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Driving success towards zero carbon energy targets for UK's Local Authorities

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ABSTRACT

This paper draws on three case studies which show feasible and economic results in meeting net zero carbon emissions targets through Smart Local Energy Systems (SLES) in different localities across England, exploring opportunities to utilise waste heat from industry. They are based on the GreenSCIES model for which the blueprint was developed in London, Study 1. It consists of a fifth generation (5G) ambient loop district heat network using waste heat from a data centre, integrated with electric vehicle charging, storage and solar PV. The network includes decentralised heat pumps and allows for (i) heat sharing between buildings and (ii) applications for heat recovery from local sources. Study 2 is based on a heat network with waste heat from a foundry and some cooling supply and heat storage in the aquifer. Study 3 explored waste heat from a glassworks and considered mine workings for providing heat storage. These SLES projects illustrate how to integrate local waste heat sources in 3G and 4G heat networks, adapting the original GreenSCIES concept, providing pathways towards net zero carbon for a diverse range of urban locations with different waste heat sources, and further demonstrate the importance of collaboration between researchers, local government and industry.

Keywords

District heating;
Renewable power;
Local authorities;
Energy integration;
Electric vehicles

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Abbreviations

SLES	Smart Local Energy System
GreenSCIES	Green Smart Community Integrated energy systems
DHN	District heat network
HP	heat pump
GWSHP	ground water sourced heat pump
ASHP	air source heat pump
BMBC	Birmingham metropolitan City council
WMCA	West Midlands combined authority
SYMCA	South Yorkshire metropolitan combined authority

1. Introduction

The UK is committed to delivering its target for zero emissions by 2050, in the light of the Global Climate Emergency. While there has been considerable progress, much work remains. In the UK, almost half of the final energy consumed is used as heat, of which the domestic, commercial and public sectors account for two-thirds. Heat is mainly used for space heating and water heating in domestic and commercial buildings, as shown in the Net Zero strategy document, BEIS Build Back Greener [1]. Improving energy efficiency in buildings through better insulation and other measures is key to reducing the heat demand and is the first step to reduce carbon emissions from heating. In terms of delivery method, heat networks are seen as one of the best solutions in urban areas where the integration of waste heat from local sources with heat pumps powered by renewable energy can deliver low cost, low carbon heat to the local community. Hence, advancing capability in ground sourced heat networks to utilising geothermal heat from the aquifer together with waste heat generated by industry provides major opportunities to decarbonise both domestic and non-domestic buildings.

Application of 4th and 5th generation heat network technology and integrating waste heat from industry into district heat networks can both improve the carbon footprint of the industrial processes and reduce their energy consumption, and at the same time supply affordable heat for local buildings. The specific added values of 5GDHC with respect to 4GDH [2] include the low temperature or "ambient" loop (reducing thermal losses) and the capability to work in heating or cooling mode independently of network temperature, with bi-directional and decentralised energy flows, as noted by Buffa et al. [3].

In the UK most heating is supplied by gas while Heat Networks are relatively uncommon. Compared to the EU28, the UK uses far more gas and less of all the remaining sources (e.g. oil, coal, electricity and biomass) and district heating provides just a few percent.

A 2018 market study showed that heat networks supplied about 12,000GWh of heat annually representing 2% of the overall UK heat demand [4]. Further, while diverse energy sources can be used in heat networks, and are widely available, the expected trend towards other non-gas energy sources such as large-scale biomass energy from waste and large-scale heat pumps was quite limited.

In a 2021 report, the UK government recognises that local authorities (LAs) play an essential role in driving local climate action [5]. Councils have significant influence over the key sectors of energy, housing and transport, and projects requiring infrastructure for water sourced heat pumps and heat networks require co-ordination across all these areas via the individual departments.

In the UK, three in four households rely on gas-fired central heating. Every householder with an individual boiler powered by gas, oil or coal is a stakeholder in the local economy and has a role to play in supporting the transition together with local business owners and entrepreneurs.

Over 300 LAs have declared a climate emergency, and nearly two thirds of councils in England are aiming to be carbon neutral 20 years before the national target [6].

The LAs in the UK are directly responsible for 2-5% of their local area's greenhouse gas emissions. However, a much higher proportion of emissions is within their influence and LA's have many levers through which to deliver action locally and prepare their areas for the changes required to reduce greenhouse gas emissions.

Figure 1 displays an "onion diagram" based on a model by the Internal Centre for Sustainability for the Government. It shows a series of spheres of influence with decreasing levels of control from (A) direct control of buildings, operations, and travel within their area, to (F) involving engaging and communicating with stakeholders. Other elements are - procurement and commissioning (B), using powers to control development and transport (C), showcasing demonstrations (D) and building partnerships (E). Each larger sphere becomes more diverse and all are overlapping and interlinked.

Figure 2 shows trends in UK greenhouse gas emissions from 2019 to 2020 which provides context for the LA climate goals, from a government report [7]. What is immediately clear is that, while significant progress has been made in many areas, most recently transport, the residential and agriculture sectors are lagging behind the power sector.

Today, heat network experience is relatively limited amongst LAs and potential users and the existing experience of heat networks across the UK is variable. Importantly, experience is gradually improving as better standards are introduced, refer CIBSE CP1 Code of Practice on Heat Networks [8]. Any infrastructure installation requires strong engagement with, and support from, the LAs who provide access to the data for assessing domestic heating demand across private and LA owned property and supply planning data for future building.

Recognising that district heating and cooling networks will have an essential role in helping to decarbonise the energy sector, it is clear that more case studies are needed to build confidence in adopting heat network (HN) designs.

The purpose of this paper is to report on three studies from the GreenSCIES (Green Smart Community Integrated Energy System) project which show a range of experience and technological learning in the design of smart local energy systems (SLES) in urban areas, developed under the GreenSCIES approach. The resulting projects provide solutions identifying how to deliver affordable low-carbon energy for local communities and thereby help the drive towards net zero carbon specifically showing a way forward for three different local authorities. While the purpose and the approach are similar in each case, the specific local conditions are widely different, and the results therefore show how to adapt the original concept to suit a range of varying geographical situations and heat sources.

