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GreenSCIES – Green Smart Community Integrated Energy Systems – Integration with Data Centres

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What you will learn

- What the potential is for integrated heat networks to help decarbonise the energy grid
- How low carbon integrated whole energy systems are being developed to serve domestic and non-domestic buildings in London
- How 5th generation smart energy networks integrating heat, power and mobility and being used to exploit the potential of waste heat sources
- Some of the technological challenges for greening data centre energy use

Abstract

The GreenSCIES project aims to deliver low carbon, affordable energy through a novel smart energy system that connects flexible electricity demands such as heat pumps and electric vehicles to intermittent renewable energy sources such as solar power. This paper presents the results of the feasibility study of a 5th generation district mobility, power and heat network in the London Borough of Islington.

The smart network facilitates the transition to electric vehicles and vehicle-to-grid supply to make the most of intermittent renewable energy and ensure end-users always get the best tariff. Heating and cooling are provided by heat pumps in buildings connected to a local network, which integrates thermal energy storage and waste heat recovered from local datacentres. Artificial intelligence underpins the system optimisation and demand side response. Low carbon heating and cooling is achieved by sharing heat between buildings and by shifting the timing of their demand to off-peak cheaper electricity; this requires a sophisticated control system and thermal energy storage.

The feasibility study also worked with key stakeholders to understand the views of end-users and others in the supply chain. The role of key thermal energy providers such as Transport for London and Data Centres is fundamental. The preliminary results indicate that the smart network can deliver up to 25% reduction on energy bills and 80% CO_2 savings compared to a baseline scenario with gas boilers, chillers and grid electricity. As the electricity grid decarbonises further it is forecasted that the network will tend to net zero carbon before 2050. The GreenSCIES concept is suitable to be replicated throughout the country and has the potential to become a world-leading example.

1. Introduction to 5G Energy networks and GreenSCIES

1.1 Why 5G Energy Networks

In 2019 the UK Government passed legislation to deliver net zero carbon emissions by 2050. The new target will require a significant reduction compared to the previous target of at least 80% reduction from 1990 levels (GOV.UK, 2019a). Heating and transport are the highest carbon emitters representing 37% and 27% of the UK total emissions respectively (GOV.UK, 2018a). Achieving the ambitious net zero carbon target will require an integrated approach to the way we use and generate energy. The UK has significantly reduced the electrical grid carbon intensity, through the generation of clean renewable electricity mainly from wind and solar renewable energy systems. Decarbonising our electricity system presents many opportunities to improve the way we heat and cool our homes and businesses, power appliances and industry, and fuel our vehicles. Electric cars are becoming widely available, and electricity is also being used to power buses, vans and taxis. Low carbon heating and cooling using heat pumps offers significant environmental benefits over conventional heating or cooling systems such as gas boilers. They also enable the sharing of heat between different applications or between buildings in a neighbourhood. Sharing of heat in this way provides the opportunity to deliver extremely efficient, ultra-low carbon, bivalent cooling and heating between buildings. In addition, heat pumps also present the opportunity to utilise heat from secondary and renewable sources such as heat from datacentres, canals, railway tunnels, industrial processes and sewage systems, which would otherwise be wasted. The London Mayor's office has estimated that the total waste heat from secondary sources in London is in the order of 71 TWh/year, which is greater than the City total heat demand of 66 TWh/year in 2010 (GLA, 2014).

District heating networks (DHNs) have traditionally used a centralised energy centre where the heat generated is supplied to multiple buildings in a neighbourhood via a network of insulated pipes carrying either steam, hot or chilled water (GOV.UK, 2018b). Figure 1 illustrates the evolution of DHNs since the 1880's and it shows that there has been a significant reduction in temperature from 100°C (1st generation networks) to ambient temperature 15 to 25°C (5th generation networks) with a subsequent increase in system efficiency. DHNs up to the 3rd generation (80°C) were mainly powered by fossil fuels. Whereas, 4th generation networks can be seen to operate around 45 to 55°C and integrate photovoltaic (PV) electricity generation. The 5th generation (5G) concept is a recent development and comprises decentralised energy centres with heat pumps and hubs for PV generation, electric vehicles (EVs) and vehicle-to-grid (V2G) charging/storage alongside large scale batteries (Revesz et al., 2019). In V2G systems, electric vehicles with bi-directional charging can store electricity generated from renewable energy sources and discharge electricity back into the grid during peak times. A sophisticated artificial intelligence system switches the flexible system assets such as the heating or cooling in reaction to the electricity grid requirements and tariffs providing demand side response.

