase, registration)	**9/18**	**20/23**	**10/12**
	Crowd-sourced	1/18	-	-
Accessibility	**Public access**	**14/18**	**17/23**	**8/12**
	Limited access by registration	3/18	5/23	1/12
	Limited access by purchase	1/18	1/23	3/12
Form of communication	**One-way communication**	**14/18**	**12/23**	**7/12**
	Two-way communication	4/18	11/23	5/12
Audience	**DNOs**	**16/18**	**16/23**	**9/12**
	Local Authorities	**12/18**	**5/23**	**2/12**
	Community groups	1/18	2/23	-
	Residents	1/18	-	1/12

The review revealed several functionality gaps, including (1) lack of visualisation at a neighbourhood spatial scale level, (2) the scarcity of multi-vector energy focus, (3) lack of utilisation of crowd-sourced data and (4) limited focus on residents and community groups. The proposed local area energy mapping approach (LEMAP) was designed to address these gaps by adopting a spatio-temporal approach for planning smart local energy initiatives while engaging community groups and residents. These aspects are further described in the following sections.

Methods and case study

The development and refinement of the proposed LEMAP tool was conducted systemically through a series of stages. Firstly, data were gathered from different private and public sources, which led to the initial development of the tool. Then, the working of the tool was demonstrated by applying it to a case study neighbourhood area in Oxford. Finally, the tool was trialled with a sample of target users and feedback was gathered to refine the tool.

Approach for developing LEMAP

LEMAP was created to spatially and temporally visualise local energy flows and energy profiles in an intuitive manner to help with the planning of smart local energy initiatives (called smart and fair neighbourhoods). The tool development processes consisted of: (1) gathering relevant energy, buildings and socio-economic data; (2) generating maps and energy profiles using the collected data; (3) creating a website to display maps and energy profiles technically (4) developing the engagement elements; (5) enabling two-way communication and interaction with users (6) improving the tool based on feedback from the trial (Figure 1).

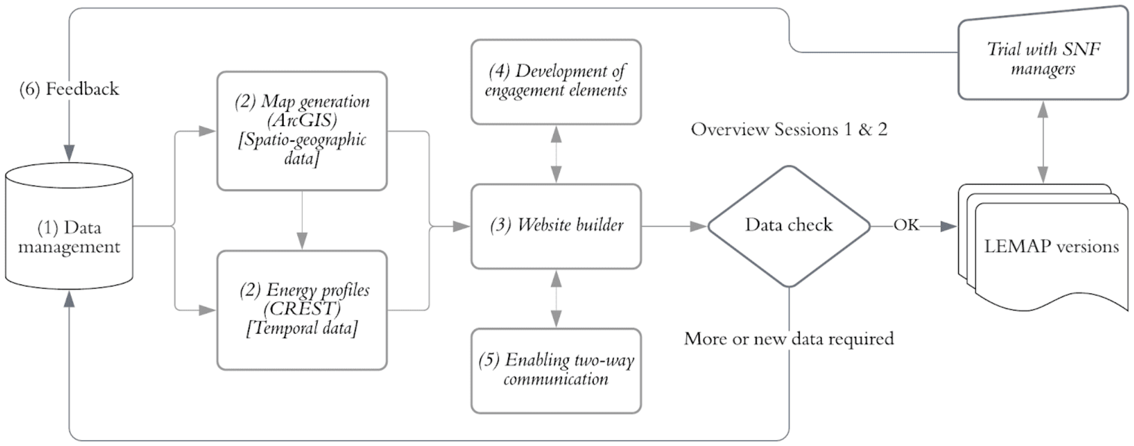


Figure 1. LEMAP development flowchart. (SFN— Smart and Fair Neighbourhoods).

To address the needs of different users, LEMAP was organised around three technical and three engagement elements. The technical elements were targeted towards project teams (local authorities) and intermediaries (e.g. community interest companies, project managers of smart local energy initiatives) involved in planning SLES projects, while the engagement elements were designed for engaging residents and community groups. The technical elements included ‘baselining’ local area energy flows in relation to socio-economic characteristics; ‘targeting’ suitable properties for low carbon technologies (LCT) such as rooftop solar, heat pumps, EV chargers; and ‘forecasting’ energy demand profiles at postcode level for different LCT scenarios. The engagement elements include: ‘Participatory mapping’ to allow residents to visualise their energy demand profiles, compare against the neighbourhood and see how the profile changes with LCTs; ‘Storymap’ for creating blogs on local energy flows; and ‘Forum’ to enable chats amongst users of LEMAP and project stakeholders. LEMAP was constructed on the ESRI ArcGIS platform using spatial data in the form of shapefiles from sources such as OS Mastermap, Geomni, Energeo, BEIS sub-national data, EPCs.

