C40 Cities

24/7 Carbon-Free Energy for London

Implementation Roadmap

Final Report

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Glossary

24/7 Carbon-Free Energy (24/7 CFE): an approach whereby every kilowatt-hour of electricity demand is matched with carbon-free electricity supply for every hour of the day, every day of the week.

24/7 Carbon-Free Energy Score (24/7 CFE Score): the average percentage of electricity consumption matched to carbon-free supply on an hourly basis over a year.

Carbon Flexing: flexing electricity demand based on average carbon intensity of the grid electricity mix.

Curtailment: reduction in energy production in order to balance with energy demand.

Demand-side flexibility (DSF): the portion of energy demand that could be increased, decreased or shifted in a specific period of time.

Demand-side management (DSM): communication and control technologies used to shift energy demand throughout the day.

Demand-side response (DSR): responding to demand-side management signals through increasing, decreasing or shifting energy use.

Distribution System Operators (DSOs): body responsible for distributing energy to consumers, who procure flexibility to manage local electricity network constraints.

Electricity System Operator (ESO): manage the movement of electricity within the energy system to maintain supply across Great Britain.

Future System Operator (FSO): proposed body who will act as independent system operator responsible for coordinating and ensuring strategic planning across the sector.

L**ocation-based mechanism:** carbon accounting method which reflects the average emissions intensity of grids on which energy consumption occurs, using average grid factors.

Market-based mechanism: carbon accounting method which reflects emissions from electricity that companies have agreed to procure through contractual instruments (e.g. through an energy certificate).

Power Purchase Agreement (PPA): long-term contract between an electricity generator and a consumer.

Scope 2 Accounting: calculation of indirect greenhouse gas emissions associated with an organisation (e.g. purchase or use of electricity).

1. Executive Summary

In the UK, the grid is decarbonising – but a fully clean grid at least cost is at risk because of a lack flexibility. Recently, the lifespan of the UK's coal plants was extended by two years to relieve concerns over energy security and coal plants were fired up to potentially provide supply as a cold snap hit.[1] [2] The UK needs greater demand-side flexibility.

London – and other cities across the UK – can provide this much-needed flexibility. By coordinating millions of consumer energy asset deployments, they can create significant flexibility capacity which can be called on for meeting energy system needs that would otherwise require gas or coal fired power plants. This capacity can replace sources of flexibility which are currently provided by fossil fuels - 96% of local flexibility needs in London in 2021 were met with gas.[3] And in doing this, London and other cities can reach their Net Zero targets faster, by relieving the network constraints that prevent faster deployment of the technologies necessary for decarbonisation.

Yet there are currently not enough incentives to enable London and other cities to unlock the scale of demand-side flexibility needed. With the right system coordination, using carbon as an incentive can provide a significant opportunity for London and the UK, to harness the flexibility potential that resides within households, businesses and infrastructure. By tapping into the ambition and commitments to reduce carbon and meet Net Zero targets, grid decarbonisation will happen sooner and London will meet its Net Zero 2030 target faster.

To do this, the Greater London Authority (GLA) has the opportunity to lead a 24/7 Carbon-Free Energy approach across London and play an essential coordinating role with policy-makers, regulators, private sector and other cities and regions to enable a locally led approach to create systems scale change.

24/7 Carbon-Free Energy (CFE) means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources at every hour of every day, everywhere.

A 24/7 CFE approach can enable the practice of 'carbon flexing', an approach matching of demand to carbon intensity of electricity, daily, hourly or moment to moment. This approach will not only create the needed flexibility for decarbonisation, but will also itself create carbon savings by maximising use of clean energy.[4] To assess the potential of this approach, the C40 and Greater London Authority (GLA), supported by Arup, Energy Unlocked and Quantenergy, have embarked on a critical project to explore how this 24/7 CFE could help unlock the city's demand side flexibility to accelerate electricity decarbonisation – within London and beyond. Key conclusions from this project highlighted:

- **Better decision making**: The hourly method of the 24/7 CFE approach can help asset owners and operators: understand their buildings better and make improved operational and investment decisions;
- **Carbon reduction:** For one building, it was found that **20–30%** of its electricity usage emissions could be avoided today through flexing its CHP operation to carbon signals;
- **Capacity:** Between **4–8 GW** of demand-side flexibility capacity could exist across London by 2030 – 2.5x the capacity of the major upcoming Hinkley Point C nuclear plant;

[1] The Guardian (2023) Coal power stations fired up and customers paid to cut energy use in the UK cold snap (available online)
[2] The Guardian (2023) UK Coal-burning power facility to stay open two years longer than planned (available online)
[3] UKPN (2022) Flexibility Services Procurement Report (available online) Though 2022 early auction results show a much better mix with low carbon sources of flexibility, the previously contracted gas will remain in the mix for years to come.
[4] Energy Unlocked (2021) The Hidden Carbon Economy (available online)

- **Decarbonisation:** London can avoid up to **9%** of its 2030 grid electricity emissions through citywide demand-side carbon flexing of its demand-side capacity;
- **Providing system needs**: **80%** of major carbon-driven demand turn-down events are expected to occur during the typical electricity network peak hours which aligning with network and system needs;
- **Technology and building type priorities:** Domestic buildings offer the most flex opportunities of all building types – representing 64% of the total carbon reduction potential in our most ambitious scenario, mainly from distributed thermal storage (heat pumps for hot water tanks as well as heating). 17% of the opportunity comes from office buildings.

The potential of a 24/7 CFE approach across London is significant. Yet the project also demonstrated that there were potential unintended consequences of this approach if pursued in an uncoordinated way by assets across the city. If a critical mass of buildings and technologies flexed to the average mix of generation supplying the grid, there is a risk that significant loads could turn up unexpectedly to chase a particular low carbon signal requiring that high-carbon supply (e.g. a gas plant) be turned on to meet the increased demand. Furthermore, instability could occur in the system if this sudden chasing of signals were not coordinated to ensure sufficient provision of power at these times. To harness the potential of 24/7 CFE across London, and to avoid possible unintended consequences, a coordinated approach is needed. Concrete steps to shape London's net zero energy system' will be required.

- **Policy-makers and Regulators:** Market design to drive incentives, avoid unintended consequences, and provide the right frameworks to enable data use will be essential to scale 24/7 Carbon-Free Energy. A regional role for energy planning should be included alongisde the role of the Future Systems Operator, carbon reporting frameworks to encourage zero carbon flexibility provision must be rolled out, and integration of electrification and flexibility within national retrofit policies must be prioritised.

- **Voluntary Standards and Commitments Bodies:** The standards and protocols governing how the private sector can claim Net Zero and other ambitious climate targets are critical in driving action on 24/7 Carbon-Free Energy. These should be updated to better incentivise a 24/7 CFE approach, including updating the greenhouse gas protocol to focus on actual use of clean energy, incorporating 24/7 into major commitments and standards like net zero green building standards.

- **Data and Technology Innovators:** Better data and innovation is needed to incorporate 24/7 CFE into business models. The provision of hourly guarantees of origin can in particular drive new business models around hourly time matching. CFE as a service, carbon flexing as a service, offsets incorporating flexibility, true green CFE energy tariffs, aggregation models and carbon flexing apps can all play an essential role in enabling London, private sector and policy-makers and regulators to accelerate deployment of 24/7 CFE approaches.

- **Greater London Authority:** London has an essential role to play in ensuring that the application of 24/7 Carbon Free within London is coordinated to maximise impact within London but also to harness the potential and avoid unintended consequences at a systems level. London's role should focus on engaging and driving leadership with the 'M10' – the 10 Mayoral Combined Authorities – as well as other regions, city-wide tracking, modelling and data coordination, and working with policy-makers to ensure a regional role in energy planning. London also must lead by example – spearheading GLA Group pilots and 24/7 CFE roll-out across GLA owned assets, incorporating electrification, flexibility enabled technologies and carbon flexing practices in its funding and financing programmes such as the Mayors Energy Efficiency Fund, and using the power of the London Plan to require and incentivise 24/7 CFE enabled technologies and practices. These actions also demonstrate how other cities in the UK and within the C40 Cities network around the world can lead action on decarbonising the grid.

Once all of these actions are in place, a 24/7 Carbon Free future will be realised.

2. The Vision: Achieving Flexibility through a 24/7 Carbon-Free Energy Approach across London

In the UK, the grid is decarbonising – but a fully clean grid at least cost is at risk because of a lack of incentives for the deployment of demand-side flexibility. London, other regional authorities and cities have a crucial coordination role in the creation of this flexibility and ultimately the transition away from fossil fuel-based energy. By coordinating millions of consumer energy asset deployments, they can create significant flexible capacity, which can be called on for meeting energy system needs that would otherwise require gas or coal fired power plants. Accelerating flexibility by deploying carbon as the incentive – a 24/7 Carbon-Free Energy (CFE) Approach - could support overall grid decarbonisation and enable London to come closer to meeting its ambitious Net Zero target by 2030.

2.1 Net Zero at Risk

The UK government has committed to a fully decarbonised electricity system by 2035, and grid decarbonisation is essential to reach Net Zero[5]. Yet recently, the lifespan of the UK's coal plants was extended by two years to relieve concerns over energy security due to the energy crisis, and over the winter of 2023 the coal plants were fired up to potentially provide supply as a cold snap hit and renewable supply was lighter than usual.[6] [7] In a renewable-based electricity system, the ability to balance supply and demand gaps because of variability without needing 'always on' power from power plants will be essential in order to achieve Net Zero. Yet this is not happening sufficiently today.