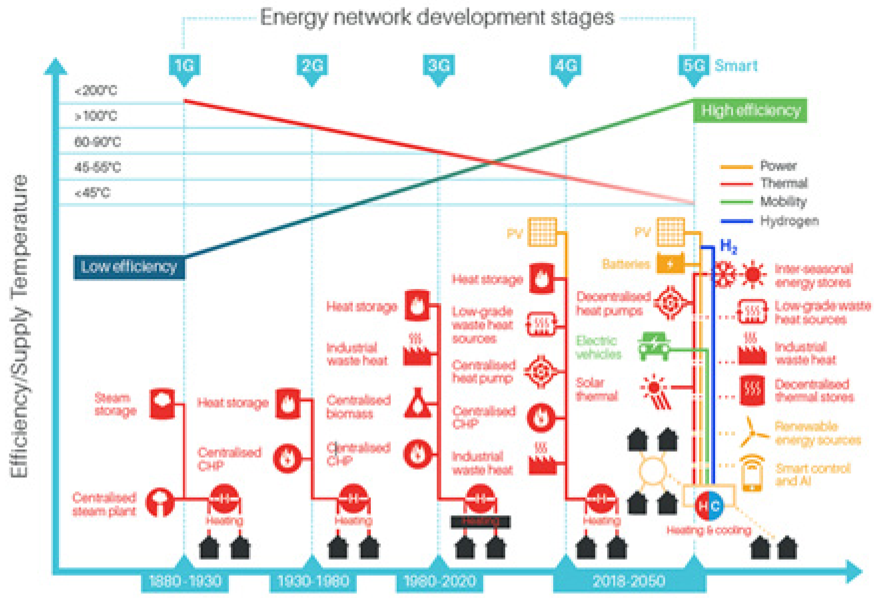

Figure 1: Energy network development stages published as a result of GreenSCIES (Revesz et al., 2019, adapted from Lund et al., 2014)

Innovative 5th generation energy networks have great potential to become the most efficient local energy systems of the future, but there are very few 5G networks worldwide (Buffa et al., 2019) and there is limited information, innovation, knowledge and skills around them. One of the biggest advantages of 5G ultra low temperature networks is the opportunity to capture waste heat from local sources. Datacentres are one source suited for connection to DHNs and these are large energy users, responsible for at least 1.5% of the electricity demand for the whole of the UK (Davies et al., 2016). Worldwide data centres account for 1% of global electricity consumption (Masanet et al., 2020). Electricity is used to power the information technology (IT) servers and for cooling the electronics, this creates a significant stream of waste heat that can be recovered and reused. Waste heat recovered from the data centre air at e.g. 30 to 40°C, can be used directly for heating, while lower temperature heat recovered from chilled water can be upgraded using heat pumps. Figure 2 compares the recent temperature evolution of DHNs with the temperature of the IT coolant used to cool the servers over the same period of time. There is a convergence in temperatures that makes heat recovery from datacentres extremely feasible. Although the electronics/chips within servers are at around 80 to 90°C, it would not be practical to have a district heating scheme connected directly to IT equipment due to risks and issues regarding interfaces of responsibility. Liquid cooling of IT equipment is today still an emerging technology expected to grow significantly within the next decades due to issues of chip cooling densities. The cooling liquid is around 40 to 50°C which will make heat recovery to district heating schemes even more feasible and simple.