Two-way communication was developed in four ways that included: (1) enabling map interaction through filters and queries (2) displaying elements, maps and corresponding data via buttons and menu bars; (3) filtering energy profiles and benchmarking data at postcode and dwelling level (using email); and by (4) enabling users and stakeholders to add content and comments.

Data sources

LEMAP brought together disparate data sources, including publicly-available, privately-available and crowd-sourced datasets on energy demand, energy resources, building attributes, socio-demographics, fuel poverty and electricity networks within the ESRI ArcGIS platform.

- *Public data* - were data accessible to the public, that included data from the Department for Business, Energy and Industrial Strategy (BEIS) on sub-national annual electricity and gas consumption (domestic and non-domestic) at different spatial scales (MSOA, LSOA, postcode), as well as energy performance certificates (EPC’s) data for domestic and non-domestic properties from the Ministry of Housing, Communities and Local Government. Data cleaning was done to make these datasets spatially mappable.
- *Private data* - were datasets accessible through special permissions or purchase, such as Geomni’s UK national building database, Ordnance Survey (OS) data on administrative boundaries and building footprints, including building area, built form, property type, and other building attributes.
- *Crowd-sourced data* - were data acquired from residents through an online survey on dwelling attributes, household characteristics and energy use. Crowd-sourced data helped to enhance community

participation by enabling addition of contextual detail and provision of customised results to residents about their dwelling energy profiles and potential for low carbon technologies. Crowd-sourced data were only displayed with the consent of the user to maintain data privacy.

Energy modelling method

Daily energy profiles were generated using the published CREST Energy Demand Model v2.3.3 (CREST) developed by Loughborough University, which is a high-resolution stochastic model of domestic thermal and electricity demand that produce hourly energy profiles based on user input. CREST runs on Excel Visual Basic (VBA) platform and allows input parameters to be adapted for customised results (McKenna & Thomson, 2016; Pimm *et al.*, 2018). The CREST model was adapted for the case study neighbourhood location and programmed to provide results for a weekday in the heating season and a weekday in the non-heating season, set to the closest days to the solstices, i.e. 20th December 2019 and 19th June 2020 respectively.

In the forecasting element of LEMAP, the CREST model was used to generate temporal energy profiles of dwellings that were suitable for deploying LCTs at a postcode level to maintain data privacy. The CREST input parameters were filled in relation to the proportion of dwellings that shared common attributes at postcode level, including building type (built form) and insulation quality.

The 'PV systems' configuration was set to 100% of dwellings with a system of 12 panels with an area of 19.2 m^2 (1.6 m^2 per panel), system efficiency of 0.15 ηpv, slope of 40° (CREST default) and south-oriented. For heat pumps, electricity load profile (winter weekday) was extracted from Love *et al.* (2017) for net electricity demand assuming take-up of 75% of air source heat pumps (ASHPs) and 25% of ground source heat pumps (GSHPs) at postcode level.

For electric vehicle (EV) chargers, a standard load was added to the electricity demand. It was assumed that EVs travel 32 km per day, consuming 0.20 kWh per km, resulting in a daily energy demand of 6.4 kWh/day. Charging times were set to a night schedule (12 am-5am) corresponding to low rates in a time of use tariff plans (Octopus flexible tariff). Home batteries were assumed to have a capacity of 5 kWh and charged with surplus solar electricity during the day. Discharge from the batteries was set at 5 pm in the peak evening period.

For participatory mapping, 54 archetypal energy profiles were generated using building attributes to represent the case study neighbourhood. Each archetype consisted of an average of 25 simulations, which proved to have a difference with metered data of less than 1.2% by Richardson *et al.* (2010). Based on the inputs in the online survey, sensitivity analysis of local input parameters was undertaken to reduce uncertainty assessment associated with the energy profiles generated by the stochastic modelling of CREST (Pianosi *et al.*, 2016). Based on sensitivity analysis, data for attributes such as the number of residents, building type and appliances were gathered for each archetype, while attributes such as user occupancy and weather conditions were left to stochastic modelling.