Furthermore, with electrification of vehicles and heating systems requiring significant increases to buildings' electricity demands, limitations on the capacity of networks also pose a constraint to Net Zero – significantly hindering roll-out of essential decarbonisation technologies such as EV chargers and heat pumps.[8] Significant investments in network capacity come at a high cost and disruption to the economy, directing funds away from investment in other aspects of net zero which could be accelerated. If these issues are not solved, then not only will fossil fuel plants need to stay online longer, but we will roll out new power plants and grid reinforcements costing £16.7 bn annually out to 2050 that could be avoided.[9] That figure does not include the enormous embodied carbon costs of new clean power plants, such as nuclear, which may still need to be built– the Hinkley Point C would result in the generation of 7 million tonnes CO2 eq. in construction (including upstream materials).[10]

2.2 The Essential Role of Demand side Flexibility

Ultimately to reach Net Zero at least cost, we need supply and demand-side flexibility to balance the increasingly complex decarbonising grid. Demand-side flexibility is projected to play an important role in enabling this transition both locally in London and nationally, with over 100GW expected in 2050, up from 6 GW today.[11]

As renewable generation has higher variability than fossil fuel sources, the grid will increasingly experience fluctuation between over and undersupply and the need for curtailment as it decarbonises. Enhancing demand flexibility by using demand-side management (through communication and control technologies to shift energy demand throughout the day) will help to balance supply-demand gaps, optimising the use of renewables to reduce curtailment and improve security of supply. Gas and coal power plants have been a reliable source

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[5] UK Government (2021) Plans unveiled to decarbonise UK power system 2035 (available online)
[6] The Guardian (2023) UK efforts to deal with energy crisis 'raise risk of missing net zero target' (Available online)
[7] The Guardian (2023) Coal power stations fired up and customers paid to cut energy use in the UK cold snap (available online)
[8] ESO (2022) Network Options Assessment (NOA) (available online)
[9] Carbon Trust (2021) Flexibility in Great Britain (available online)
[10] NNB Generation Company HPC Limited (2021) Life cycle carbon and environmental impact analysis of electricity from Hinkley Point C nuclear power plant development (available online)
[11] ESO (2023) Flexibility (available online)

of flexibility (in 2021 96% of local flexibility needs in London were met with gas) with their ability to turn up and down in response to demand peaks and troughs.[12] Having more predictability and control over changes on the demand side will be essential to removing this dependency on gas flexibility and enable renewables and storage to provide the same service. The main barriers to achieving the target of a 100% renewable grid by 2035 are the mobilisation of investment in the necessary low carbon generation, storage and networks, followed by the efficient operation of the system, including the need for a much more dynamic demand-side to balance the supply variability.

London Net Zero: The Accelerated Green Pathway

In 2022, the Mayor of London selected a preferred pathway for London to reach net zero by 2030. Named the 'Accelerated Green' pathway, it prescribes highly ambitious deployment targets for interventions and electrified technologies. By 2030, the pathway targets:

- 2.2 million heat pumps installed
- 1.5 GW of rooftop solar PV deployed
- 460,000 domestic connections to district heat networks
- Reductions to the total heat demand of London's buildings of almost 40% through building fabric improvements

2.3 The Potential for London as a Power Plant Equivalent

London has an ambitious 2030 Net Zero target, twenty years ahead of the UK's nationally binding target – and it needs electrification and the deployment of essential electrified technologies to achieve this.[13]

With its ambition to roll out these technologies, it not only provides a decarbonisation pathway – but it also creates an enormous potential to provide the demand side flexibility which is important for facilitating UK wide renewables deployment, and ultimately decarbonisation. These technologies, combined with smart systems, can actually behave as a power plant would, providing the flexibility that is needed to keep the lights on and avoid the high carbon 'always on' power from plants.

And in so doing, it can reduce costs and disruption within the city. As London seeks to rapidly electrify heating and transport, the capacity of electricity networks will also experience increasing pressure. Demand-side flexibility will be one of London's key levers for managing constraints on these networks, and it will also reduce work and disruption to London's economy and facilitate the increased deployment of decarbonised heating and transport technologies. Flexing, and having more control of where flexibility capacity is installed, will also enable London to avoid mass disruption driven by digging up roads to install network capacity – enabling the city to adhere to its 'Dig Once' approach[14]. If London could 'flex' demand, it could reduce energy system costs in London directly by £500m annually with wider system benefits of £900m/year, which lower energy costs for everyone.[15]

Because London is 23% of the UK's total energy demand[16], starting in London is extremely important, but coordinating with other regions to ensure this local role is strengthened will be essential.

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[12] UK Power Networks (2022) Flexibility Services Procurement Report (Available online)
[13] Greater London Authority (2022) London Net Zero 2030: An Updated Pathway (available online)
[14] Mayor of London (2023) The Dig Once approach (Available online)
[15] Carbon Trust (2021) Flexibility in Great Britain (Available online)
[16] According to the Digest of UK Energy Statistics 2021, published by the UK Department for Business, Energy and Industrial Strategy (BEIS), London's total energy consumption for 2019 was approximately 42.5 TWh. The UK's total energy consumption for 2019, according to the same source, was approximately 184.2

Accelerating Flexibility and Decarbonisation Through a 24/7 Carbon-Free Energy Approach

Demand side flexibility is not happening at the scale it needs to, but an approach which incentivises flexibility by linking its impact to carbon could provide the acceleration needed. If this approach were applied in London and then scaled up across the country - not only would London achieve Net Zero faster, but so would the UK.

24/7 Carbon-Free Energy is a measurement approach which enables tracking and measuring the grid decarbonisation within London and the barriers and opportunities. The approach is that every kilowatt-hour of electricity demand should be matched with carbon-free electricity supply for every hour of the day, every day of the week, and it has been championed by companies with ambitious goals for energy procurement to go beyond matching annual electricity consumption to annual renewable production.[17] The approach measures performance, and progress towards 24/7 CFE, through measuring a 'CFE Score', the average percentage of electricity consumption matched to carbon-free supply on an hourly basis over a year[18].

24/7 Carbon-Free Energy means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources at every hour of every day, everywhere.

The concept's origins lie in the private sector's ambition to play a role in decarbonising, the recognition that they have tremendous power to accelerate the renewables transition through their own actions, and increasing pressure from investors and the climate movement to show more 'additionality' in their approach to renewables. Developed and championed by Google, the 24/7 CFE approach enables entities to move away from simply procuring renewables – through green tariffs or Power Purchase Agreements (PPAs) – towards operating carbon-free[19]. This approach not only enables them to demonstrate more transparency in their actual carbon use but provides more incentives to undertake demand side actions compared to achieving renewables targets through green tariffs or non-additional Power Purchase Agreement (PPAs)[20].

A 24/7 CFE approach can also enable the practice of 'carbon flexing', an approach of matching demand to carbon intensity of electricity, daily, hourly or moment to moment.[21] Demand side flexibility linked to a carbon signal rather than a price signal can leverage individual entities' interest in advancing carbon accounting, and contributes to a wider systems goal, ensuring that flexibility provision is zero carbon (compared to gas fired power flexibility).

At a systems level, if a 24/7 CFE approach, with carbon flexing, is scaled up, it would improve the utilisation of renewables, moving demand to times when renewables are more readily available and therefore reducing renewable curtailment – deliberately capping renewable production because of our inability to use it at that moment in time. This flexibility linked to a carbon signal could align with reducing peak demand and thereby enable renewables to provide more of the overall supply. Overall, this can reduce capacity constraints on the grid infrastructure and therefore delaying the requirements of capacity upgrades, increasing the uptake of electrification technologies by using carbon as an incentive to create flex-enabled buildings.

London's Powers to Accelerate 24/7 CFE

In fact, our research demonstrates that if a 24/7 Carbon-Free Energy approach was deployed across London, it could create the scale of flexible capacity equivalent to 2.5 Hinkley Point C Power Plants. Imagine, London as a cluster of buildings and vehicles that together behave as a power plant would. And in doing this, our modelling demonstrates that it could achieve up to a 9% annual reduction in its overall city emissions.

And importantly, the Greater London Authority has the powers to do this, in line with the C40 24/7 Carbon-Free Energy C40 White Paper which identified cities as having a key role to play in decarbonising the grid.[22]

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[17] United Nations (2023) 24/7 Carbon-free Energy Compact (available online)
[18] SE4ALL (2023) Join the Movement for a 24/7 Carbon-Free Energy Future (Available online)
[19] Google (2023) Operating on 24/7 Carbon-Free Energy by 2030 (available online)
[20] Climate Change Committee (2020) Corporate Procurement of Renewable Energy- Implications and Considerations (Available online)
[21] Energy Unlocked (2021) The Hidden Carbon Economy (Available online)
[22] C40 (2022) 24/7 Carbon-free energy for cities: Opportunities, challenges and pathways for urban energy systems (available online)

It is directly responsible for setting planning policy standards for new developments, has a suite of programmes which support retrofit including potentially demand side flexibility measures, and has the convening role to harness the interest of the private sector in accelerating a 24/7 CFE approach and influence to work with regulators and policy makers to accelerate the approach.