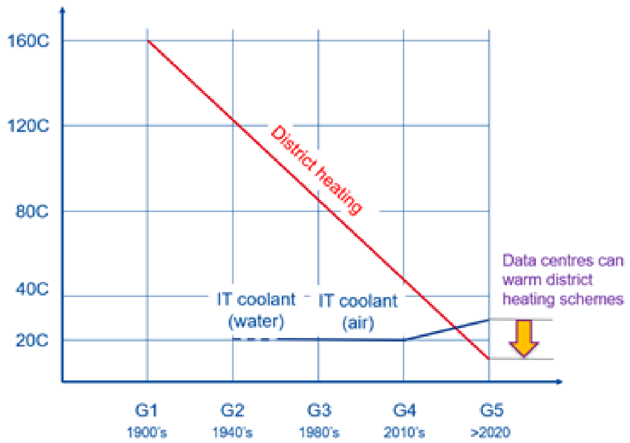

Figure 2: District Heating Networks temperature evolution over time and corresponding datacentres IT coolant temperature

1.2 The GreenSCIES concept

The GreenSCIES low-carbon integrated energy system is being developed to serve more than 10,000 residents, 3,500 homes, and 10 very large non-domestic buildings in the London Borough of Islington, which is the most densely populated borough in the UK. The concept illustrated in Figure 3, shows a smart local 5G energy network that integrates heat, power and mobility. The Islington network will recover waste heat from underground ventilation shafts and from local data centres. Local power will be generated with solar photovoltaics and low carbon mobility is provided by electric vehicles.

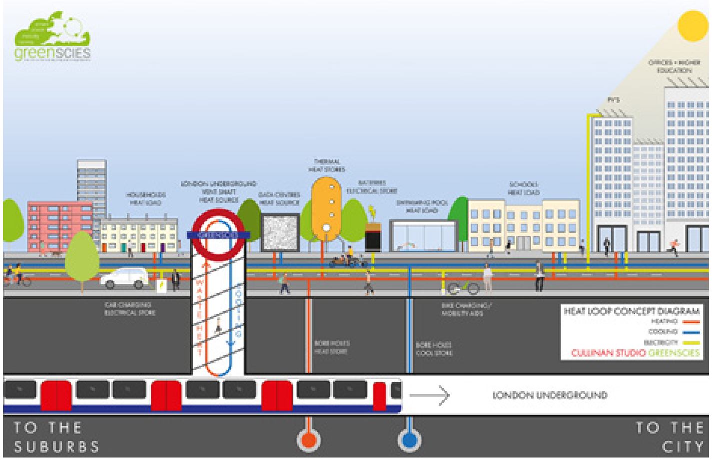

Figure 3: GreenSCIES concept design

This paper describes the design approach used to develop the GreenSCIES concept, how the scheme was modelled and results, and specifically how data centres can be configured to integrate within the scheme, as well as the benefits and risks associated with their integration.

2. The GreenSCIES Design

This section describes the scheme investigated in more detail, the modelling carried out and the results achieved.

2.1 The Design approach

In developing the smart network the design approach for the study is summarised below:

1. Identification of physical boundaries in the area e.g. major roads, railways;
2. Identification of initial energy network clusters with high energy density;
3. Mapping of energy sources and demands;
4. Identification of low carbon technologies suitable in the locality;
5. Definition of flexible smart control strategies to integrate the whole scheme;
6. Development of network outline designs;
7. Development of the CAPEX models;
8. Develop techno-economic models and modelling scenarios;
9. Using the techno-economic model to carry out sensitivity analysis.

Using the above approach, a number of schemes were developed for detailed modelling. Figure 4 shows one scheme that includes a 2 km network route connecting sixteen energy centres that supply the energy demand to 19 connected buildings including two data centres across the network. The scheme also connects PV and electric vehicles. The decentralised energy centres are effectively a 'micro-grid' flexing the heat pumps, PV and electric vehicles batteries in function of the electricity grid demand and tariffs. Figure 5 illustrates the concept design, it shows the heat network and how it connects to energy centres and the two-local data centres. The scheme also includes boreholes to supplement and balance the network as required.