Case study application and trial

The working of LEMAP tool was demonstrated by applying it to a socially-disadvantaged neighbourhood (Rose Hill), located in the south-west of Oxford city. The neighbourhood was selected since it was part of the smart and fair neighbourhoods (SFNs) initiative and had an active community group that aspired to achieve a zero-carbon estate. The neighbourhood was also part of a previous ERIC research project which involved a domestic trial of smart home batteries and rooftop solar (Gupta & Bruce-Konuah, 2017a; Gupta & Bruce-Konuah, 2017b), thereby making it data-rich.

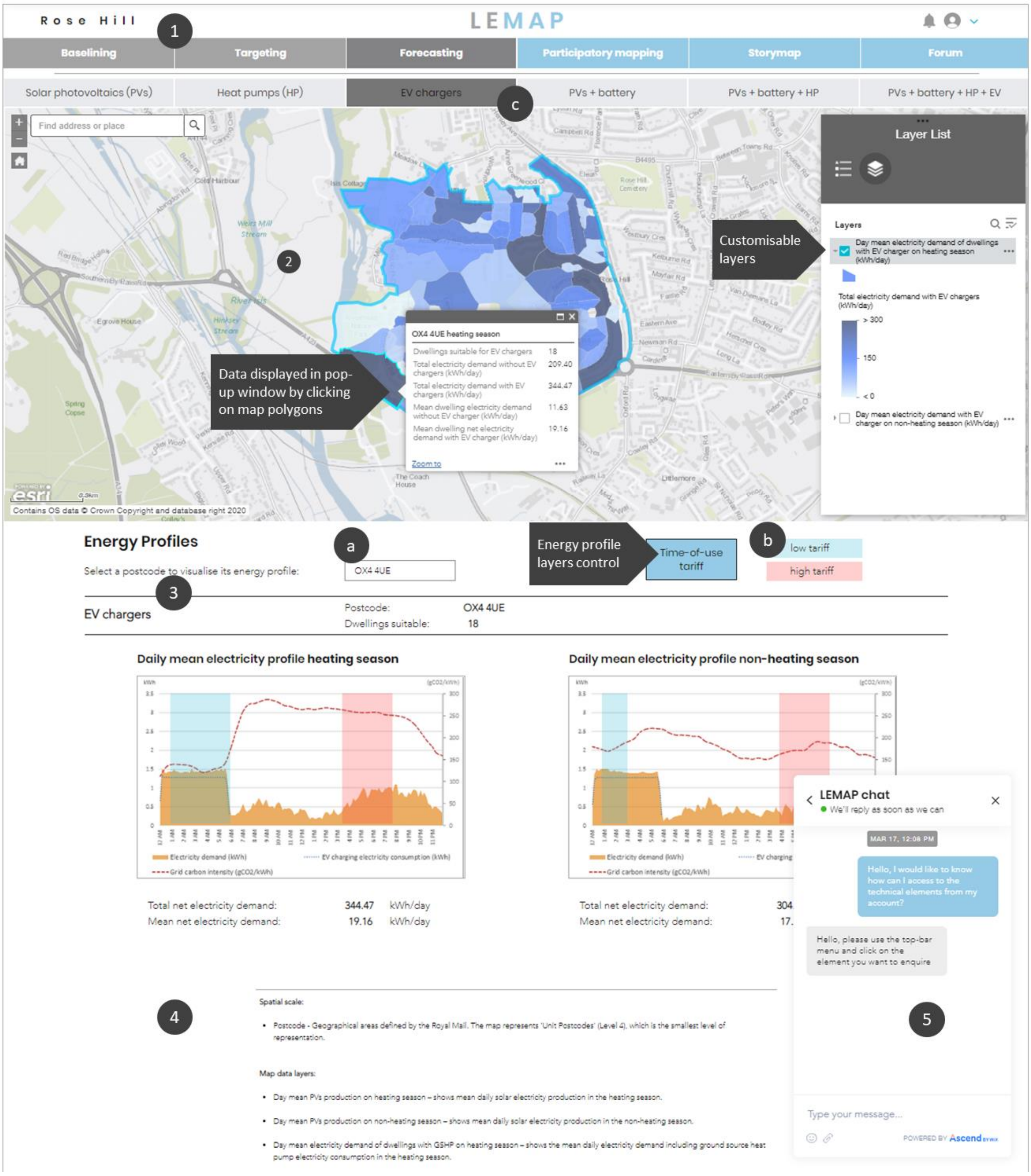
Following the application of LEMAP to Rose Hill area, a trial of LEMAP was conducted with six project managers of a community interest company who were responsible for planning SFNs as part of Project LEO, one of the Government-funded SLES demonstrators. Henceforth, this group of users are called SFN project managers. The trial was run for SFN project managers through three sessions to avoid information overload.