The work referenced in this paper has been reported individually as it has progressed, ref e.g., Revesz et al. [9,10], Marques et al. [11-13]. This paper summarises all three projects, including the overall experience of collaborating with different LAs and comparing the variations in demand as well as the design adaptations required in the different locations. The analysis focuses on the concept level technical design and associated techno-economic assessment.

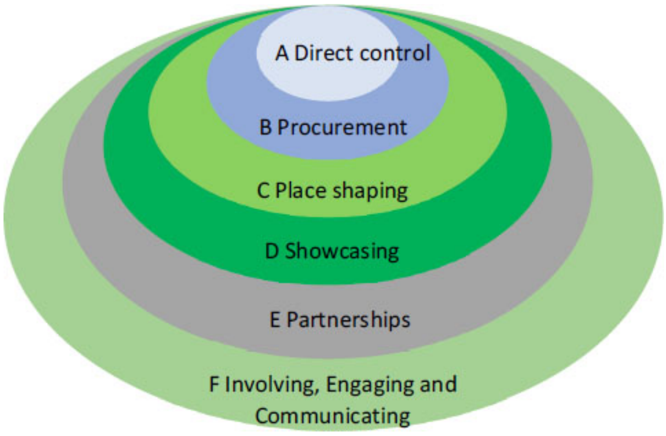

Figure 1: Supporting Local Authorities

1.1 GreenSCIES Project Approach

The GreenSCIES approach is to deploy an innovative methodology for the development of integrated thermal, power and mobility smart energy networks comprising a low temperature ambient loop HN [9]. The series of projects reported here tested the use of different waste heat sources in separate locations, exploiting locally available industry. Together these projects test the potential for replication of the original concept, showing how it could be adapted in each case to fit the local situation.

The original GreenSCIES scheme was developed for residences in London and was used to develop the concept for local communities elsewhere in the UK. Detailed design was completed after an initial feasibility study, overall 2019-2022, and the project is now with the London Borough of Islington (LBI). Importantly, to maintain the GreenSCIES concept, all the SLES projects should deliver lower carbon heating, cooling, power and e-mobility powered by renewable energy and waste heat, locally sourced and the resulting design should be at affordable cost with involvement from the community. The importance of social acceptance of energy

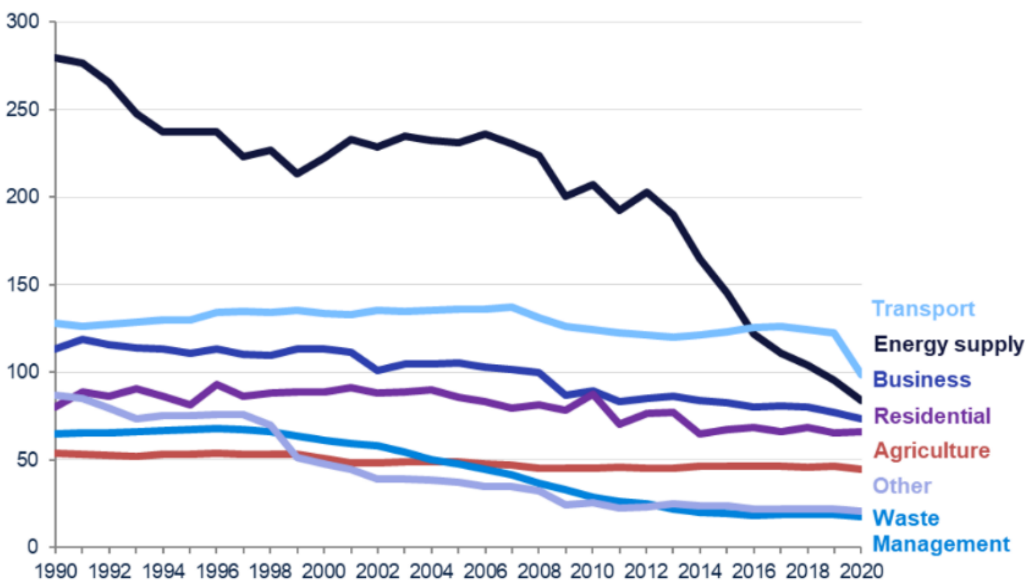

Figure 2: Trends in Emissions ($MtCO_2e$) by sector

transformation projects has been recognised in other renewable energy development projects in Europe [14].

The research team comprised 15 independent companies and was led by London South Bank University, partnering with the London Borough of Islington (LBI) to agree the strategy and scope. The same methodology was applied in each regional study. For this, partnerships were agreed at the start of the research programme with two other UK regions, the West Midlands and South Yorkshire. The specific areas were defined via a technical screening of zones with potential for developing an innovative smart local energy network. These focused on areas in need of significant energy savings, as prioritised by the different LAs in each case. Criteria included the need for council owned housing planned for development or refurbishment close to potential sources of industrial waste heat.

All three schemes were aligned with the strategic objectives of the local authority to research the innovative application of large-scale district heat networks (DHNs) with thermal storage and utilising waste heat from local industry, and council representatives were involved directly in each project. Overall, a range of sources have been tested – data centres, a hospital, a metal foundry, a glassworks and minewater. In the West Midlands and in South Yorkshire, the local industry has heritage significance.

In addition, a key foundation of the GreenSCIES approach is participative communication achieved through stakeholder workshops and focus-group discussions to encourage buy-in from the communities involved in the changes. These include the residents and the local businesses as well as the authorities responsible for the area.

Having identified potential energy network clusters, the methodology progressed through a series of steps: mapping energy sources and demands, identifying suitable low carbon technologies in the area, establishing smart control strategies to integrate the scheme, developing outline network designs, cost models (CAPEX) and techno-economic models to estimate the OPEX and CO_2 savings potential over a baseline case (with gas boilers and petrol/diesel vehicles and grid electricity). Each scheme varies considerably in design according to the available local resources and the scale of opportunity.

2. Case studies

This section summarises the three SLES case studies in London, the West Midlands and South Yorkshire.