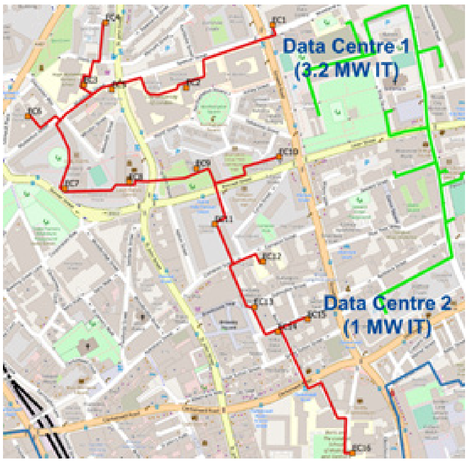

Figure 4: 5G network route

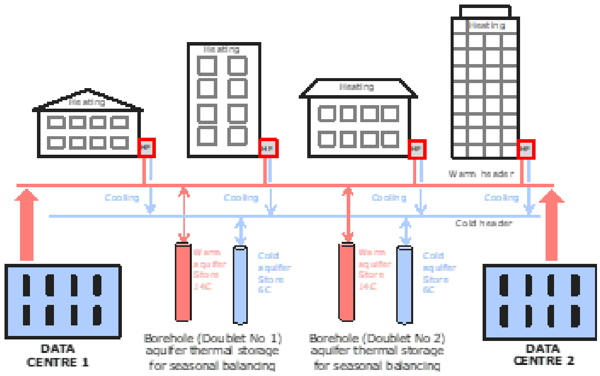

Figure 5: Detail of concept design with data centres

2.2 Techno-economic model

Techno-economic modelling was used to determine the operational expenditure of the proposed 5G network, and the carbon savings were estimated based on operational and capital expenditure (OPEX and CAPEX). EnergyPRO (EMD, 2014) was the commercial software modelling tool employed. The modelling tool uses half hourly supply/demand data alongside complex electricity tariffs, control strategies and demand side management (DSM). EnergyPro can optimize the operation of any combination of energy supply and demand in accordance to all preconditions such as weather conditions, technical properties of the different units, maintenance costs, fuel prices, taxes, subsidies, etc. A number of scenarios were modelled to test the financial and carbon reduction impact for each of the key technologies identified i.e. solar PV, heat pumps, thermal storage, V2G, batteries, etc. These were compared against a baseline case i.e. gas boilers and grid electricity.

Key financial assumptions:

- 2017 UK spot market electricity import and export prices downloaded from Elexon
- Electricity Import Price Levies (RO, FITs, CfD etc.) for 2019
- Gas price £25.2/MWh
- Climate Change Levy rates for 2020
- UK Power Networks DUoS Red Amber and Green tariff structure and prices for London for 2019
- Triads modelled as 20 x 2hr Triad warning periods
- 25% reduction in heating and cooling sale price (compared to existing gas boilers)

Key technical assumptions:

- Base case of existing gas fired boilers
- Carbon factors based on diminishing figures using predicted figures published by BEIS (GOV.UK, 2019b)
- Existing gas boilers will provide backup only and therefore avoiding the use of natural gas
- Heat pumps operate ~4,500 full load hours per year and supply 75/55°C to the connected buildings
- 100m^3/MW thermal storage – to smooth heat pump load and avoid expensive electricity tariffs
- All options are based on electricity connections 'behind the existing building meter'
- Two data centres act as a year-round constant heat source (cooling load)

Table 1 summarises the techno-economic modelling scenarios (Revesz et al. 2019)

Table 1: Techno-economic modelling scenarios

	Scenario	Description
1	Limitless aquifer	Assumes that the aquifer heat replenishes itself and can only be used as an open system
2	Aquifer thermal energy storage (ATES)	Assumes that the aquifer heat cannot replenish itself and therefore it can be used for seasonal or inter seasonal thermal storage
3	ATES and solar PV	Solar PV is added and operates behind the meter alongside each heat pump
4	ATES and V2G	V2G is added at each energy centre
5	ATES, solar PV and V2G	In addition to ATES and V2G, solar PV is added at each energy centre. These operate behind the meter alongside the heat pumps
6	ATES, solar PV, V2G and bespoke batteries	ATES, solar PV, V2G in each energy centre. In addition to V2G bespoke batteries are added. Both the PV and the batteries operate behind the meter alongside the heat pumps