- *Overview session (19 January 2021)* - provided rationale and introduction to the tool.
- *Overview session (3 February 2021)* - details about the capabilities of the tool.
- *Training session (10 February 2021)* - provided live demo, user guide and trialling the tool.

Results

Overview of LEMAP

The spatial-temporal mapping approach of LEMAP brought together over 20 discrete datasets comprising contextual maps, building attributes, socio-demographics, electricity networks, energy demand, energy resources, energy profiles and blog stories for the Rose Hill area in Oxford as a case study. As shown in Figure 2, the user interface of LEMAP was designed to be navigated through (1) an interactive bar with buttons at the top for filtering content (2) map window extended to the length of the display screen (3) energy profile display and interactive buttons (4) description of the map layers, data sources and notes about the LEMAP element (5) chat box located at the bottom right of each page. The energy profiling aspect of LEMAP consisted of (a) filter profiles by dwelling or postcode (b) benchmarking profiles against grid carbon intensity, national average and time-of-use tariff (c) profiles for individual and grouped LCT scenarios (Figure 2).



☑ Day mean electricity demand of dwellings with EV charger on heating season (kWh/day)

Total electricity demand with EV chargers (kWh/day)

☐ Day mean electricity demand with EV charger on non-heating season (kWh/day)

OX4 4UE heating season

Dwellings suitable for EV chargers	18
Total electricity demand without EV chargers (kWh/day)	209.40
Total electricity demand with EV chargers (kWh/day)	344.47
Mean dwelling electricity demand without EV charger (kWh/day)	11.63
Mean dwelling net electricity demand with EV charger (kWh/day)	19.16

Select a postcode to visualise its energy profile: OX4 4UE

EV chargers

Postcode: OX4 4UE
Dwellings suitable: 18

Total net electricity demand:	344.47	kWh/day
Mean net electricity demand:	19.16	kWh/day

Total net electricity demand:	304
Mean net electricity demand:	17.

Spatial scale:

- Postcode - Geographical areas defined by the Royal Mail. The map represents 'Unit Postcodes' (Level 4), which is the smallest level of representation.

Map data layers:

- Day mean PVs production on heating season – shows mean daily solar electricity production in the heating season.
- Day mean PVs production on non-heating season – shows mean daily solar electricity production in the non-heating season.
- Day mean electricity demand of dwellings with GSHP on heating season – shows the mean daily electricity demand including ground source heat pump electricity consumption in the heating season.

LEMAP chat
We'll reply as soon as we can

MAR 17, 12:08 PM

Hello, I would like to know how can I access to the technical elements from my account?

Hello, please use the top-bar menu and click on the element you want to enquire

Type your message...

POWERED BY Ascend BY WIX

Figure 2. Forecasting element with EV scenario enabled; energy profile filtered to 'OX4 4UE' postcode with 'time-of-use tariff indicator turned on; and chat window opened.

The online interface of LEMAP was designed using 'Editor X' web builder platform, where registered users could access the different elements and create storymap entries. While community interest companies and local authorities could access the three technical (baselining, targeting, forecasting) and three engagement elements (participatory mapping, storymap, forum) for planning smart local energy initiatives. Community groups and residents' (householders) access was restricted to the three engagement elements.

Technical elements

The *baselining* element in LEMAP consisted of mostly publicly available maps of local area energy flows with socio-economic and dwelling characteristics combined with subnational annual electricity and gas consumption and EPCs at Lower Layer Super Output Area (LSOA) level comprising 400-1,200 households as well as postcode and property levels. The spatial data layers was organised in three baselining tabs – context, energy demand and energy resources. Each of the tabs had multiple data layers at different spatial scales with the ability to filter by data attributes. This is shown in Table 2 below.