2.1 London SLES

The first scheme is in the London Borough of Islington (LBI). Following an initial feasibility study in 2019, a more detailed design project has now been developed for a Smart Local Energy System (SLES) to deliver significant carbon saving for residents, schools, and businesses. This is a 5th generation heat network comprising a low-temperature (13 to 25°C) ambient loop with interseasonal storage in the subsurface aquifer to counteract higher winter heat demands and keep the ambient loop stable. Such 5G schemes have a very different topology from 4G (45 to 60°C) and 3G (60 to 90°C) networks. They comprise decentralised heat pumps rather than a single large unit, giving opportunities for sharing heating and cooling across an ultra-low temperature loop. The ultra-low temperature 'ambient loop' also offers a more direct opportunity to capture low-temperature waste streams that even a 4G scheme could not. In urban areas, there are many opportunities to capture low-grade heat sources that could be integrated into 5G networks [11].

The LBI scheme demonstrates how the ambient loop allows for interchange of heating and cooling between buildings by using heat from a large data centre as a source. In addition, local power is generated with solar photovoltaics (PV) and electric vehicles (eV) provide low carbon mobility. The design of the loop includes a series of energy centres, buildings which house the necessary heat pumps and/or heat exchangers. The system has several decentralised energy centres across the network that function as a 'micro-grid' flexing the heat pumps, PV and electric vehicle batteries in relation to the electricity grid demand and tariffs [10,11].

Specifically, the main heat source for the Islington scheme is that recovered from cooling a data centre. Heat recovery from data centres is attractive because of the constant load throughout the year. The key 'anchor loads' are housing estates managed by LBI, currently supplied by centralised gas boilers, which are easy to connect to a heat network. The scheme also connects a university campus, a library and a theatre.

The heat network is illustrated in Figure 3. This connects 402 domestic properties and 8 businesses. The total heat demand of the network is 10.5 GWh and the cooling demand is 9.3 GWh, mainly from the data centre. There are six energy centres, fitted with individual heat pumps (600 to 2600 kWth), thermal storage (80 to 210 m^3), 610 kWpk solar PV generation and 49 electric vehicle chargers, [10,11]. Extensive hydrogeological modelling has been carried out which adds

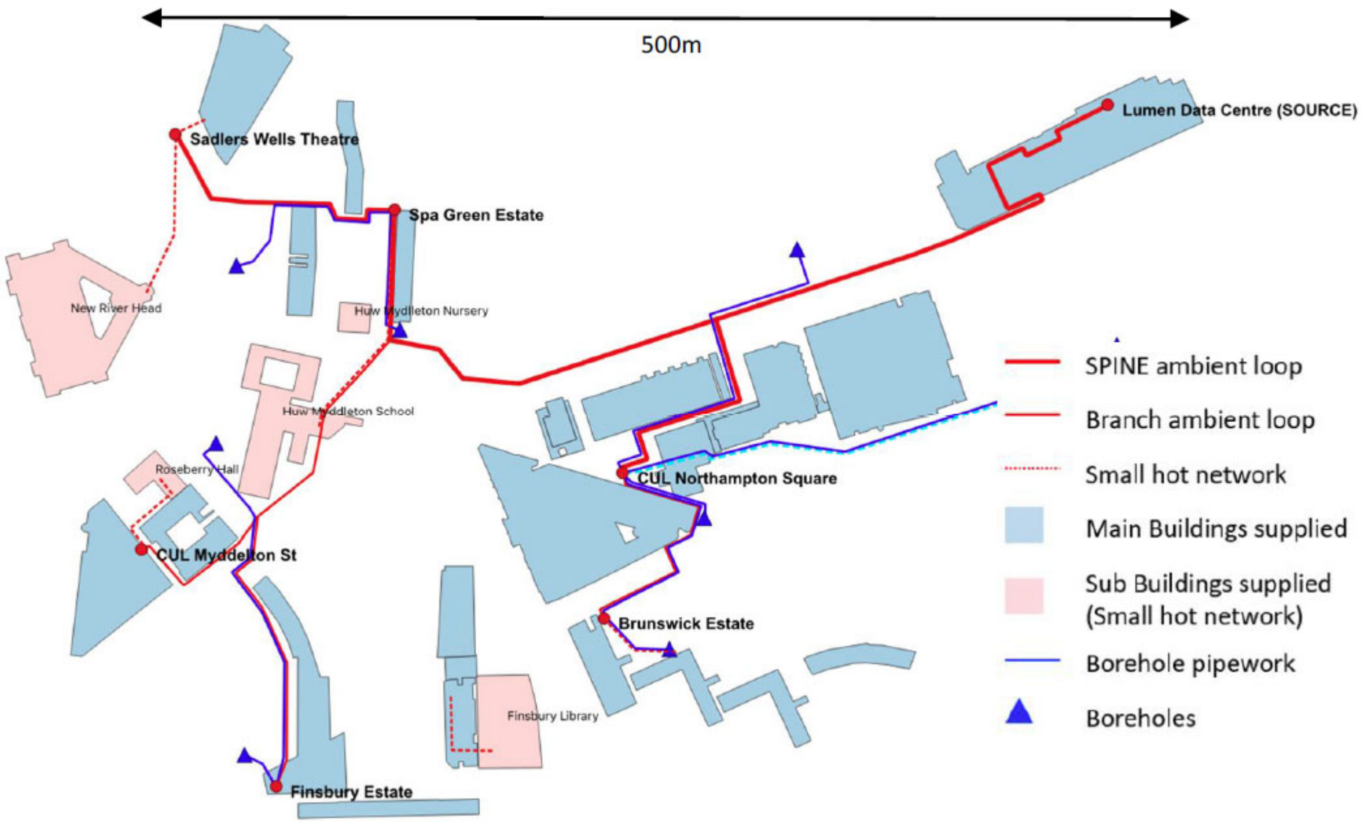

Figure 3: The New River Scheme in Islington, London

confidence to the sustainability of the subsurface warm and cool zones [15].

2.2. West Midlands SLES

The area of interest for the West Midlands project is focused in a Birmingham local authority, Sandwell, just outside the city centre, shown in Figure 4.

At the outset, the connection with the West Midlands was through the Combined Authority (WMCA), who state a target for net zero emissions by 2041 in the West Midlands Natural Environment plan [16]. Specifically, the requirement was to apply GreenSCIES thinking to 3rd generation district heat networks (HN) previously proposed for re-development within the Birmingham Metropolitan District. The local Sandwell Metropolitan Borough Council, SMBC, objectives include the need to address fuel poverty, to deliver energy cost savings, support economic development and establish revenue generation opportunities as well as to deliver significant carbon savings. These align well with the overall aim of the GreenSCIES approach.