2.3 Techno-economic model results

Figure 6 shows the estimated difference in annual operational surplus compared to the baseline (gas boilers) for all the scenarios modelled. The best performing scenarios include ATES and solar PV, this is because the PV generates additional savings by displacing grid electricity/increasing export revenue. V2G adds a cost of £1000 per car, because of the very limited number of cars assumed to be available the absolute improvement in OPEX is relatively small, this is expected to change in the future as EVs became the norm. Batteries and V2G are able to store electricity so that expensive periods can be avoided. Figure 7 shows the network estimated CO_2 savings averaged over a 25-year period.

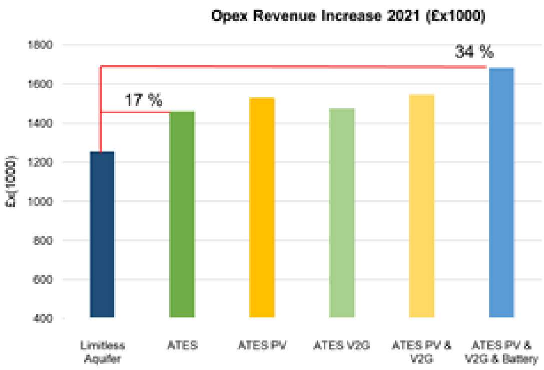

Figure 6: Opex revenue increase for each technology

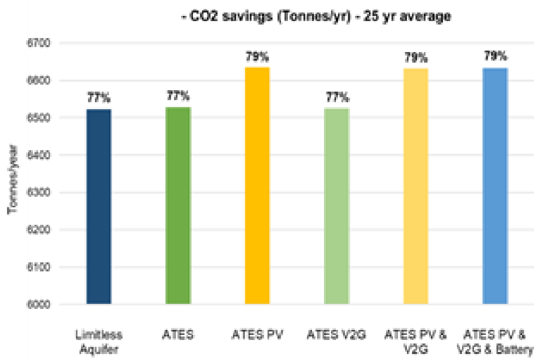

Figure 7: CO_2 savings over a 25-year period

The 5G network can provide CO_2 savings of approximately 80% over the baseline case (with gas boilers, chillers and grid electricity). The greatest savings are achieved with ATES and solar PV. V2G batteries and stationary batteries result in lower savings due to losses associated with charging and discharging. As V2G and battery technology evolves and more renewable energy is added to the electricity grid, the network carbon savings will tend to increase to 100%, contributing to achieving the net zero carbon target by 2050.

3. Heat recovery from data centres

This section describes the detail as to how GreenSCIES might best connect to a data centre and the associated benefits with connection and the risks/challenges.

3.1 Connection of the Data Centre to GreenSCIES

Data centres mainly use air to cool IT equipment, which is cooled using direct expansion, chilled water, or direct or indirect air systems. Free cooling can be applied to all of these systems, and in many cases do not need refrigeration (Tozer and Flucker, 2012). Distributing the cooling energy in built up areas in cities normally requires chilled water systems, which is the case for the GreenSCIES data centres network in Islington. Therefore, the heat recovery is done with chilled water. Figure 8 shows a schematic of the heat flows between the data centre and the energy centre within the district heating network.

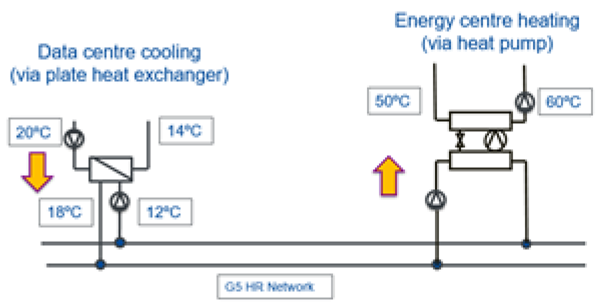

Figure 8: Schematic of the heat flows between the data centre and district heating network

In Figure 8 the schematic indicates a data centre heat exchanger which can be connected to either the primary or secondary chilled water system. Figure 9 and 10 show a schematic of the data centres primary and secondary chilled water heat recovery systems respectively.