Table 2. Details of baselining element – data layers, spatial scale and filters

Map	**Data layers**	**Spatial scale**	**Filters and count**
Context	- Primary substations location - Postcode border - Building type and use - Fuel poverty - Homeownership - Unemployment rate	- Site - Postcode - Property - LSOA - LSOA - LSOA	- none - none - count number of dwellings and room average - number and percentage of dwellings in fuel poverty - ownership and rents percentage - unemployment, retirement, student and self-employed rates
Energy demand	- EPC properties - Postcode border - Building type and use - Electricity and gas consumption	- Property - Postcode - Property - LSOA and postcode	- EPC rating and building attributes (age, form, type, walls and heating system energy efficiency) - none - none - number of meters per area and mean and total consumption
Energy resources	- Primary substations location - Dwellings with PV and dwellings with batteries - EV public chargers - EV domestic chargers	- Site - Dwelling - Site - Postcode	- none - number and orientation of panels, system size, roof type, battery status, car ownership; and count - none - none

The purpose of the targeting element was to identify dwellings that were suitable for deploying different low carbon technologies (LCTs) at a property and postcode level. Six LCT scenarios were created, ranging from solar photovoltaics (PVs), Heat pumps, EV chargers, PVs + batteries, PVs + batteries + heat pumps, and PVs + batteries + heat pumps + EV chargers. Publicly and privately available datasets were superimposed based on common parameters such as address or UPR and filters were applied for each LCT scenario to generate corresponding maps to help LEMAP users target suitable areas and dwellings for take-up of LCTs.

Table 3. Data layers and assumptions behind LCTs scenarios

LCT scenario	**Data layers**	**Assumptions***
Solar photovoltaics (PVs)	- Dwellings suitable for PVs - Dwellings need to improve EPC for PVs - Estimated annual average solar irradiance	- Roof not thatch; EPC greater than 54 - Roof not thatch - Energeo parameter
Heat pumps (HP)	- Suitable for GSHP - Greenspace areas - Priority GSHP - Suitability for ASHP - Priority ASHP	- Not mid-terrace, insulated dwellings, double glazing, premise area greater than 25 m2, bedroom count greater than 2 - Suitable for GSHP, basement or main fuel electricity - Insulated dwellings, double glazing - Suitable for ASHP, main fuel electricity
EV chargers	- Suitable for EV charger	- Suitable for PVs and batteries, off-street parking

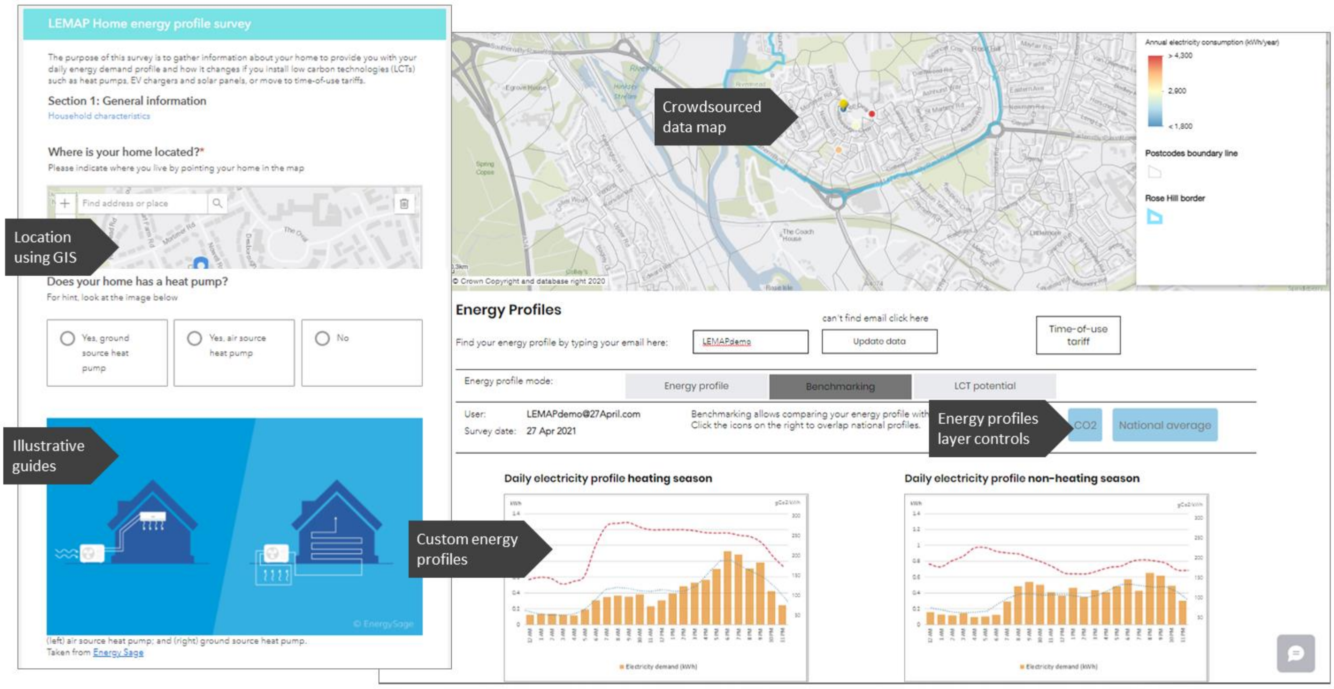
PVs + batteries	- Suitable for PV and battery - Priority battery	- Suitable for PV - Suitable for PV and have basement
PVs + batteries + heat pumps	- Suitable for battery and GSHP - Suitable for battery and ASHP - Green space areas	- Suitable for GSHP, suitable for PVs and batteries - Suitable for ASHP, suitable for PVs and batteries
PVs + batteries + heat pumps + EV chargers	- Dwellings suitable for battery, heat pump (any) and EV charger (time-of-use tariff)	- Suitable for GSHP or ASHP, suitable for PVs and batteries, suitable for EV charger