2.4 The C40-GLA 24/7 Carbon-Free Energy for London Project: Unlocking the City's Demand-side Flexibility to Achieve Net Zero

In light of the urgency to achieve demand-side flexibility to decarbonise the grid, the C40 and Greater London Authority (GLA) have embarked on a critical project to explore how a 24/7 CFE approach could help unlock the city's demand side flexibility to accelerate electricity decarbonisation – within London and beyond. The project built on London's existing energy decarbonisation ambitions, with ongoing participation in C40's Renewable Energy Accelerator and its commitment to driving a 100% renewable energy target.[23] In devising the methodology, the project drew in learning from the funder Google's pioneering development of the 24/7 CFE score methodology and expanded on the body of knowledge created through previous projects FlexLondon and The Hidden Carbon Economy.[24] [25] [26]

The project is the first of its kind to explore the application of 24/7 Carbon-Free Energy applied to a city with solely a demand side focus, as the original methodology was developed to focus on demand matching to grid supply or other procured energy. The project has included the following key components:

London's 24/7 Carbon-Free Energy Project

1. Developing a London 24/7 CFE score and assessing barriers and opportunities to improve the score.
2. Modelling the potential of citywide flexibility technology and use.
3. Stakeholder engagement and convening of an Advisory Council.
4. Design of a pilot to trial flexing energy use to times of the day, with the lowest carbon intensity.
5. A Roadmap to scale 24/7 Carbon-Free Energy in London, the UK and beyond

[23] C40 Cities (2020) Renewable Energy Accelerator (Available online)
[24] Google (2023) Operating on 24/7 Carbon-Free Energy by 2030 (available online)
[25] Greater London Authority (2018-2020) FlexLondon (available online)
[26] Energy Unlocked (2021) The Hidden Carbon Economy (Available online)

3. The Potential: London's Carbon-Free Energy Performance Today and in The Future

The London 24/7 Carbon-Free Energy project assessed the potential and the extent of the opportunity for a 24/7 CFE and carbon flexing approach in London's buildings through completing multiple packages of technical analysis. The analysis showed that London's demand side flexibility potential could represent multiple gigawatts of capacity by 2030 and the 24/7 CFE carbon flexing approach could offer significant carbon and system benefits starting from today.

3.1 The Impact of a 24/7 CFE and Carbon Flexing Approach in London

The London 24/7 Carbon-Free Energy Project completed comprehensive analysis to assess the potential for a 24/7 CFE approach for London's buildings, which included:

- Specific carbon flexing use-cases were assessed through performing analysis on selected individual buildings in London,
- Citywide Carbon-Free Energy (CFE) scores were developed for London today and in 2030 through modelling of all London's buildings' electricity demands without any carbon flexing,
- The impact of citywide carbon flexing on London's 2030 CFE performance was assessed by projecting deployment of demand-side flexibility technologies and modelling their operation across London.

This modelling undertaken by Arup, Energy Unlocked and Quantenergy demonstrated that the scale up of demand-side flexibility-enabled technology, coupled with flexibility linked to a carbon signal, can offer significant opportunities to improve London's CFE performance, avoid emissions, and deliver wider benefits. The full results of the modelling are included in the accompanying modelling report, Appendix A. These findings highlight how the uptake of a 24/7 CFE approach can help buildings improve their decision making and have immediate carbon impact today. With wider scale up, the approach can help London to achieve its decarbonisation ambition, and the approach can play a valuable role to incentivise immediate deployment of flexibility which can be leveraged for delivering on other priorities too.

3.2 Building Level: Better Decision Making and Immediate Impact

The project aimed to understand the potential for carbon flexing to improve the 24/7 CFE performance of London's buildings both today and in the future. Analysis was completed for selected individual buildings currently in operation. Then, citywide modelling was performed to develop an estimate of London's current CFE score; this modelling was also extrapolated to develop a projection of London's 24/7 CFE score in 2030 and examine how operation of demand-side flexibility could impact London in the future.

Analysis was performed on selected individual buildings in London to assess the potential for specific carbon flexing use cases in actual buildings today. This building level analysis has shown how the hourly method of the 24/7 CFE approach can offer a more accurate decision-support tool for building operators, while carbon flexing and electrification can provide clear benefits.

Two buildings within Transport for London (TfL)'s portfolio were selected. These were chosen because they had very detailed data available, and will need to decarbonise in the near future, given the Mayor's ambition to lead by example across the GLA Group estate. Results of the analysis are presented in Table 1 below.

Table 1: Building-level analysis results

Building	What was modelled	Fuel switching results	Carbon flexing results
Pier Walk: Central London commercial building owned by GLA group	adding heat pumps and solar to the building flexibility applied to part of the central plant and heat pumps	213 tCO_2 saved from fuel switching to heat pumps (annually) 29.3% CO_2 reduction	Additional 34.7 tonnes 4.8% annual added benefit This would be improved if thermal storage were added
Palestra Building – Option 1: Central London commercial building owned by GLA Group	heat pump replacing CHP flexibility including heat pump, central plant and absorption chillers	811 tCO_2 saved from fuel switching to heat pumps (annually) 40% CO_2 reduction	62.7 tonnes from carbon flexing 3% annual added benefit This would improve if thermal storage were added
Palestra Building – Option 2	flexibility to a carbon signal of existing CHP with thermal storage	N/A	CHP operating hours are reduced and carbon savings of between 20%-30% annually.

The headline findings of this analysis for the buildings today are as follows:

- **Fuel switching yields 29-40% carbon savings** from replacing existing heating systems with heat pumps. This provides huge on-site carbon benefits, but these are not aligned with price. Annual price increases from electrification are significant because prices of electricity are higher than gas in today's market. Palestra sees an annual increase of £739,257 in energy costs when switching CHP for heat pumps.
- **Flexibility without thermal storage yields 3-5% annual carbon savings.** For building operators, it is possible that flexing just one new asset will not seem significant when spread across the electrical load of a building as a whole. However, even at this scale, asset financiers may be most interested in this additional annual value given they hold these assets for over 20 years.
- **20% - 32% carbon savings is possible from flexing the existing CHP plant (including thermal storage) to use grid electricity instead of on-site gas where grid carbon intensity is low**. (20% savings are achieved with 24 hour thermal storage; 30% with unlimited thermal storage). Flexibility to a carbon signal for certain assets and buildings could therefore provide options to building operators and owners – to allow existing assets to be maximised for annual carbon savings before full electrification (heat pump replacement), saving embodied carbon and costs (particularly while electricity prices are so high).
- **Building operators will need a comprehensive approach to flexing controllable loads across the building to see the most carbon benefit**. Each building is different and as we electrify more loads in buildings, different electrical loads will require optimisation according to their daily and seasonal uses (i.e., lighting is less flexible than chillers; heating provides flexibility in winter but not summer).
- **The carbon flex potential is maximised with diversity and a portfolio of variable generation and flexible demand**, for instance combining on-site generation and other storage such as thermal storage (hot water tanks). It would be increased further if individual buildings were brought together to find co-location opportunities that increase diversity of the local smart energy portfolios.

Only with further piloting and data analysis would it be possible to understand the full flexing potential if optimising the building across all electrical loads, in conjunction with the building occupant's needs. As outlined in the project overview, this project includes the designing of a demonstrator pilot and as such this would provide an opportunity to further explore full flexing potential.

3.3 Citywide Scale: Carbon-Free Energy, Flexibility Capacity and Carbon Savings

To gauge London's current CFE performance, the progress needed to achieve its aim of 24/7 CFE, and assess the opportunities for carbon-driven demand-side flexibility, we developed an estimate of London's 'CFE score' as a city.

The CFE Score Calculation Methodology

A CFE score is a metric to measure progress towards the goal of achieving 24/7 CFE; a CFE score measures the percentage of electricity consumption matched to carbon-free electricity supply on an hourly basis over a year. Google, the funders of this work, have developed a methodology for the calculation of CFE scores.[27] The Google methodology considers contracted PPAs and the average hourly CFE proportion of the grid supply mix as the Carbon-Free Energy options to match demand with CFE supply at each hour of the year. For this project's development of a citywide CFE score for within London's boundaries, distributed local renewable generation was considered instead of renewable PPAs. For London, distributed renewable generation is essentially limited to rooftop solar PV. This means that the citywide CFE score was defined as:

CFE Score results 2019 and 2022

The citywide profiles developed suggest that London's CFE score in 2019 was 23.5%, while its score in 2022 was 43.8% (see Figure 1). The hourly CFE matching contributing can be visualised with heatmaps; hours with the most CFE matching are shown in green, while those with the least are shown in black (Figure 1 provides an example of the 2022 heatmap).