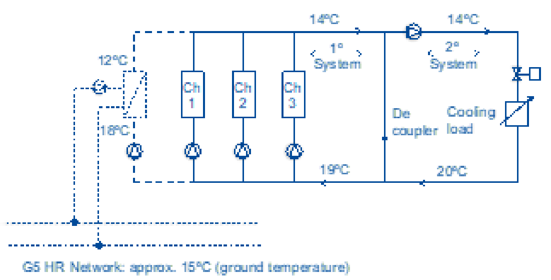

Figure 9: Primary chiller heat recovery system

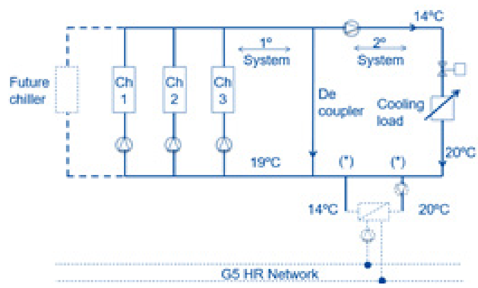

Figure 10: Secondary chiller heat recovery system

In the primary chiller system, the heat recovery potential is a fraction of the total cooling load i.e. number of chillers and heat recovery units operating. For a primary system with four chillers and one heat recovery unit the total heat recovery potential is one quarter of the total load. In the secondary chiller system, the connection to the 5G network requires large connections to the secondary chiller pipework and it is more expensive than a simpler connection to the primary chiller system. The advantage of connecting the 5G network to the secondary chiller system is that the heat recovery potential is the full load and the heat recovery temperatures are slightly higher, increasing the heat recovery potential of the system.

Another very important consideration is that if the temperature of the district heating network should increase even slightly above the temperature set points to satisfy the data centre chilled water supply temperature, a primary chilled water heat recovery system would have to disconnect, whereas for a secondary chilled water heat recovery system this would not be necessary. This makes the secondary chilled water heat recovery system more flexible and reliable.

3.2 Establishing the benefits

Based on the existing data centres a scenario was analysed to establish the difference between recovering heat from the primary or secondary chilled water systems. It was assumed that the primary system uses three chillers as heat recovering units at 85% load of 1 MW. For the secondary system it was assumed that the total secondary chilled water load was 4.2 MW. As can be seen in Figure 11 data centres have a constant cooling load that can supply most of the district heating network demand, except for peak winter periods where existing boilers and aquifer thermal storage are required for seasonal balancing.

Figure 11 shows the potential heat recovery from data centres to the 5G network from primary and secondary chilled water systems.

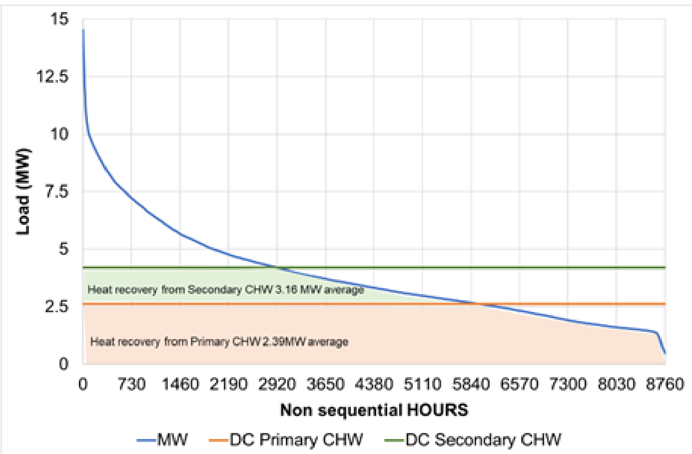

Figure 11: Heat recovery from data centres to the 5G network

Assuming a seasonal coefficient of performance (COP) for the chillers of 4 (chilled water supply at 13°C) and the electric energy cost of £0.10/kWh the energy recovered from the primary/secondary chilled water systems was 21GWh/year – 28GWh/year representing savings for the data centres of £520k/year – £690k/year. Furthermore, if all the cooling energy could be dissipated by the aquifer, this would equate to 37GWh/year with savings of £920k/year.