* General assumptions: only dwelling used for residential purposes were analysed; rented (private and social) properties will not install LCTs; listed buildings are not suitable for LCTs; flats are not suitable for LCTs; all roofs have a suitable orientation for a solar panel.

The *Forecasting* element presented maps and energy profiles of mean daily electricity consumption demand for each of the six LCT scenarios at the postcode level. The maps and energy profiles were generated from CREST calculations and filtered by postcode and LCT scenarios. For the first time, users could see how daily energy profiles would vary with the deployment of different types of LCTs, singularly and in combination, and how time-of-use-tariffs would affect the operational timing of these technologies.

Engagement elements

A key aspect of the engagement side of LEMAP was the *participatory mapping* element that allowed residents in the case study neighbourhood to provide data about their dwelling using an online survey and obtain mean daily energy profiles based on their survey inputs, as well as visualise their dwelling's annual energy consumption on a map. Using the principle of crowd-sourcing, accurate and latest data about the physical and household characteristics was gathered from residents through an online survey. The data provided was used for selecting the appropriate energy profile (archetype) to help residents understand benchmark electricity and gas consumption against national averages and see how their energy profile changed with the deployment of LCTs and TOU tariff (Figure 3).



LEMAP Home energy profile survey

The purpose of this survey is to gather information about your home to provide you with your daily energy demand profile and how it changes if you install low carbon technologies (LCTs) such as heat pumps, EV chargers and solar panels, or move to time-of-use tariffs.

Section 1: General information

Household characteristics

Where is your home located?*

Please indicate where you live by pointing your home in the map

Does your home has a heat pump?

For hint, look at the image below

○ Yes, ground source heat pump

○ Yes, air source heat pump

○ No

(left) air source heat pump; and (right) ground source heat pump. Taken from Energy Sage

Energy Profiles

Find your energy profile by typing your email here: LEMAPdemo

Energy profile mode: Benchmarking

User: LEMAPdemo@27April.com

Survey date: 27 Apr 2021

Benchmarking allows comparing your energy profile with Click the icons on the right to overlap national profiles.

Figure 3. Participatory mapping survey (left) and participatory mapping interface showing results mapped and corresponding energy profile archetype and national benchmarking (right).

The mean daily energy profiles showed hourly energy demand in colour tagged bars since it is easier for residents to read and relate it to their daily schedule (Valor *et al.*, 2019; Escudero *et al.*, 2020). In the 'benchmarking' mode, energy profiles were overlapped with grid carbon intensity, typical energy demand profile and TOU tariff'

(Octopus flexible tariff). For the case study area, about 54 archetypal profiles were generated to fit all possible user input combinations based on their survey answers, as specified in Table 4.