The improvement of score between 2019 and 2022 is highly encouraging and highlights the success of supply-side electricity grid decarbonisation over recent years (distributed solar PV's contribution to the scores was near-negligible). However, significantly more progress will be required for London to reach the goal of 100% 24/7 CFE. This will require further phasing out of dispatchable gas generation, making progress incrementally more challenging. In this context, demand side flexibility will be a fundamental lever for London to meet its goals and match every future kilowatt-hour of demand with low-carbon electricity supply.

$$\text{CFE SCORE} = \frac{\text{Embedded CFE} + \text{Consumed Grid CFE}}{\text{Total demand}}$$

Embedded CFE: annual sum of hourly distributed PV generation matched to hourly electricity demand
Consumed Grid CFE: annual sum of hourly electricity demand supplied by the CFE portion of grid supply
Total demand: total annual electricity demand of London's buildings

[27] Google (2023) Operating on 24/7 Carbon-Free Energy by 2030 (available online)

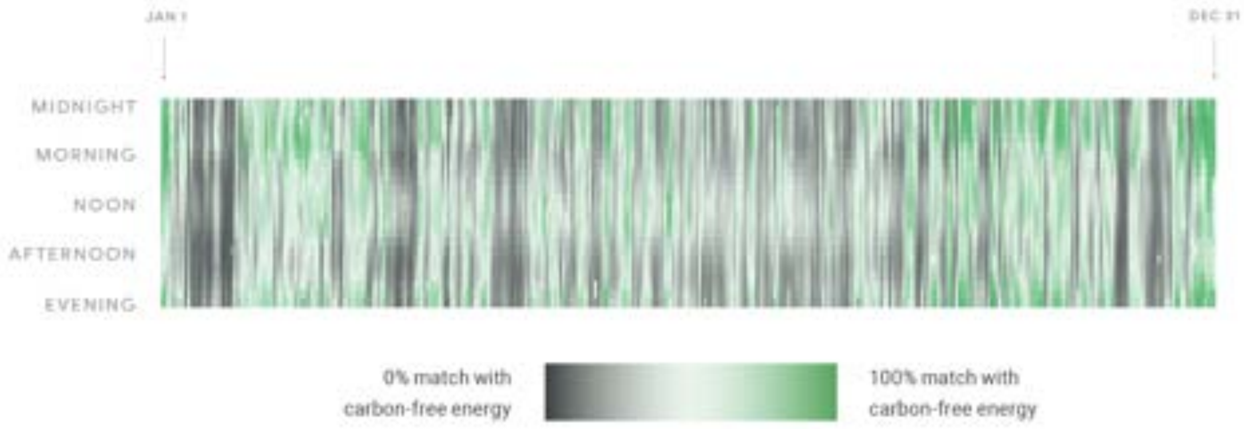


Figure 1: 2022 London hourly CFE matching (43.8% CFE)

Citywide 2030 carbon flex modelling

To examine the future citywide potential for demand-side flexibility to contribute to London's decarbonisation ambitions in 2030, we developed three scenarios and three CFE scores which included:

1. **London 2030 without demand-side flexibility:** This 2030 **'no-flex'** scenario required modelling the significant changes anticipated for London's electricity system – including new electricity loads of EV chargers and heat pumps; further deployment of rooftop PV; and further supply-side decarbonisation of the electricity grid mix. No demand-side flexibility operation was modelled.

2. **London 2030 with some demand-side flexibility deployment and carbon flexing:** This **'flex-enabled'** scenario based deployment of demand-side flexibility technologies on typical projections. For example, considering 18 GWh of distributed thermal storage installed and treating 7% of aggregated domestic appliance and cooling electricity demand as shiftable by 2030. The demand-side flexibility technologies were modelled engaging in carbon flexing.

3. **London 2030 with maximum demand-side flexibility deployment and carbon flexing:** This **'max-flex'** scenario based deployment of demand-side flexibility technologies on maximum projections. For example, considering 42 GWh of distributed thermal storage installed and treating 19% of aggregated domestic appliance and cooling electricity demand as shiftable by 2030. The demand-side flexibility technologies were modelled engaging in carbon flexing.

In all three scenarios, Rooftop PV, EV, heat pump, and district heating levels of deployment were aligned to the Mayor's Accelerated Green targets. However, while the Accelerated Green pathway considers demand-side response at a high-level, it does not offer specific targets for the deployment of the demand-side flexibility technologies. Therefore, we developed a list of most relevant technologies for London's buildings to facilitate the flexing of grid electricity consumption while meeting buildings' various types and categories of service demands (Table 2) and considered two different scenarios for deployment of these technologies in Scenarios 1 and 2.

Table 2: Flexibility technologies considered

Technology		Description
	Behind-the-meter (BTM) battery storage	Batteries store electrical energy for use at another time. Stationary batteries can charge from the grid or on-site PV generation and discharge to meet any of a building's electrical loads, whether time-critical or not.
	Thermal storage	A thermal store can heat up using an electrical heating technology (like a heat pump) and load the grid at an earlier time to supply space heating and/or hot water at another time. Thermal stores include hot water tanks in heat networks and individual properties.
	EV smart charging	Often EVs will be plugged in for more time than needed to sufficiently charge their batteries. Smart charging sees EVs' batteries charged at the most desirable times in their plugged in periods, rather than as soon as plugged in.
V2G	EV Vehicle-to-grid (V2G)	Through bi-directional chargers, V2G sees vehicles use some of the energy stored in their batteries to supply back to meeting a building's electrical loads, or back to the grid, at times over the period it is plugged in for.
	Smart shifting of appliance and cooling demands	Through smart systems deployment in appliances and building management systems, other non-time-critical electrical loads can also be shifted to other times, while unnecessary loads can be shed through use of these controls.

Results of modelling the three scenarios show clear emissions benefits to widespread demand-side carbon flexing, with avoided grid electricity emissions of between 5.6–9.3% depending on the flexibility deployment scenario. This translates to between 180–300 ktCO2 p.a. savings and substantial increases to London's 2030 CFE score. A maximum flex response of between 4.1–7.8 GW was observed in the citywide carbon flexing scenarios. To put this into context, peak demand in Great Britain on a cold winter day could be 60 GW, and current annual procurement of flexibility by UKPN is in the hundreds of megawatts[28]. For between 600-1600 hours a year, at least 3 GW of flexible capacity is utilised in the modelling, which is the size of the Hinkley Point C nuclear power plant.[29]

[28] Ofgem (2019) State of the Energy Market 2019 (available online)

[29] The planned twin unit UK EPR is capable of generating 3,260MW of secure, low carbon electricity for 60 years. (further information online)

2030 Citywide Carbon Flex Modelling Results

	2030 no-flex	2030 CFE flex-enabled	2030 CFE max-flex
CFE Score	62.9%	65.5%	67.2%
Grid emissions avoided (compared to 2030 no-flex)	-	5.6% (180 $ktCO_2$ p.a.)	9.3% (300 $ktCO_2$ p.a.)
Maximum flex response	No flex operation modelled	4.1 GW	7.8 GW
Number of hours in 2030 with >3GW flex response	No flex operation modelled	600	1,600
Heat pump, district heating, EV and PV deployment	According to Accelerated Green targets		
Energy storage, smart shifting, smart charging, and V2G deployment	No flex operation modelled	According to typical projections (e.g., 18 GWh distributed thermal storage)	According to maximum projections (e.g., 42 GWh distributed thermal storage)

Implications for Design of 24/7 CFE Actions

The modelling highlighted several key implications for how 24/7 Carbon-Free Energy actions should be designed.

- **Co-optimisation:** Encouragingly, the modelling results suggest that carbon flexing could align well with other priorities like the need to manage network constraints; 80% of demand turn-down events over 2 GW occur during the typical electricity network peak hours of 07:00-11:00 and 17:00-21:00, while 81% of demand turn-up events over 2 GW occur outside of these peak hours. Given the complementary nature seen here, it is suggested that the emissions benefits offered by the 24/7 CFE approach can be a valuable mechanism to incentivise immediate deployment of flexibility which can be leveraged for delivering on other priorities too.

- **Technologies to prioritise for flexibility:** Under the 2030 max flex scenario, the modelling suggests that thermal storage will contribute 64% (192 $ktCO_2$ p.a.) of the citywide emissions savings from carbon flexing. Distributed thermal storage – heat pumps linked to heating and hot water storage – provides most of this (165 $ktCO_2$ p.a), and thermal storage from heat networks provides a notable amount of this contribution (27 $ktCO_2$ p.a.). With large, centralised stores operated by single actors, heat networks' flexibility can be easier to leverage than distributed technologies.

- **Building types to prioritise:** The modelling results also suggest that some types of buildings are likely to offer more flexing opportunities than others. In the results, residential buildings offer the most opportunities for avoiding grid electricity emissions (with 62% of citywide emissions avoided under the 2030 max flex 2030 scenario), while office buildings avoid 17% of citywide emissions.

- **Specific technologies can have attributed carbon values from carbon flexing:** The results evidence how the introduction of energy storage and smart shifting technologies can deliver tangible emissions benefits beyond those achieved through electrification and deploying renewables. Table 3 below shows the electricity usage emissions avoided through the introduction of each technology under the 2030 flex-enabled modelling scenario, normalised per unit.

Table 3: Grid electricity emissions avoided by each flex technology in 2030 through carbon flexing

Technology	Grid electricity emissions avoided per unit	Notes
Thermal storage – distributed	230 gCO_2 p.a./Litre	Assumes tank storage
Thermal storage – heat networks	45 gCO_2 p.a./Litre	Assumes tank storage – heat networks show lower benefits per litre than distributed thermal stores due to the much larger size of stores per property
Smart shifting of appliances and cooling	11,000 gCO_2 p.a./home	Figure is for domestic only
EV smart charging	34,000 gCO_2 p.a./EV	Averaged across building types
V2G	191,000 gCO_2 p.a./EV	Averaged across building types
BTM battery storage	15,000 gCO_2 p.a./kWh installed	Averaged across building types

- **The CFE Score may need to be revised to incentivise action**: As CFE scores only consider electricity consumption, it does not encourage fuel switching - if a building switched its heating system from a gas boiler to a heat pump, its CFE score may not increase despite clear overall emissions benefits. Additionally, as the CFE score is a percentage metric, it is not guaranteed to reward measures to increase efficiency in buildings. Therefore, some revisions to the methodology to create the right incentives for cities may be needed.
- **System coordination is required to avoid unintended consequences:** While there is a clear overall trend of carbon flex responses aligning well with network needs, the carbon flexing modelling results show some demand turn-up events occurring in the morning and evening peaks, which could put additional pressure on networks during constrained times. Also, while it is expected that buildings would respond their flexibility to the average mix of generation supplying the grid, the modelling results suggest there is a risk that if significant loads in London turn up unexpectedly to chase a particular low carbon signal based on the average grid mix, high-carbon supply (e.g. a gas plant) could sometimes be required to turn on to meet the increased demand (further detail is found in the accompanying modelling report). Furthermore, a sudden chasing of uncoordinated signals could create grid instability if not controlled and managed to ensure continued availability of power. As well as system coordination, open and transparent data on system control decisions can help stakeholders understand their interactions with the wider system and improve decision making.
- **Piloting:** Undertaking pilots will be critical to validate the findings of the modelling and build a deeper understanding of the potential for carbon flexing in London's buildings. We need to test the findings of the use cases, understand better the potential for carbon savings at an asset level, and understand the challenges of actual implementation and how carbon flexing interacts with competing priorities in real buildings. We also need to understand what types of incentives might be required for shifting demand, in order to understand better whether a large-scale uptake of flexibility in response to carbon 'signals' would be possible and likely.