A previous feasibility study from 2018 delivered a proposal involving a development with 674 new houses and 270 flats within three existing tower blocks. The total heat demand given was 6,772 MWh with a peak demand of 2.9 MW. Water Source Heat Pumps (WSHPs) were proposed to recover heat from the nearby canal, with an estimated 2 MW maximum capacity based on the flow rate and temperature of the canal.

In order to develop the original scheme, the area under consideration was widened to explore new sources of waste heat and to expand the network. In this GreenSCIES study, the network was connected to the new hospital, which was not investigated in the original study. Additional opportunities identified include a supermarket and a metal foundry (as the main waste heat source).

In summary, the GreenSCIES proposal is to install two energy centres (at the hospital and the supermarket), both with 3 MWth heat pumps recovering heat from the chilled water systems with boreholes connecting to the aquifer for thermal storage supplying 3,128.7 MWh to each energy centre. Both sites are prime candidates for both electric vehicle charging and solar PV generation. At the foundry, on an adjacent industrial site, the main heat recovery opportunities from the factory processes are from the casting track, the steel shot and some locations in the plant where the ambient temperature reaches 48°C.

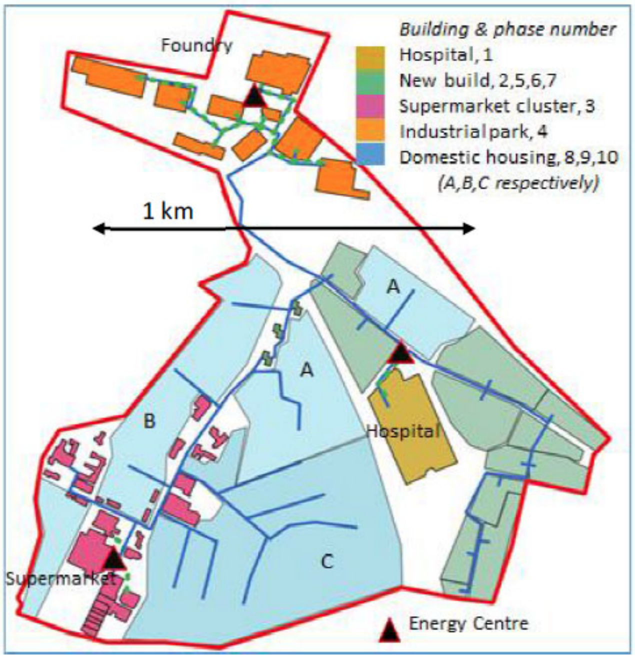

Figure 4: WMCA Sandwell Heat Network

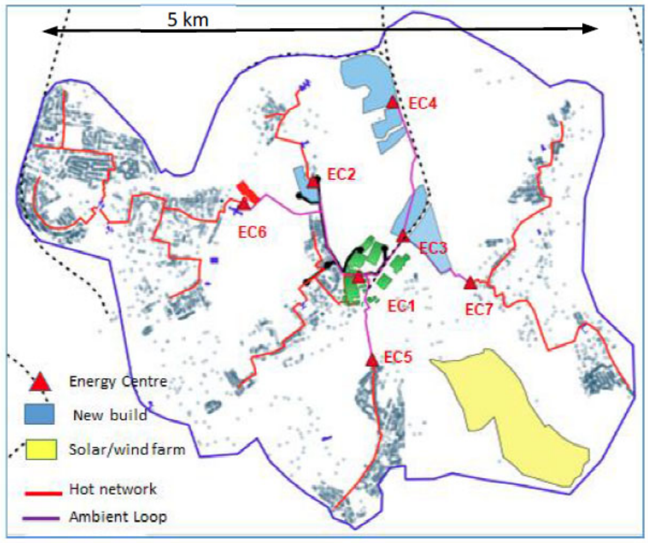

Figure 5: BMBC Barnsley Heat Network

In the proposed plan, the HN is built in a series of phases, starting at the hospital. The building sequence is summarised as follows: (1) hospital; (2) tower blocks; (3) supermarket cluster including non-domestic properties; (4) foundry and light industrial properties; (5) to (7) new build homes; (8) to (10) existing domestic properties within the red line boundary, refer Figure 5. In total, with the completion of Phase 10, the GreenSCIES-Sandwell network connects 3,168 domestic properties and over 70 businesses. The total heating and cooling demand is 57.2 GWh/yr and 6 GWh/yr respectively.

The plan illustrated in Figure 4 shows a mainly 3G DHN (75°C) connecting existing buildings with some cooling supply to the hospital and supermarket. This is a consequence of the heat source temperatures and the higher temperatures required by existing buildings. The new developments would be supplied by a 4G DHN (60°C). As is typical for the UK with significant variation in demand for heat, between winter and summer, the opportunity for interseasonal storage of heat in the aquifer was also investigated. Available data from the British Geological Survey indicates that the Sandwell aquifer is highly productive with a yield of 12.5 l/s which suggests that the aquifer is suitable for ground water sourced heat pumps.

The final scheme includes solar PV generation installed at the hospital, 300 kW, and the supermarket, 1 MW, as well as on the industrial park buildings, 2.5 MW, amounting to 3.8 MW in total. The network also includes the addition of up to 40 eV charging points distributed along the network benefitting from shared trenching.

2.3. South Yorkshire SLES

In South Yorkshire, the work began in collaboration with the South Yorkshire Mayoral Combined Authority, SYMCA, formerly Sheffield City Region. Their Energy Strategy sets a target for net zero carbon emissions by 2040 [17]. This strategy aligns well with the objectives of the GreenSCIES approach - to drive clean growth and decarbonisation in local businesses and industry, to promote investment and innovation in low carbon energy generation, distribution and storage, and to improve the energy efficiency and sustainability of the built environment. They also seek to accelerate transition to ultra-low emission vehicles (ULEVs) and transport systems which fits the GreenSCIES aim to integrate mobility through eV charging.