Table 4. Variables characterising archetypal profiles in participatory mapping

CREST parameters	CREST Archetype input	Survey answer
Number of residents (3 variables)	- 1.5 - 3.5 - 5	- '1 or 2' - '3 or 4' - '5 or more'
Building- dwelling type (6 variables)	- improved detached - detached - improved semi-detached - semi-detached - improved terraced - terraced	- ‘detached’ + insulation* - ‘detached’ + no insulation** - ‘semi-detached’ + insulation* - ‘semi-detached’ + no insulation** - ‘terraced’ + insulation* - ‘terraced’ + no insulation**
Appliance configuration (3 variable configurations)	- no: chest/upright freezer, TV2, dishwasher, tumble dryer, washer-dryer; 0.2 electric shower - default - yes: chest/upright freezer, TV2, dishwasher; 0.5 tumble dryer, 0.5 washer-dryer	- low - '1 or none' - medium - 'between 2 and 4' - high - '5 or more'

*answered 'yes' to all insulation and double-glazing questions; **answered 'no' to any insulation or double-glazing questions.

The *Storymap* element consisted of a blogging platform in which users such as SFN project managers could visually summarise the key findings from applying LEMAP to a local area. The story map consisted of linked spatial maps, text, images, videos and links to external references. The story map could serve as a visual platform for those planning local energy initiatives to communicate information derived from the technical elements with the residents of the local area. This could help to bring inclusiveness and transparency of information flow, which was found to be lacking in the review of tools undertaken.

The *forum* element was designed to be non-mapping in nature and was included primarily to stimulate communication between LEMAP administrators and users, project delivery teams and residents, as well as amongst residents of the local area. It included a forum functionality and chat platform open to the users who could contribute through entries, likes and comments. The forum and chat could also be used for sharing feedback about the tool - the different ways in which LEMAP was used, any pitfalls encountered, and insights developed.

LEMAP trial: user feedback and refinement

Three sessions were run with the SFN project managers of a community interest company who were responsible for planning smart local energy (SLE) initiatives in different neighbourhoods in Oxfordshire as part of Project LEO. Alongside demonstration of the tool in the sessions, a visual user guide was shared to provide step-by-step guidance into using LEMAP. Following the training and trial sessions, an online survey was completed by the SFN project managers. This was followed by an open discussion between the authors and SFN project managers to provide feedback about the functionality and usefulness of the tool. The key findings of the feedback were as follows:

- SFN project managers were highly receptive to the tool's usefulness. The majority of them (n: 83%) agreed or strongly agreed that LEMAP would help in the planning and delivery of the smart and fair neighbourhoods.
- The majority of the project managers (n: 67%) found LEMAP easy to understand and navigate.
- All six project managers valued the transparency of the tool in terms of the details about the underpinning data layers and their sources along with the filters used to select suitable areas and dwellings for the deployment of LCTs.
- The organisation of LEMAP in terms of the six constituent elements (baselining, targeting, forecasting, participatory mapping, storymap and forum) was found to be logical by 83% of the project managers.

- The targeting, forecasting, and participatory mapping functions were found to be the most useful planning of SFNs.
- The overall majority of the managers (n: 83%) found the LEMAP approach innovative in providing spatial intelligence about local areas.

The SFN project managers proposed the following changes to the functionality of the tool. These were grouped as:

- *Immediate changes* - minor improvements addressing debugging issues, such as use of terminology and size of display screen.
- *Structural changes* - addition of spatial data layers such as information about socio-demographics of the local area.
- *Future changes* - addition of third-party data by users and roll-out of the tool at the county level.

Subsequently, an updated version of LEMAP (version 2.0) was created based on the feedback received from the trial with SFN project managers. The debugging issues were addressed. Special attention was paid to improve user experience; maps were set to be responsive to screen size, and the user interface was further simplified. Baselining element was enriched with time-series data related to historical trends in gas and electricity consumption at LSOA level. Additional private databases were added, such as consumer classification database for showing socio-economic characteristics of the local area to help project teams design customised smart energy offers for residents.