While the results of the citywide modelling highlight the emissions and wider benefits that scale up of a 24/7 CFE and carbon flexing approach could bring, they also highlight risks of potential undesired, unintended consequences, pointing to a role for coordination of carbon 'signals' and other local network needs at a localised scale alongside national system operators.

4. Collaboration to drive Carbon as an Incentive for Flexibility: Actions Required

The modelling demonstrates the significant potential to accelerate Net Zero in London and flexibility capacity for the UK if a 24/7 Carbon-Free Energy approach is pursued in London. We know that that the private sector is already acting on 24/7 Carbon-Free Energy, and that there is a risk of unintended consequences if that continues without potential market design interventions and regulatory and policy oversight and coordination In order to achieve this potential and avoid the unintended consequences, active collaboration and coordination will be essential – alignment of incentives incorporated into market design will be required to ensure that there is coordination between the assets flexing and the wider system needs

To achieve this collaboration and coordination, London and other cities, regions and Combined Authorities have an essential role to play. They can bridge the bottom-up approach of entities applying 24/7 Carbon-Free Energy voluntarily with the top-down system needs of regulators and policy-makers. They must work with the wider market and regulators and policy-makers, private sector, and data and technology innovators to direct action to where it can be most impactful – for example, recognising that from our modelling that while the private sector is acting first, the greatest potential for flexibility capacity and carbon reductions lies in residential and distributed thermal storage. They also can lead by example, incorporating incentives and requirements into their own programmes and policies, and piloting and testing solutions across their own assets.

By collaborating and coordinating, four key actors can drive an overall market and system transformation that creates the incentives and conditions for 24/7 Carbon-Free Energy – enabling Net Zero faster and at least cost. This includes:

- **Voluntary standards, commitments and measurement approaches drive the private sector to adopt and invest in 24/7 CFE:** Already the private sector is beginning to time- match their procured electricity to the most carbon free sources in order to pursue more robust action on their operational emissions, and this will accelerate as more standards and commitments are upgraded to focus on carbon-free energy use. In 2023, guidance and best practice will be issued by the UKGBC which will further accelerate an asset and portfolio approach to carbon flexing.[30] While the modelling demonstrated a higher potential for residential, private sector action will create the momentum and the test-bed needed to drive change and scale across all sectors. The role of voluntary standards will continue to be essential to accelerate the momentum towards 24/7 CFE.

- **Government reacts to manage unintended consequences – and undertakes market re-design and policy setting:** As voluntary action reaches scale, a threshold will be reached – and recognition from national policy makers and regulators of the potential for the unintended consequences then accelerates the need for a national policy and regulation coordinated approach, in order to avoid unintended consequences and risks from a more 'uncontrolled' bottom-up approach. Incentives should be designed into policy and regulation to incentivise the right kinds of bottom-up behaviours that will maximise the system benefits and minimise the risks and unintended consequences. Critical for success is to avoid the costs of uncoordinated 'bottom up' and 'top down' approaches, and that particularly regulators and policy makers understand the motivation and approaches of the private-sector and cities which are driving them to act.

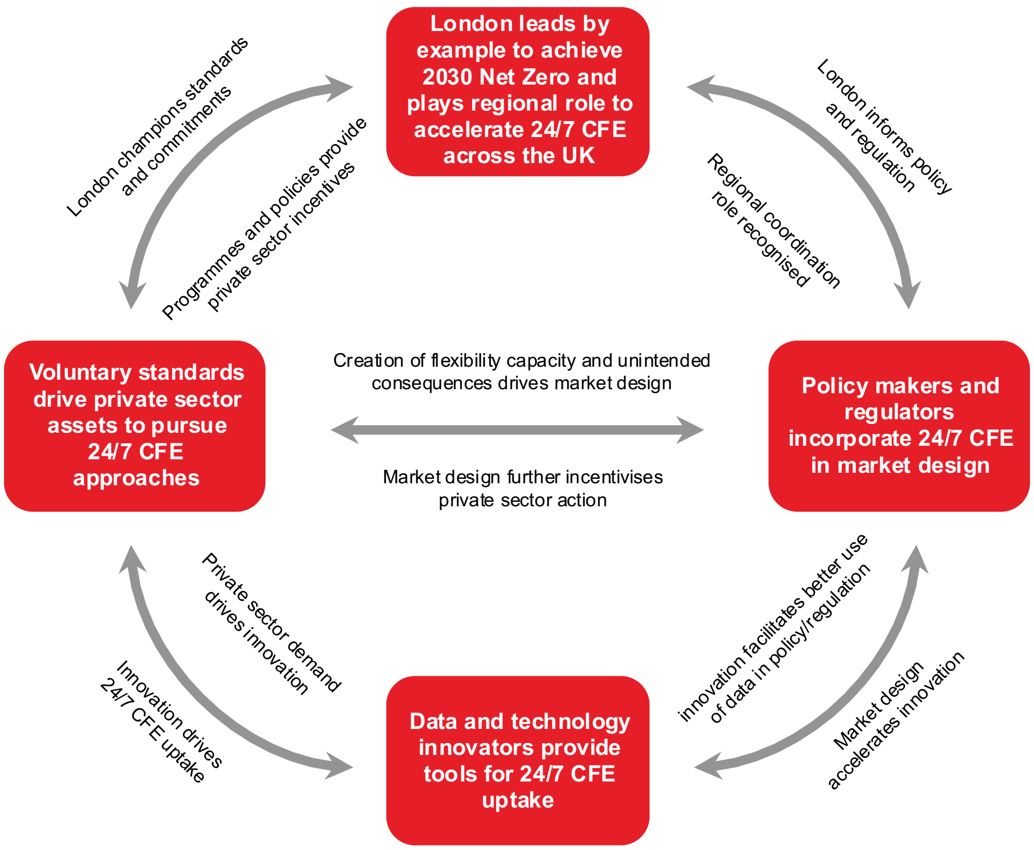
- **Technology and data innovators:** Innovation in the market is already happening, but this further accelerates to meet the private sector interest, driven by the voluntary standards and commitments – further providing opportunities for the private sector to follow a 24/7 CFE approach, and offering opportunities for cities to drive action.

[30] UKGBC (2023) Renewable energy procurement (available online)

- **London and other cities and regions leading by example drives regional planning alignment:** As the private sector acts, London and other cities and local authorities will continue to introduce demand side flexibility-enabled technologies – such as heat pumps, vehicle to grid charging – and demand side flexibility overall to both accelerate the technologies needed to reach Net Zero but also to mitigate costs and delays required for network reinforcements. 24/7 carbon flexing has both a temporal and locational element, and cities and regional authorities are well placed to unlock the opportunity - building on and accelerating private sector efforts, while deploying the local policies and investment needed to help bridge together with national frameworks and whole system decarbonisation.

In the next 5 years, actions by the private sector, London and other cities and regions will be imperative to test the technology and provide the evidence base for the design of incentives and benefits to further accelerate carbon flexing. They will be actively looking to either use more energy at the times when more renewables are on the system or avoiding the hours when carbon free electricity is scarce. As this happens, market-design and accompanying policy and regulation will step up to coordinate what is already happening at a localised and distributed level. While this offers a more 'scrambled' nature to the development of a new flexibility market; overall, it will support the faster formation of a more structured, controlled, centralised approach. 24/7 CFE approaches are not a silver bullet, but they do support alignment in location, time and market incentives towards a transition to the decarbonised electricity system which we know will be different to what exists today.

Scaling of flexible technologies and carbon flexing can be accelerated through the right incentives and market interventions – but action must be coordinated to avoid system level unintended consequences and maximise impact.



Overall, regulators and policy-makers, global and national standards bodies driving private sector action, and data and technology innovators will play essential roles in accelerating the design of a market which facilitates the right incentives and interventions to realise a 24/7 Carbon-Free Energy system. Critically, London has the opportunity to play an essential connecting role between this wider systems design and the local level, driving action through its own policies, programmes and assets but also coordinating with regulators and policy-makers to ensure the design of a system recognises and facilitates the importance of demand-side flexibility planning at a local level.

4.1 Regulators and Policy-Makers: Integrate CFE Into Market-Design

There are two key issues which a 24/7 Carbon-Free Energy approach designed into regulation and policy can address. First, there is not sufficient investment in flexibility ahead of when it will be needed in a more decarbonised system, with the risk that we do not reach the national 2035 target of a 100% renewable grid.[31] Today, distribution system operators (DSOs) who are responsible for distributing energy to consumers, procure flexibility to manage local electricity network constraints. Yet there is a lack of certainty of financial return in providing flexibility services due to fragmentation of energy flexibility markets, ultimately leading to a misalignment of business needs and the energy market needs. Furthermore, flexibility procurement similarly is designed to allow technologies to compete on price, not carbon intensity, which is why so much flexibility continues to be provided by gas fired power plants and the markets therefore continue to favour high over low carbon sources.