The first step involved regional screening to explore areas for a 5th generation ambient loop network with sharing of heating between buildings and heat recovery from a local industry source, including mine water, an option in former coal mining areas. The Carlton area in the Metropolitan Borough of Barnsley was selected from a short list of areas, Barnsley having been highlighted in a review by the Coal Authority [18]. Also, in this area some new housing developments are planned and there is land available for solar and or wind farms.

A map of the area of interest is shown in Figure 5 centred on a local glassworks, an industry with high waste heat output.

The local Barnsley Metropolitan Borough Council, BMBC, recognises the opportunities for new housing including social housing, and the legacy of skills associated with former traditional industries of glassmaking and mining, and there are some challenges for overcoming existing fuel poverty and social deprivation in some areas.

The area of interest includes planned new developments totalling 1,500 new homes, a mix of low/medium density semi and detached houses and some higher density terraces. Within the boundary, existing properties comprise 4,858 (28%) social housing, 2,855 (16%) private rented and 9,801 (56%) owner-occupied, total 17,514 homes.

Figure 5 illustrates the full build-out. The HN is built in a series of stages, starting at the glassworks and connecting the energy centre EC1 to housing in the Monk Bretton district immediately southwest. Phase 2 extends north to reach the first phase of the new development continuing into the Carlton district. Phases 4 to 7 complete the connections to the remaining new development sites as shown on the map. The demand to Phase 7 is estimated as 20,000 MWh total heat and 4,500 MWh total electricity. A further 4 phases complete the network for the whole area shown within the boundary area of interest; Phase 8 adds a southerly extension to Lundwood, Phases 9 and 10 extend west to Athersley and Phase 11 extends eastwards to Cudworth and completes the network reaching all these areas where there is significant social housing.

In total, the proposed plan connects 25% of the existing private housing amounting to 7,616 dwellings. The energy demand is 63,647 MWh total heat and 12,841 MWh electricity.

The glassworks is a high temperature 24hr operation throughout the year. The site covers a large industrial area with space for an energy centre and for borehole drilling. While there are a range of heat opportunities, e.g., from the furnaces, from the electrostatic precipitators and from the cooling towers, the focus initially was on heat recovery from lower temperature process water that is collected in lagoons on site via a network of gullies. This avoids any interruption to the process operations. Data was gathered in the winter months to monitor the temperature in two different site locations and showed an average 28 °C within a range of 17- 48 °C. Heat recovery estimated as 7MW would be by a double tube cylindrical heat exchanger sited in one of the gullies.

At full build-out a further 8 MW of heat is required to meet the peak heat demand, and this could be met from the water stored in the abandoned mines below the area. Recent temperature measurements from boreholes in the Barnsley region are consistent with published research giving a mean geothermal gradient of the Yorkshire coalfields >30°C km^{-1} [19]. Seam levels below the glassworks site give depths to several worked seams in this location with the shallowest, Winter seam, at 60 m below mean sea level (msl) and the deepest, Lidgett seam, at 270 m below msl. The most extensively worked seam in the area is the Barnsley seam at a subsurface depth of around 180 m below msl. The abandoned workings would potentially deliver higher flow rates than the subsurface shale and silt formations with coal measures. It is believed that these seams can also provide interseasonal thermal storage to help balance the system.

A model has been suggested using the deepest Lidgett, or more extensive Barnsley seam c 250 m below surface as the warm bubble and the shallowest Winter seam which is assumed cooler. The proposal is for 3 pairs of boreholes each delivering 3.1 MW, assuming at 500 mm diameter to deliver 75 l/s and three heat exchangers (at full build-out), although only one is needed up to Phase 7. Possible locations at surface have been identified which meet the criteria of reaching both shallow (cool) and deeper (warm) seams with well-heads on the glassworks site, close to the energy centre. A second pair could be sited nearby with the third pair close to EC2. Shell and tube heat exchangers would be needed to cope with the expected mine water which is highly saline. These have wider tubes and an automatic cleaning system to reduce the risk of fouling. A valve arrangement is used to control injection or abstraction to/from the mine.

Further work is needed to address some of the uncertainties inherent in the scheme, particularly around flowrate, temperature and water quality. Estimates are currently based on reasonable assumptions aligned with subsurface measurements from available reports and publications.

A ‘heat recovery only’ scheme is potentially simpler, but still requires a pair of boreholes, at a significant capital cost. Also, the water temperature at the glassworks can reach as high as 48 °C and when this is the case then summer injection makes sense. This suggests a control system to inject when heat demand is less than 7 MW and the glassworks temperature is above say 30 °C thus offering additional thermal energy for storage in the mine.

The final scheme incorporates a 20 MW solar farm and a 10 MW wind-farm connected to the nearby energy centre at the glassworks site.

The potential for eV charging was also explored. This assessed the vehicle-use cases in the area of interest, the parking availability and the proximity to the network route and energy centres. Buildings of interest included schools and other service providers such as medical centres.

2.4. Similarities and differences

There were some challenges in the different study regions. For WMCA, the requirement by Sandwell Council to focus on building on some pre-existing feasibility studies limited some of the design options. The proposed network covers an area for re-development and with the need for socio-economic improvement and it includes a high proportion of council owned property. Initially, the nearby canal had been tested for potential as a low-grade heat source however this was discounted due to too high a cost. The hospital and supermarket both have cooling needs, but insufficient for balancing the network. Hence, the extension to the foundry for high grade industrial waste heat leads to a far more extensive network than for LBI and comprises mainly a high temperature network, 3G with a 4G component for the new developments.

For South Yorkshire, the local heritage industries of glassmaking and mining in Barnsley offer potential waste heat sources. Heating from abandoned mines is low-grade and the agreement with the glassworks for this study was specifically to investigate the potential of recovering heat from the waste heat cooling tanks on their site. As with Sandwell, there were significant limitations in the area of study for a cooling demand. And, similarly, this required a higher temperature heat network loop to link with the existing housing.

These two replication studies were thus markedly different from the London Islington situation in a central city context where the final design was selected from screening a larger set of options with more tower blocks planned for refurbishment and where heating and cooling demands were more easily balanced.

3. Modelling Analysis and Results

Table 1 provides a summary of the features for each scheme. This illustrates the extent to which the original GreenSCIES approach has been adapted to each local geography and heat source.