Discussion

Overall, the spatial-temporal mapping approach of LEMAP was found to be innovative and useful for extracting local intelligence rapidly and accurately. The tool allowed users to systematically move from *baselining* to *targeting* and then *forecasting* while also enhancing community engagement through *participatory mapping*. The trial feedback showed that SFN managers considered these functionalities of LEMAP vital for the planning of smart local energy initiatives. The modular nature of the tool in terms of the six underpinning elements brought flexibility and adaptability to the tool in terms of what elements to customise for which neighbourhood, based on the low carbon aspirations of the area and the scope of the planned SLE initiative.

Visualisation of spatial and temporal aspects of local energy, as well as the balance between technical and engagement aspects, was a novel feature of the LEMAP tool. The literature review showed that these capabilities were not present in any tool to date. For example, the display of energy profiles in conjunction with carbon intensity and TOU electricity tariffs can help to stimulate action amongst resident to shift the timing of energy demand away from off-peak hours (grid balancing), whether for saving money, carbon or generating a positive environmental impact.

LEMAP brought together disparate sources of data from public and private sources at the dwelling level, which required sensitivity in handling data to maintain data privacy. This is why ethical arrangements were put in place in terms of seeking permissions and informed consent from residents before any data provided by them through online surveys was visualised. This is why LEMAP was designed to aggregate data at different spatial resolutions such as postcode and LSOA. Aggregation of data at these spatial scales was considered acceptable by most SFN project managers, although a few suggested having more detailed granularity, raising the questions of, what spatial scale works for whom? And, how to provide high-resolution data without affecting data privacy? Also, given the variety of data layers underpinning LEMAP, to maintain data quality, the tool was designed to provide the data source and year of data collection for each data layer to highlight any mismatch in dates for different datasets.

The crowd-sourcing of data through residents was found to increase the accuracy of the tool with more local data. It was also realised that local interpretation and validation of the nationally gathered data (public and private) was necessary to identify errors and give confidence to local communities. Therefore, community engagement was seen to be vital for the tool's success since it helped to improve the accuracy and richness of the data. The citizen science-based participatory mapping approach could also provide the means to engage with local residents through the means of a map. The storymap and forum elements would also enhance communication between the users of the tool and the wider community. Despite these strengths and benefits, since LEMAP was designed as an online tool, it could ignore the residents that were not internet savvy, raising the question of how to include users who are not or cannot be digitally active? For the inclusion of such users, the capability to rapidly create traditional reports from the LEMAP analysis of neighbourhoods may need to be considered.

Conclusion

Geospatial mapping tools have the capability to provide spatial intelligence and engage local communities if they moved beyond a one-way flow of representing local energy flows to two-way interaction with local communities. This paper has described the development and trial of an online and interactive spatial-temporal community engagement tool called LEMAP for planning smart local energy neighbourhoods in Oxfordshire (UK). The review of existing local energy mapping tools and approaches confirmed the absence of such tools in the local energy sector. LEMAP was designed to engage with community groups, community interest companies, local authorities and residents. It was applied to Rose Hill, a socially-deprived but data-rich neighbourhood in Oxford.

The tool brought together public, private and crowd-sourced data on energy demand, energy resources, building attributes, socio-demographics, fuel poverty and electricity networks within the ESRI ArcGIS platform. Postcode and dwelling level energy demand profiles were generated using the CREST energy demand model. The tool was organised around three technical and three engagement elements that include baselining, targeting, forecasting, Participatory mapping, Storymap and Forum. Project managers in a community enterprise organisation in Oxfordshire were trained online to use LEMAP to plan for energy management at the neighbourhood level. Participatory mapping was found to enrich the tool and engage communities to provide local data through online surveys and highlight any discrepancies in the public and private data through local data interpretation.

The trial and feedback from the user group emphasised the need for LEMAP to be scaled up to the county level and rolled out to other communities for planning and delivering SLE initiatives. In future, LEMAP will be deployed in a variety of SFN neighbourhoods that aim to install low carbon heating with TOU Tariffs, EV chargers, and rooftop solar with batteries. Using a capability lens approach developed by the Centre for Sustainable Energy (Roberts et al., 2020), households based on their socioeconomic characteristics will be identified in terms of who are likely to adopt different LCTs and those who could be left behind. The tool could also help District Network Operators (DNOs) to overlay network constrained areas with areas that have the potential for deploying distributed energy resources to support local grid balancing.

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