In addition to the financial benefits, data centres will have the benefit of improving their energy metrics (The Green Grid). The Power Utilisation Effectiveness (PUE), which is the ratio of energy used by the data centre over a year in relation to the IT energy, is improved by reducing compressor energy due to heat dissipated to the district heating network. Legacy data centres had values of PUE over 2, typical data centres are today around 1.6, and new designs utilising extensive free cooling are around 1.2. There will be similar improvement with the Carbon Utilisation Effectiveness (CUE). Many legacy data centres are improving their efficiency (PUE) by improving air management in the data hall (to reduce air recirculation and air bypass), raising the temperature set points to improve the refrigeration COP and increase free cooling hours, introducing variable frequency drives on fans and pumps and introducing free cooling technologies (Tozer and Flucker, 2015). In the case of GreenSCIES the free cooling is substituted by connecting to the district heating system.

Of particular interest for this project will be the Energy Reutilization Effectiveness (ERE) which is a similar metric to PUE but considers the amount of energy that is reutilised outside of the data centre. With no energy reutilisation (like most data centres) the ERE is the same as the PUE, but if all the energy of the data centre was reutilised externally, the ERE could in theory be zero. A scheme such as GreenSCIES would allow the impact on ERE to be very significant.

The overall 5G smart network environmental impact includes improved air quality and a pathway towards a zero-carbon sustainable future. There is also significant social impact in terms of reducing fuel poverty, supporting individual energy use reduction and increased employment and training associated with the deployment of 5G networks. Also, community engagement during the network design benefits both end-users and the data centres, which are keen to minimise their environmental impact on the local community.

3.3 Challenges, risks and barriers for adoption of 5G energy networks integrated with data centres

Smart local energy systems have a wide range of stakeholders, including end users, local authorities, energy suppliers, prosumers, asset owners, consultancy and developers among others. Stakeholder mapping was undertaken in the London Borough of Islington and was followed by one-to-one interviews, focus groups and two workshops to identify key challenges and opportunities for the GreenSCIES smart energy network. Each of the stakeholder groups have different priorities, however common challenges/opportunities include:

- Reliability – energy outages (planned and unplanned), resilience, convenience, service design, accessibility, comfort, data protection and cyber security
- Operational efficiency – heat system losses, demand risk
- Accountability – transparency, who owns the company, supply, individual control, trust in provider
- Disruption – space taken in people's homes, privacy, special connection
- Cost – financing of the network

This section identifies the risks and challenges for heat recovery from data centres. Data centres are particularly averse to risk and their business focus is zero downtime. Hence, they have strong focus on minimising human error (management, operations, handover and commissioning) and on the mechanical and electrical (M&E) infrastructure reliability and topology (Uptime Institute). It is quite common for the type of data centres used for collocation of services (as in GreenSCIES) to be concurrently maintainable whereby any plant or distribution path of the M&E can be taken out of service without interruption of IT systems, and also fault tolerant to most failures.

Connection to DHNs will require designing out any heat recovery instances that could produce datacentre downtime. Examples of those potential instances are loss of DHN flow, high temperature in the network leading to partial cooling of the data centre, control interface issues between the 5G network and the data centre, operational human errors from the 5G heat recovery systems, etc. Risk analysis would have to be carried out during the design, commissioning and operating phases to address any potential issues.

Overall, there is still a lack of economic and technical knowledge on the impact of connecting data centres to DHNs. The business model on selling waste heat to 5G networks needs to be further developed to exploit this secondary heat source to its full potential.

Conclusions and next steps

The paper has introduced the concept of 5th generation smart energy networks that integrate heat, power and mobility. This low temperature network allows exploitation of waste heat sources, sharing of heating and cooling between buildings, smart control and flexible access to renewable energy, storage and low carbon transport. This is a complex integrated low carbon energy system with technical and non-technical challenges and opportunities. A design methodology has been presented to implement the whole energy system, addressing the technical challenges identified during the feasibility study. Non-technical barriers have been identified through a comprehensive stakeholder engagement.