For each study, the modelling was applied in a series of steps, initially for the heat network alone and then for successive additional scenarios involving the integration of power from additional renewable power, e.g. from solar PV and other sources, and the integration of mobility through the installation of vehicle charging points along the network. Clearly there is wide variation in the design of the network in each different location. In each area, space on the roofs of buildings for the proposed installation of solar panels varied considerably. Similarly, the sites showed varied opportunities for installing and generating revenue and storage capacity from eV chargers.

All three schemes set out to meet the strategic objectives of the local authority, and to pioneer the application of large-scale DHNs with thermal storage and utilising waste heat from local Industry. Integration of power from solar PV and mobility through the installation of vehicle charging points along the network complete the demonstration of the initial GreenSCIES concept.

3.1. Techno-economic model assumptions

Techno-economic modelling was undertaken to determine the operational expenditure, CO_2 emissions, internal rate of return over a 40-year period and net present value over a base case.

EnergyPro (EMD, 2014) was used as the modelling tool [20]. This is well-suited to the analysis required taking account of how any proposed energy system is affected by all factors in the economic and technical environment refer [3]. EnergyPRO, developed and evolved to assist in the assessment of the feasibility of different energy units in the energy systems, and can also model larger complex systems, refer [21]. The software employs half hourly supply/demand data alongside electricity tariffs, control strategies and demand side management. EnergyPro can optimise the operation of any combination of energy supply and demand in accordance with the weather, maintenance costs, fuel prices, taxes, subsidies, etc. More details are given in [9]. EnergyPro can also address the range of scales required in these studies. The financial assumptions included the UK spot market electricity import and export prices and Climate Change levies for 2019.

Table 1: Features and scale for GreenSCIES feasibility studies in three locations

	London	West Midlands	South Yorkshire	
Features	*Islington*	*Sandwell*	*Barnsley - total 11 phases*	*Barnsley (phases 1-7)*
District Heat Network (HN) type	5DH (15'C / 9'C)	3DH (75 °C) / 4DH (60 °C)	3DH/5DH Source 1 (20°C / 15°C); Source 2 (25°C / 8°C)	
HN supply, flow /return	75 °C / 55 °C	Existing buildings: 75 °C / 55 °C New build: 60 °C / 40 °C	Existing buildings: 75 °C / 55 °C New build: 60 °C /40 °C	
Balance	balanced heating & cooling	heating demand is 10x cooling demand	no cooling *(in this model, see text)*	
Heat source(s)	Data Centre	Hospital - CHP & chillers Supermarket - chillers Industry: Foundry Aquifer	Industry: Glassware Mine water	
Water & thermal storage	Aquifer	Aquifer	Mine water	
Type of connections	residential, public, commercial	mainly residential	mainly residential	
Number of connections	2,228	3,238	7,616	2,491
Buildings	existing (flats & tower blocks)	existing houses / New Development	existing houses / New Development	
Pipework length (m)	1,227	6,260	16,673	4,473
Annual Heat demand (GWh)	10.5	58.1	63.6	31.4
Annual cooling demand (GWh)	9.3	6	n/a	
Energy Centre Heat Pumps (HP) *Total HP capacity (MWth)*	*6 Energy Centres* *6.8*	*3 Energy Centres* *18*	*7 Energy Centres* *21*	*4 ECs* *6.6*
Number of eV charge posts (max.)	49	40	104	64
Renewable power	611 kW solar PV	3.8 MW solar PV	10 MW (wind) 20MW (solar farm)	

Electricity charges comprising both kWh unit charge and DUoS (Distribution use of System) for the red, amber and green tariffs were obtained from the relevant power company and were applied to all the buildings connected to the network. Carbon factors were based on diminishing figures using predicted figures published by GOV.UK (2019c) [22].

The techno-economic model was applied in each study to several different scenarios, one based on the heat network alone and then the heat network with additional renewable power input as appropriate to the locality, e.g. from solar PV, and/or wind-farm etc. The Islington scheme was also modelled with the addition of battery storage although this proved to be uneconomic. The work analysed the integration from the installation of eV chargers along the pipework route from electric vehicles (eV) in terms of revenue to the DNO as well as potential contribution to energy storage.

The base case counterfactual was gas boilers or air source heat pumps for existing properties and for new build homes the counterfactual was always air source heat pumps (noting the UK post 2025 gas ban for new build). In each study the modelling was applied to different scenarios: the Heat Network, the Heat Network with solar PV and energy from the windfarm in the Barnsley case, and thirdly with the further addition from the eV to the network.

3.2. Techno-economic results

The next section expands on the results for the replication studies in the West Midlands and South Yorkshire for comparison with the original scheme.

3.2.1. Sandwell network, West Midlands

Figure 6 illustrates some of the outputs from the modelling. It shows the GreenSCIES Sandwell HN generation by source at each build phase for one scenario, the heat network only. In phase 1 CO_2 emissions for the hospital are significantly reduced (without displacing the CHP) and phase 2 helps to replace the tower blocks night storage heaters. The heat pump (HP) from the supermarket provides heat from phase 3 and the foundry heat recovery and aquifer HPs supply most of the heat source from phase 4 until phase 9, so that the supermarket HP is fully utilised again by phase 10 when all domestic properties are connected. In this case there is no revenue from the waste heat in the modelling. Further scenarios were modelled adding the power contribution from solar pV and vehicle charging.

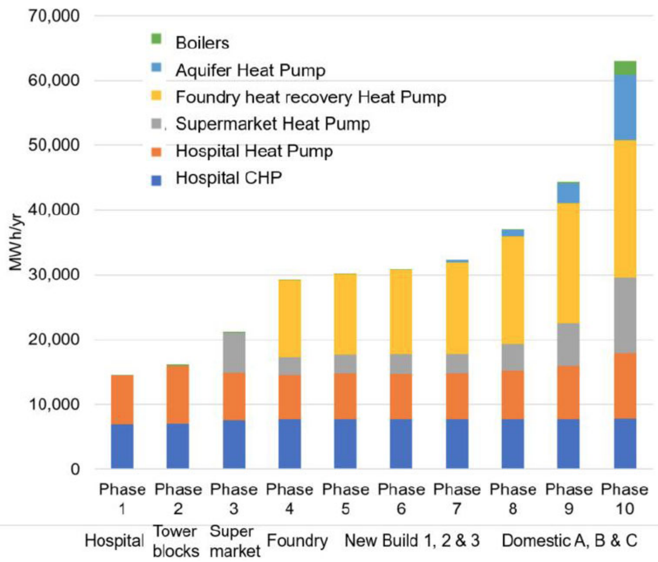

Figure 6: Sandwell study - GreenSCIES network generation by source, based on data from [12]