Overall, price and carbon intensity of energy are not directly correlated, particularly in higher penetration renewable grids – meaning, lower prices at particular times of day do not correlate with lower carbon intensity.[32] Policies relating to flexibility are currently driven primarily by concerns over energy security and pricing (e.g. following the supply concerns in the 2022/23 winter), rather than explicitly valuing or prioritising carbon reductions. Therefore, designing a system which creates the right incentives for flexibility will be critical to provide least cost options for flexibility. Potential incentives include regulated incentives, carbon accounting and climate commitments, finance and funding mechanisms.

International and national examples demonstrate the potential to incentivise and drive a 24/7 CFE approach:

- In February 2023, the European Commission proposed detailed rules on the definition of renewable hydrogen in the EU[33]. The rules enforce additionality from hydrogen, by specifying that electrolysers used to produce hydrogen will have to be connected to new renewable electricity production, so that hydrogen production is supporting decarbonisation. Part of this will include a criteria that renewable hydrogen is only produced when and where sufficient renewable energy is available.
- In the UK, the new Hydrogen Standard now requires half-hourly assessment of electricity inputs as well. [34]
- California's Self-Generation Incentive Programme, which incentivised behind the meter batteries, adjusted its methods in 2019 due to a slight increase in emissions due to batteries not operating to align with carbon intensity.[35]

These are examples of how policy, and carbon accounting generally, can and needs to adapt to incentivise more action to both increase renewables and reduce carbon at time of use. If applied in a similar way to energy consumption, carbon flexing would become far more mainstream to support organisations achieving net zero targets.[36]

[31] UK Government (2021) Plans unveiled to decarbonise UK power system 2035 (available online)
[32] Energy Unlocked (2021) The Hidden Carbon Economy (Available online)
[33] European Commission (2023) Commission sets out rules for renewable hydrogen (Available online)
[34] UK Government (2022) UK Low Carbon Hydrogen Standard: emissions reporting and sustainability criteria (available online)
[35] Green Tech Media (2019) Cutting the Carbon From California's Self-Generation Incentive Program (available online)
[36] CA Gov (2023) Self- Generation Incentive Program (SGIP) (Available online)

Overall, we have identified ten potential areas for policy makers and regulators to enable a 24/7 CFE approach, in order to scale flexibility availability and carbon reductions.

These focus on the important role of the flexibility procurement market, the need for the right data and digital infrastructure, network carbon reporting, market-wide half-hourly settlements, REMA and RIIO-ED2 regulatory frameworks, the critical local role of the Future Systems Operator, LAEP integration, National Retrofit and Electrification Support Measures, Regulation of Heat Networks and Heat Network Zoning.

Flexibility Procurement Market

District Network Operators (DNOs) are increasing their procurement of flexibility. In so doing, they are already starting to recognise the local value of flexibility and aim to drive longer term certainty for the market to invest in providing this local flexibility. However, DSOs today are prevented by regulation from procuring low carbon options over high carbon options - they can differentiate only on price. Working toward standard carbon accounting of the procured flexibility, as the DSOs are already doing, would be a good first step to ensuring lower carbon flexibility is able to compete.

However, DNOs currently procure flexibility for limited needs, particularly to delay higher cost network upgrades. With 24/7 CFE approaches, building owners, operators and investors may see many more hours of the day when their flexibility could be valued, and this provides useful insights to the DSOs on the potential for flexibility that is currently implicit (or not recognised and valued by the market explicitly today). In our findings for London, up to 3 GW of available flexible capacity for between 600-1600 hours could become a resource for the DNO, which could be explored in a pilot that analyses the hours this 'carbon flexibility' already overlaps with their existing flexibility needs today or those anticipated in future.

Data and Digital Infrastructure

Whatever the design of the new system, consumer and system interaction should decarbonise the system (not increase emissions). Available data about environmental attributes, time and location of demand should evolve along with other data needs.

Data needs to be transparent and instantaneously available at real time for multiple participants across the system. The system operator(s) need greater visibility of the location and scale of flexibility within their areas. To enable widespread participation in CFE, the current gap in data visibility between transmission and distribution level will need to be addressed.

This will be achieved by introducing infrastructure such as a digital spine, asset registration and standardised appliance rules. A feasibility study into a 'digital spine' was recently announced[37] - this is a proposed piece of system-wide digital infrastructure to connect energy system participants, enabling them to exchange data simply and securely. The aim will be to have interoperability between different consumers, providers and operators and for the data to be accessible by DNOs/DSOs and the ESO. This would likely complement and further enable the two-way dataflows required for effective flexibility services by providing a national platform and standards.

Transmission and Distribution Network Carbon Reporting

BEIS and Ofgem have set out an expectation for transmission and distribution network and system operators to develop consistent methodologies for carbon reporting and monitoring and for this to be in place by 2023.[38] The Energy Digitalisation Taskforce have recommended that Ofgem closely monitor the development of these

[37] Arup (2023) Arup appointed to research energy system "digital spine" feasibility (Available online)

[38] BEIS and Ofgem (2021) Transitioning to a net zero energy system: smart systems and flexibility plan 2021 (available online)

methodologies to then produce an industry standard.[39] In the future, there is an ambition to mandate dynamic carbon reporting and aim for a more granular level. This would assist 24/7 CFE by providing consistent datasets across the UK but does not address the need for a real-time signal, which was recommended by the Energy Digitalisation Taskforce[40]. Readily available carbon signals from trusted sources are key to the development of products that can interpret and respond to these signals. For carbon flexing specifically, real-time signals as well as carbon-related data predictions may be required for more dynamic controls over 24 hour periods.

Market-Wide Half Hourly Settlements (MWHHS)

An industry led programme is currently being overseen by Ofgem to introduce Market-wide Half Hourly Settlements (MWHHS), in order to enable a faster, more accurate settlement process for all market participants, introducing site specific reconciliation using half-hourly meter readings[41]. This will be available for domestic and small non-domestic users by October 2025 which can then, with smart meters, enable suppliers to introduce more widespread flexibility Time of Use tariffs and products rather than the relatively niche range currently available. This will enable CFE by increasing market options and competition for flexibility services, which can respond to carbon signals if suitable real-time data is available alongside. Policies and data systems as well as protocols relating to customer meter data will be required for MWHHS, which also supports 24/7 CFE.

Better Integration and Coordination of Local Area Energy Planning

Local authorities across the UK are in a strong position to drive progress on cutting carbon emissions through Local Area Energy Planning (LAEP), an approach that translates a net zero goal into actionable steps through whole-system energy modelling and stakeholder-driven decision-making[42]. LAEPs include a focus on:

- Gas, hydrogen, heating, cooling and electricity networks;
- All forms of renewable and low-carbon energy resources;
- Local energy generation and storage;
- The residential and non-domestic built environment;
- Energy for industry and agriculture (where relevant);
- Energy for transport.

The location of flexibility is critical to ensure that flexibility is available where it is most needed. The role of the LAEPs will play a key role in achieving this, and closer coordination between those planning the flexibility needs and the LAEPs delivering it is essential. Although LAEP is not a legal requirement for local authorities in England and Wales, Ofgem recommends that gas and electricity network operators work with them to create plans. Better integrating the role of LAEPs into central policy and regulation, such as the Review of Electricity Market Arrangements (REMA), RIIO-2 (price controls) and the role of the Future System Operator (FSO) would enable a controlled approach to locally-led flexibility. Each of these mechanisms are explored in further detail below.

Wider implementation of LAEPs across London and the UK would support 24/7 CFE by demonstrating a need for investment in electricity networks to support large scale demand flexibility and involve a wider set of stakeholders so that there is awareness of the potential effects on the network (if implemented). As methodologies improve, a LAEPs could be a useful starting point for identifying and quantifying flexibility potential in a specific area. This could provide a more complete, bottom-up view to enable better system wide design.

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[39] BEIS, Ofgem and Innovate UK (2022) Energy Digitalisation Taskforce report (available online)
[40] BEIS, Ofgem and Innovate UK (2022) Energy Digitalisation Taskforce report (available online)
[41] MHHS Programme (2023) Programme Overview (Available online)
[42] Arup (2023) Whole-system energy planning: helping local authorities decarbonise their local areas and achieve net zero (Available online)

Review of Electricity Market Arrangements (REMA)

The UK government has begun electricity market reform, starting with a consultation where 92% of respondents support the idea of market reform with the goals of decarbonisation at least cost to consumers.[43] REMA consultation conclusions were published in March 2023. REMA will play a key role in enabling demand-side flexibility and defining the shape of future demand side response markets, with 'whole-system flexibility' one of the criteria which the reforms should improve. REMA is reviewing options for splitting the wholesale market into variable and non-variable generation, and other reforms to pricing that recognise the importance of location in enhancing and investing in the lowest carbon electricity system, and will continue to seek evidence on pricing to drive these outcomes.

Carbon flexing and 24/7 CFE approaches more broadly can shed light on the extent to which regional governments and the private sector might focus their own strategies on time and location-based decision making for their own operations and investments. 24/7 CFE approaches would encourage companies to invest in controlling their own demand – either efficiency or flexibility – and investing in PPAs, a form of 'splitting' the market that is already being used by many companies and starting to be used by local governments as well.