GreenSCIES offers a low carbon integrated whole energy system serving more than 10,000 residents, 3,500 homes, and 10 very large non-domestic buildings in the London Borough of Islington. The robust investigation of many heat, mobility and power scenarios has delivered an 80% reduction in carbon emissions and addressed fuel poverty for a significant number of residents by reducing energy bills by up to 25%. As the electricity grid decarbonises further, the carbon savings of the network will tend to 100% achieving the net zero carbon goal.

Whilst aquifer thermal energy storage can be used for chilled water systems cooling (typically chilled water at 12°/6°C), data centres have the advantage of operating higher chilled water temperatures over 12°C (up to 20°C) which provides the flexibility to provide more cooling energy. The feasibility of heat recovery from data centres will be further enhanced with the advent of liquid cooling of IT equipment which will rapidly expand in the data centre industry. The district heating scheme is an optional resource for data centres, which is in their best interest to use. However, this will be under the control of data centres to minimise risk and will always have chillers as backup. In principle, the heat recovery is more beneficial from the secondary circuit than from the primary chilled water system, as all the data centre heat can be utilised. For data centres heat recovery in this way has the advantage of reducing their PUE which directly impacts their OPEX (operating expenditure). A scheme such as this will have a very high impact on the Energy Reutilisation Effectiveness, a well-established data centre metric (Green Grid), and very appropriate for branding.

Following the successful feasibility study, the GreenSCIES consortium has been awarded funding from Innovate UK to carry out the next phase of the project. GreenSCIES 2 started in March 2020 and it will deliver the detailed design for the integrated smart local energy network in the London borough of Islington. The overarching goal of the project is to deliver a validated, "shovel-ready" technical design with commercial agreements and funding in place for demonstration, and a plan for national and international replication.

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Catarina is a Senior Research Fellow at London South Bank University (LSBU) with 13 years' experience working on funded research projects in the areas of food, refrigeration and thermal storage materials. She is the Project Manager for GreenSCIES a large consortium project on local smart energy networks that combine heat, power and mobility. Catarina has worked simultaneously in the industry and academia through an industrial CASE award PhD and two knowledge transfer partnerships between LSBU and Adande Refrigeration Ltd. She won an Innovate UK business leader of the Future award in 2015 and managed Adande's Engineering department for 3 years leading the development of novel award-winning energy efficient products and certification to international markets. She has 6 years' experience writing EN and ISO standards. Catarina is the President of the International Institute of Refrigeration (IIR) CaRe (Careers in Refrigeration) working group that aims to make refrigeration more visible to the general public and inspire a young generation to join this field. She regularly organises international workshops for CaRe and it is a member of the Institute of Refrigeration steering group on Women in Refrigeration, Air-Conditioning and Heat Pumps.

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One of the world's most preeminent data centre cooling experts

Robert's wide and extended experience in the Mission Critical Facilities industry working on design, reliability, energy efficiency and commissioning together with his academic achievements have provided him with the theoretical and practical tools to develop innovative solutions. These include free cooling designs, commissioning strategies, air management metrics and data centre energy assessment tools. He is the author of over 60 papers on reliability and energy efficiency and refrigeration, has authored several patents on data centre free cooling designs, has written many white papers (in English and Spanish) and speaks regularly at Data Centre Dynamics conferences. He was awarded the prize for Outstanding Contribution to Industry at the inaugural DCD LATAM awards. He is a Visiting Professor at London South Bank University and has participated in many technical committees (ASHRAE, CIBSE, BREEAM, The Green Grid, and European Code of Conduct).

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Invitation to join this presentation

The IOR invites you to join this webinar meeting for free by registering to reserve your place to attend via: https://register.gotowebinar.com/register/1630280376006103308.

The presentation starts at 4:00pm on Thursday 2 April 2020 – you can listen live or we can send you a recording afterwards.