3.2.2. Barnsley network, South Yorkshire

For Barnsley, the proposed network is built in a series of phases in a similar way to the Sandwell study and the results were generated for a series of scenarios, first the heat network alone and then with the addition of other renewable sources, the energy from a solar farm, 20 MW, proposed for nearby land (refer Fig 3B) plus that from a small-scale wind-farm, 10 MW. The final scenario included contribution from recommended eV charging points. For the heat network alone, the energy was modelled with distributed heat pumps at the energy centres, whilst for the combined power sources the modelling considered a large heat pump supplying the whole network with the solar and wind-farms connected behind the meter.

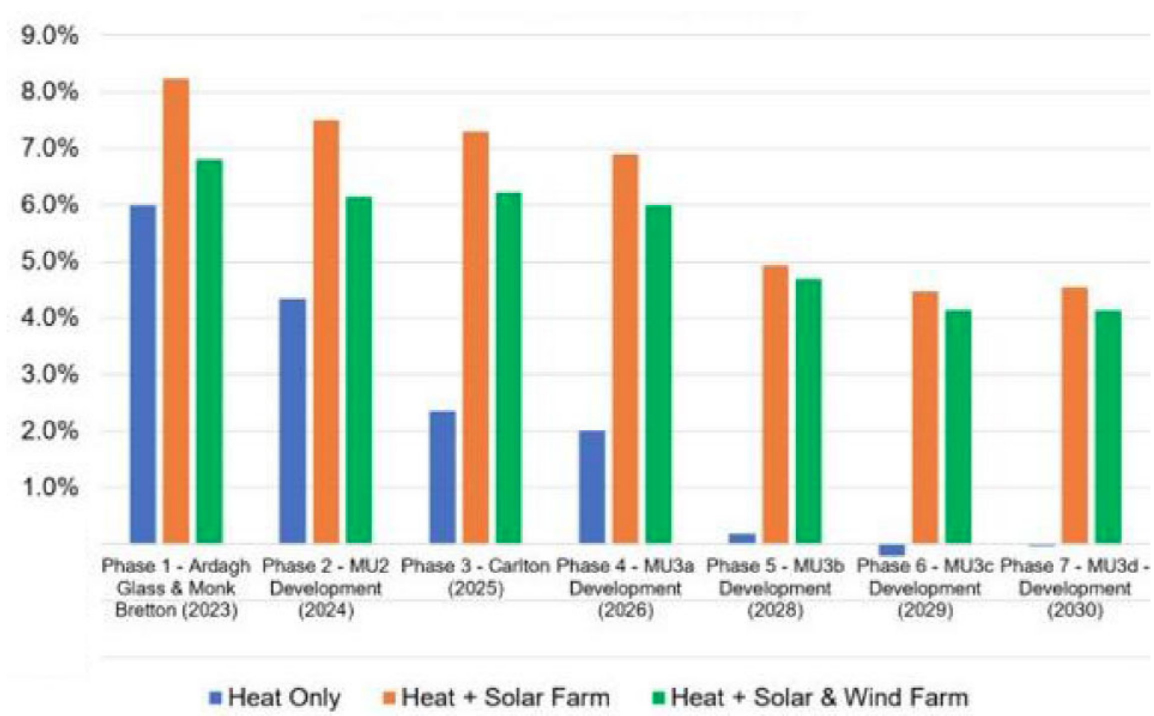

Figure 7: Internal rate of return for the first 7 phases of model build, based on data from [13]

Table 2: Summary Techno-economic results for GreenSCIES SLES Feasibility studies

	London	West Midlands	South Yorkshire	
Features	*Islington*	*Sandwell*	*Barnsley - total 11 phases*	*Barnsley (phases 1-7)*
Scenarios analysed	*Heat only* *Heat + Solar PV* *Heat + Solar PV+ eV*	*Heat only* *Heat + Solar PV* *Heat + Solar PV + eV*	*Heat only* *Heat + Solar PV* *Heat + Solar PV + Windfarm*	
Annual Carbon savings CO2e tonnes	5,443	2,825	5,903	5,241
Counterfactual	vs gas	vs gas & ASHP	vs gas & ASHP	vs gas & ASHP
total Capex (£ x 1000)	1,600	53,571	163,002	70,000
IRR (40 Years) without grant funding	0.70%	15%	6% (1.8% vs gas)	4.1% (2.6% vs gas)

The Barnsley study is used to illustrate some of the financial outcomes from the modelling. Figure 7 shows the internal rate of return (IRR) for one of the scenarios as the project develops through the first 7 phases and gives positive IRRs throughout. This covers some social housing, schools and some buildings on the glass-works site and includes all the proposed new build developments in the area investigated. This subset would provide savings of up to 3,763 Tonnes CO_2/yr for an investment of £70 m over 10 years.

Here, regarding the eV charging potential, analysis showed that the opportunity for revenue and returns on capital investment are less than in higher density areas such as Islington and Sandwell and may not be as beneficial to the scheme for example where the charge points proposed do not have enough use to deliver a return on investment or have use cases where vehicles are plugged in for long enough to participate in energy services. Again, there is no revenue from the waste heat in the modelling. Table 2 compares the carbon-saving and indicative economic results of the techno-economic modelling across all the studies. Internal rate of return was used to compare the economics of the schemes as this manages the widely different scale and variation within each individual scheme and is unaffected by the discount rate.

The modelling results compare the original GreenSCIES scheme in Islington against gas boilers. For the Sandwell and Barnsley schemes, some air-sourced heat pumps (ASHPs) were included for the new build (post 2025). The economics improved significantly with the addition of solar PV and – for Sandwell - eV charging points which can be integrated at the three Energy Centres. Here, the IRR improved 5% by full build-out compared with results for the heat pumps only model. There are several contributing factors. With solar PV and storage, it is possible to avoid periods with the highest tariffs; the trenching shared for both pipework and cabling reduces overall capital and for eV, the revenue is high relative to the cost of electricity.