RIIO-ED2

RIIO-2 is the second set of price controls implemented by Ofgem for the Great Britain gas and electricity markets, covering 2023-2028 for electricity distribution and gas 2021-2026.[44] Within the RIIO-2 business plan guidance, electricity network companies were encouraged to engage with the LAEP process as stakeholders and to take account of LAEP outputs with regards to planning of whole system solutions and investment.[45] As LAEPs involve the assessment of electrified heating, EVs and energy storage at the low-voltage network level, investments to enable the implementation of the LAEP pathways will also benefit 24/7 CFE by increasing the number of flex-enabled assets that can be handled in a given region and providing a route for the Local Authority to be engaged with the DNO (whether as stakeholders in the LAEP process, or during implementation). RIIO-2 determines the revenues that DNOs can collect from customers and therefore the amount available for investment in the network, alongside specific innovation funding (Strategic Innovation Fund, Network Innovation Allowance).

RIIO-2 will require the consideration of flexibility first before network development solutions, and will require specific incentives and outputs to support low carbon technology uptake. If incentives are aligned with carbon, RIIO-2 could enable a 24/7 CFE approach.

Future Systems Operator (FSO)

The FSO is the proposed body who will act as independent system operator responsible for coordinating and ensuring strategic planning across the sector.[46] The FSO will be required to deliver on three objectives in its role: net zero; security of supply; and efficiency and economy. In delivering these objectives, the FSO will take a whole system (gas and electricity) view and identify where flexibility is needed to ensure a secure, resilient, and decarbonised energy system. In doing so, the FSO will be providing strategic advice and analysis to BEIS and Ofgem to support policy development. The FSO is expected to be setup in or by 2024 and could be a key stakeholder in driving policy that is supportive of flexibility services such as 24/7 CFE. It will be required to deliver a new electricity transmission network planning output called a Centralised Strategic Network Plan (CSNP), a plan for all load related network planning on the electricity transmission network.

It is critical that the government recognises the essential role of the FSO in working collaboratively and strategically with regions, Combined Authorities and LAEPs – particularly given its remit as a centralised entity to facilitate local input. Benefits of a regional system operator for city-level coordination has been

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[43] UK Government (2022) Review of electricity market arrangements (available online)
[44] Ofgem (2018) RIIO-2 framework decision (available online)
[45] Ofgem (2018) RIIO-2 Business Plans Guidance Document (available online)
[46] Ofgem (2021) Future System Operator (FSO) (available online)

explored in West Midlands showing local benefits of £720 million from aligning energy system value with local industrial priorities to foster local job creation and development investment[47].

The FSO new focus on net zero is very welcome, but this will require many actions in parallel. In the next 5-10 years, local flexibility will be handled by regions and combined authorities and an interim coordinating role or function will be required.

National Retrofit Policy and Electrification Support Measures

It is essential to align national retrofit policy and measures with the need for flexibility. Currently, retrofit policy and approaches are focussed on energy efficiency yet future flexibility will need to be incorporated, through programmes such as the Social Housing Decarbonisation Fund, the Boiler Upgrade scheme, and overall heat pump deployment. Innovation pilots through UKRI and BEIS focussed on place-based innovation should incorporate flexibility. Furthermore, there is a need to recognise the benefits of smart controls as part of retrofit (as well as new home standards, and a need to adopt smart control technology standards).

In the recent 'Powering Up Britain' energy 'blueprint' published by government, the focus on heat pump deployment and potentially shifting the levies now applied only to electricity onto gas would also support 'carbon flexing' - because gas, while being higher carbon than today's grid mix, is much lower priced to consumers, disincentivising a shift to more flexible electric heating, if coupled with smart controls.[48]

Though the 24/7 CFE score itself does not count efficiency directly, efficient buildings reduce energy demand requirements and create options for further electrification, procured or on-site generation to be sized appropriately, reducing the cost of achieving 24/7 CFE.

Regulation of Heat Networks and Heat Network Zoning

Decarbonised heat networks' large heat pumps and thermal stores, combined with significant demand diversity, could offer some of London's most flexible demand-side assets. Centralised and operated by a single entity, these networks can be far easier to leverage than individual properties' heating and storage.

An increase in the energy supplied by heat networks is envisaged in all UK net zero scenarios, with upcoming heat network zoning policy from DESNZ expected to be a key enabler by stipulating heat networks as the required heat supply option in designated areas.[49] Increased regulation of heat networks (particularly for domestic supplies) is expected to bring them more into line with the consumer protection available for natural gas supplies as Ofgem's role will expand to include heat networks. The heat network regulation is expected to come into force in 2024 as part of the Energy Security Bill, while heat network zoning is set to be implemented from 2025.[50] Many cities across the UK are involved in pilot projects and development in preparation for heat network zoning and are receiving the signal that many buildings will be mandated to connect to heat networks. DESNZ believes that as much as 20% of buildings could connect to low carbon heat networks by 2050.[51] A large proportion of those are likely to be electrically driven. Some may have the capability to switch between sources which would allow for a significant opportunity for flexibility.

Regulation which increased heat network deployment including mandating heat network connections would support 24/7 CFE by offering large assets, operated by a single entity, that can be flexed to a carbon signal. Heat pumps, battery storage etc. in a heat network can also be more readily flexed than in individual properties as there is greater demand diversity and system inertia (via large thermal storage).

4.2 Data and Technology Innovators: Finance and Commercial Models

With greater interest from the private sector in a 24/7 CFE approach, a strengthened role of the GLA and other combined authorities, and conducive regulations, it is likely that new finance and commercial models would

[47] Coventry City Council (2023) West Midlands Regional Energy System Operator (RESO) project (available online)
[48] UK Government (2023) Powering Up Britain: Energy Security Plan (available online)
[49] UK Government (2023) Energy Security Bill Contextual Note: Heat Network Zoning and the Planning System (available online)
[50] UK Government (2022) Energy Security Bill (available online)
[51] Energy UK (2023) Towards a roadmap for heat networks (available online)

emerge that could further strengthen and accelerate a CFE approach. The intention is that not only operational benefits, but upfront funding of flex-enabled assets could be possible just as energy service contracting for efficiency can provide the up-front capital for investing in efficiency.

We believe that there are a number of emerging business models that can be incentivised or could be pursued, and these include:

- **Hourly guarantees of origin:** The private sector has voluntarily been working toward the 'Energy Tag' standard that can support granular (hourly) 'Guarantees of Origin' that are an evolution of today's market design.[52] Environmental attribute certificates are used today to back green tariffs and currently are accounted annually, but with new pilots underway, some of the registries for these environmental attribute mechanisms are working toward hourly certificates. These guarantees allow a company to report '100% CFE for an hour during which they purchased a certificate and used the corresponding volume of electricity. These 'tags' could underpin a number of use cases.
- **Trading and managing energy in line with a 24/7 CFE approach:** 'CFE manager' services with prices changing based on the environmental attributes of each hour allow service providers to manage an energy buyer's CFE Score. CFE Management service offers could provide – control of assets (or higher level electricity supply) and market purchasing (ie: PPAs) to achieve a certain CFE score. Startups like FlexiDao are offering this kind of management service for companies who are committed to '24/7 CFE' beyond 100% renewables.[53]
- **CFE Tariffs**: Just as currently green tariffs are backed by annual environmental attribute certifications in the UK, the time stamp of these certificates could by shrunk to half-hourly or hourly in line with electricity settlement periods. Setting household unit rates based on carbon intensity could be done in real-time following implementation of MHHS and with a suitable industry-backed carbon signal, directly incentivising consumers to flex demand where possible to cheaper/lower carbon time periods (even if they are not explicitly seeking CFE). Suppliers could also differentiate themselves in the market by providing more granular matching (i.e. via hourly RECs) in a similar way to current green tariffs. Companies, like Granular Energy in the UK, are providing utilities with the tools to create 24/7 CFE products for their customers.[54]
- **Aggregation and demand side management as a service:** Companies are already aggregating small loads across many buildings and local energy systems to offer grid services and bring flexible assets to market, and this same software could be used to manage 24/7 optimisation. Technology providers to building owners and operators today use sophisticated algorithms to predict weather, sense occupancy or time the controls of devices to 'smooth' demand. In conjunction with aggregators, technology combinations and portfolios can be managed to ensure secure supply or reduce costs as well as manage '24/7 CFE' With the expected increase of assets seeking to apply a 24/7 CFE approach, these aggregators would be able to access more and more MWh and bring those explicitly into energy markets.
- **Apps and guidance:** A huge challenge going forward is how to ensure Carbon-Free Energy is available to all and is affordable. Apps, guidance and education could be an area for innovation alongside government information, and could enable more widespread carbon grid factor awareness and drive more 24/7 CFE conducive behaviour.
- **Offset credits:** There is the potential for the development of carbon credits to value flexibility either in combination with hourly RECs or separately. This model could be linked to retrofit credits, alongside an existing scheme like UK's Retrofit Credit[55]. or linked to multiple aggregated assets and their carbon performance.

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[52] EnergyTag (2023) Defining and building a market for hourly energy certificates (available online)
[53] FlexiDao (2023) Moving towards 24/7 Carbon-free energy (available online)
[54] Granular Energy (2023) Next-generation clean energy trading and management (available online)
[55] HACT (2023) Retrofit Credit (Available online)

4.3 Global and National Standards Bodies: Update Voluntary Standards and Commitments

Around the world, and particularly since COP21 (The 2015 United Nations Climate Change Conference in Paris), voluntary standards in climate change have been driving significant and transformational action on climate. The standards and protocols governing how a company can claim Net Zero and other ambitious climate targets are therefore critical in driving action on 24/7 Carbon-Free Energy. The key actions to drive 24/7 CFE within Global and National Voluntary Carbon Standards include updating the greenhouse gas protocol, incorporating 24/7 into major commitments and standards like the WorldGBC Net Zero Buildings Commitment, and updating 24/7 CFE measurement approaches to better incorporate avoided emissions and non-electrified heat.