3.3. Discussion

In all areas, the early results from economic modelling show that it is possible to decarbonise large residential areas including their social housing stock using heat networks that provide options to utilise waste heat from local industry. Each study showed positive IRR over 40 years even without grant funding and the range in scale and building type across the projects highlights significant differences. The studies all began with exploring large areas and, across the combined work, engaged with a range of very different industries for recovering their waste heat.

The work evolved through several phases. From the initial feasibility study in Islington, the research team developed a detailed design for smaller proposal which was selected from a wide range of options available in a dense urban environment. The reduction was partly in response to the removal of the Renewable Heat Incentive (RHI) government grant at the time and requires smaller capital investment.

In Islington the properties are densely packed in blocks and towers and the cooling generates revenue to the system from the data centre. The scale is the smallest, 1200 m pipework, but the dense urbanisation is challenging and trenching is not always possible. Overall, there is an optimal balance of heat demand and supply. However, costs for work in London are highest, and the cost of the counterfactual is cheaper for large communal gas boilers.

Options for the studies in Sandwell and Barnsley were more limited and the lack of cooling required components of 3G and 4G heat networks. These show that the flexibility to combine with other renewable sources and to install eV can deliver significant improvements to the economics.

In Barnsley, recovering up to 7 MW of heat from the wastewater from the glassworks is feasible and can be economic, as is using old mine workings as a heat source. This potentially allows seasonal storage of heat to act as back-up and top-up to the main industrial source, and there is scope for further optimisation.

The study in Sandwell shows the highest IRR, 15%. It looks more attractive than Barnsley because, in addition to the lower eV charging potential, there is a higher linear heat density leading to lower capex and lower heat losses per MWh supplied. Also, higher temperatures are expected from the foundry compared to the cooling water monitored from the glass factory. Thirdly, the capex modelling for Barnsley used higher costs for retrofitting houses with individual boilers.

Today the ownership for the original scheme has moved to LBI council, and the projects in Sandwell and Barnsley are likely to be taken to the next phase by the local authorities, SMBC and BMBC respectively.

Annual carbon savings from each of these three schemes, once implemented, is typically in the region of 5,000 tonnes /yr. Whilst the heat pump/heat network combination is one of the leading carbon solutions, it remains challenging to make it economic.

4. Conclusions and Recommendations

Given that district heating and cooling networks have an essential role in helping to decarbonise the energy sector, these and similar case studies can help to build confidence within UK's local authorities and regions for accelerating the adoption of similar smart local energy system designs.

4.1. Conclusions

Overall, these studies offer the opportunity in three very different types of location for providing low cost-low carbon heat energy for heating and cooling domestic and commercial properties. They explored large-scale networks to address the traditional terraced housing typical of many industrial towns and cities in the UK. They also provide solutions utilising energy from a range of industry waste heat sources, thus providing simultaneous opportunities for decarbonisation of those industries.

They indicate huge potential for water-based heat network systems supplying heating (and cooling) to homes and buildings using waste heat from a variety of industrial sources – a data centre, a metal foundry, a glassworks, and minewater, in each case local to the area of interest and including some proportion of social housing.

It was not possible to adopt all elements of the GreenSCIES approach in the study areas for testing replication. These cases lacked the combinations which offered the balance of heating and cooling demand required for 5G low-temperature ambient loops. There were fewer opportunities for 5G schemes amongst these sites, however, this does not preclude the potential. More extensive screening work is likely to deliver more options.

The techno-economic analysis results demonstrate the value of combining 3G and 4G heat networks with other renewable sources and with eV potential. As well as improving the economic return, these investments can promote the transformation of transport to renewable sources.

These are major projects with significant capital investment requirements. In all three areas the work has resulted in building knowledge and confidence across local government and industry in the range of local options.

In each case, there are large carbon savings compared to gas boilers, however, these savings are more marginal against individual ASHPs. By contrast, the financial performance is reasonable against ASHPs, but poor against gas boiler counterfactuals. Additional revenue from PV and from eV charging which also benefits from shared civil engineering in construction can significantly boost the economic returns for the projects. Even where the value from including eV charging is perceived relatively small, the opportunity is there for decarbonisation of transport in the area and thus improved air quality. High capital costs require government support and long-term investor confidence.

These studies also create opportunities for decarbonisation of industry. The projects support UK's Local

Authorities and Regions in meeting their strategic goals, providing mitigation against fuel poverty, education and skills development and show the potential to incorporate local legacy industries such as glassworks and mining. Economically, they help establish new revenue generation opportunities through heating sales, eV charging, and offer flexibility with integration of PV and windfarm electricity generation. In addition, they have the potential to stimulate new development using natural assets in the case of minewater and supporting local industries, in the case of the metal foundry and glassworks.

The technology is proven, capitalises on the high efficiency of water-sourced heat pumps, and reduces the dependence on the use of critical resources required increasingly in the electrical industry.

The financial results confirm that whilst the heat pump/heat network combination is one of the leading low carbon solutions, it is still challenging to make it economic at large scale due to the higher levies placed on electricity compared to gas, and grant funding may continue to be needed to assist local authorities with the necessary capital investment.

The financial performance is better where there are high housing densities and a low temperature network, possible where heating and cooling demands are in balance. All the examples summarised here utilise waste heat from industry and hence create opportunities for decarbonising, as well as making steps towards tackling these difficult industrial de-carbonising challenges. Given the global challenges of recent years with impacts on energy prices this is more urgent than ever. These projects can help to stimulate developments more widely in the UK while the academic work continues to reduce some of the barriers to success.

4.2. Recommendations

So far too little has been achieved with the decarbonisation of heating in the UK and it is critical to encourage local authorities to explore the integration of local industrial waste heat options as part of their way forward to net zero. They are in a unique position to identify and co-ordinate opportunities for Smart Local Energy Systems which integrate mobility, power and heat as part of on-going and future development plans and to encourage industry to cooperate. The larger the range of connections to SLES the greater the flexibility and potentially better system coefficient of performance, COP. There are major benefits working with local industry in terms of investment support and the potential to build on local knowledge and skills and to involve the local community.

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