Updates to the Greenhouse Gas Protocol

A current barrier to hourly 24/7 CFE matching, and more generally accelerating a carbon free grid in London and the UK, is found within current carbon accounting standards, particularly the GHG Protocol Corporate Standard.[56] The Greenhouse Gas Protocol sets out the internationally acknowledged approach to Greenhouse Gas (GHG) accounting and reporting standards and includes the GHG Protocol Scope 2 Guidance[57] (Corporate Standard) and the GHG Protocol for Cities.[58]

The guidance explains two distinct methods for scope 2 accounting:

- **Location-based method** which reflects the average emissions intensity of grids on which energy consumption occurs using average grid factors.
- **Market-based method** reflects emissions from electricity that companies have agreed to, through contractual instruments (e.g. through energy certificate).

In the Corporate GHG Protocol, companies must report on both – but companies often choose the market-based method to claim 'Net Zero' in Scope 2. As such, a private sector entity can claim Net Zero in Scope 2 emissions if it has procured the equivalent MHs of renewable electricity through contractual instruments (such as, in the UK procuring a green tariff or a power purchase agreement in the UK). In the Cities protocol, they must report on the location-based method – but can also (where relevant) report on the market-based method, although few do because of the complexity.

Within the Corporate GHG Protocol, there have been concerns that there is a mismatch between what is being reported and what is reflected in GHG emissions on the ground. Google, who have spearheaded the 24/7 Carbon-Free Energy approach, recently outlined their concerns in relation to the Greenhouse Gas Protocol Update' (2023)[59], noting that current accounting does not go as far as it could in representing true and fair accounting of companies emissions, or the effectiveness of market-based interventions. Their concerns and recommendations also reflect other guidance and notes, including from the UKGBC[60] and the Committee on Climate Change[61] particularly in two areas:

- **Creating a stronger connection between physical markets and contractual instruments:** Under the current accounting system, geographic boundaries for scope 2 do not correspond to the physical market where the energy is consumed, meaning no guaranteed direct impact on the grid where the company draws its energy. For example, a company could be claiming net zero in scope 2 using the market-based mechanism, purchasing from a grid which has a much reduced (or net zero) carbon emission than the grid where they are actually taking their real electricity use from. This company could be drawing real energy from a grid which is fully reliant on fossil fuels, and are therefore not contributing to decarbonising that grid. There could be a greater shift in protocols in the future which

[56] World Resources Institute (2021) GHG Protocol Scope 2 Guidance: An amendment to the GHG Protocol Corporate Standard (Available online)
[57] World Resources Institute (2021) GHG Protocol Scope 2 Guidance: An amendment to the GHG Protocol Corporate Standard (Available online)
[58] World Resources Institute (2021) GHG Protocol for Community-Scale Greenhouse Gas Inventories (Available online)
[59] Google (2023) Building more accurate and effective greenhouse gas accounting (Available online)
[60]UKGBC (2023) Renewable energy procurement (available online)
[61] Climate Change Committee (2020) Corporate Procurement of Renewable Energy – Implications and Considerations (available online)

incentivises the use of market instruments which sets a boundary around purchased clean energy coming from within the same grid. This would have an impact on how 24/7 CFE reporting would work, with time matching to PPA (purchased on the same grid as use) being required.

- **Time matching and real grid impacts**: The second issue outlined is in relation to annual volumetric tracking. The current guidance allows for use of annual emissions factors in carbon inventory reporting. This overlooks the daily and seasonal variability in grid mix, and can result in a dramatic overstatement of market-based GHG reductions, when compared to more granular time analysis of energy use and grid carbon factor (for example by the hour). This would involve updating the guidance to better reflect the variability in the different approaches being utilised on the ground and their real impacts on grid decarbonisation, and looking at a more granular approach to time matching.

Overall, it is expected that current carbon accounting methods will be improved over time taking into consideration the points outlined by Google; already, the Greenhouse Gas (GHG) Protocol is taking evidence on changes to the Corporate Standard and market-based methods to incentivise investment in flexible technology and smart systems.

Net Zero Buildings Guidance

Around the world, guidance has been developed to provide clarity, transparency and consistency on what a net zero carbon building actually means. The World Green Building has set a definition of a Net Zero building, incorporated into national guidance including the UK and is incorporated into the World Green Building Council Net Zero Carbon Buildings Commitment [62] which sets out requirements for global corporations looking to commit to Net Zero across their portfolios.[63] The Cities component of the Commitment is led by the C40 under the Net Zero Carbon Building Accelerator[64]. There are also other standards such as the IFC Edge Net Zero Carbon Building and the International Living Future Institute 'Living Building Challenge'.[65] [66] In nearly all of this guidance, the definition of operational carbon is aligned to the GHG Accounting Protocol specifying that Scope 2 Net Zero can be achieved with the procurement of on-site or off-site renewables.

The UK Green Building Council will soon be the first green building council to call for a 24/7 CFE approach, with guidance to be issued during 2023.[67] They will suggest moving towards a scoring system which assesses energy procurement based on renewable-sourced and attributed, additionality, plus time-matching, to reflect this important role of time-matching in representing system additionality. We believe this guidance will drive a significant shift in the UK towards CFE. Furthermore, many more companies are signing up to the 24/7 Carbon-Free Energy Compact, championed by SE4All which will further drive CFE commitments.[68]

Building on this significant guidance from UKGBC, we need to see more of an overall shift in the requirement of Location-Based Accounting – either as a base in the GHG Corporate Accounting Protocol or incorporated into key commitments such as RE100 or the emerging Green Building Council standard in the UK. [69] [70] We recognise that this will suddenly lead to a drop in the ability of many companies and buildings to be able to claim net zero, which could have an unintended consequence of increased demand for offsetting – which could be addressed if there were flex offsets enabled as outlined earlier.

Measurement of Progress: C40 and SE4All 24/7 CFE Compact

Overall, we need more sophisticated ways of measuring progress against a 24/7 CFE future. The current 24/7 CFE score provides one method of tracking progress, which could be supported be a number of other methods to demonstrate a more complete picture of progress.

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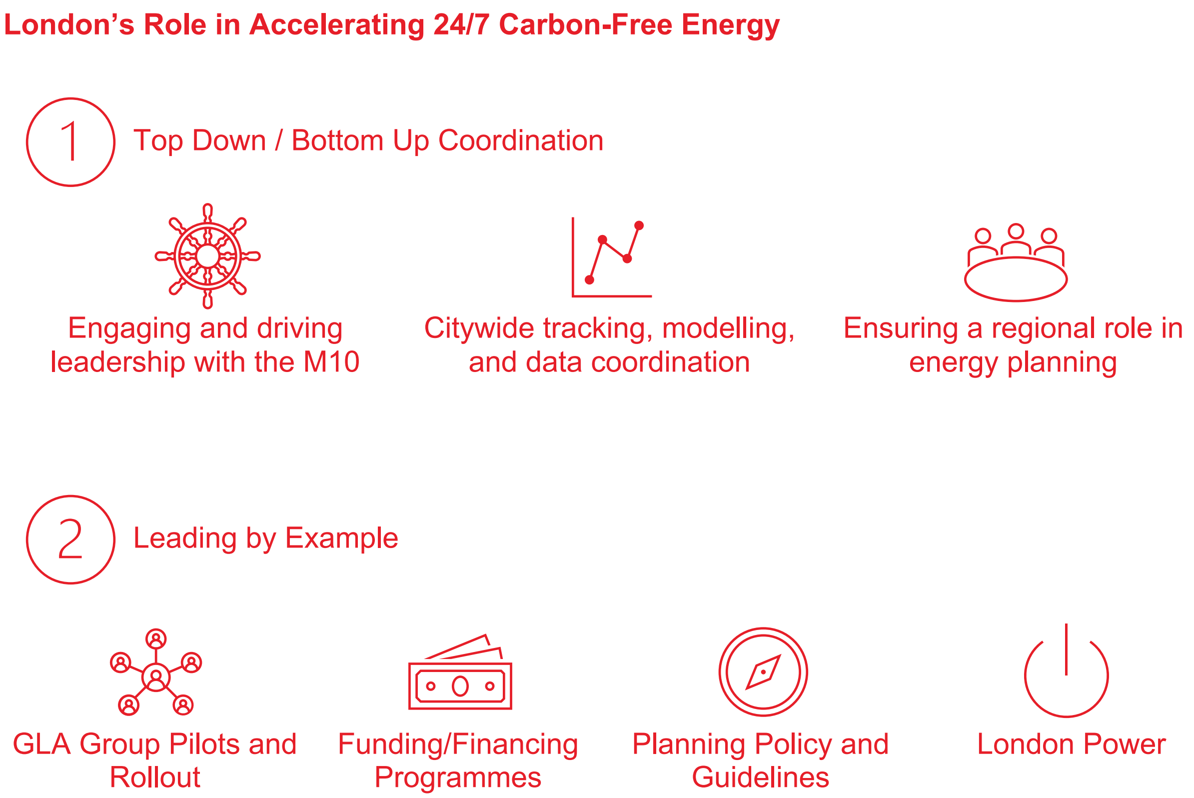
[62] World Green Building Council (2023) The Net Zero Carbon Buildings Commitment (available online)
[63] World Green Building Council (2023) What is a net zero carbon building? (Available online)
[64] C40 Cities (2023) Net Zero Carbon Buildings Accelerator (available online)
[65] EDGE (2023) Zero Carbo Pledge (available online)
[66] International Living Future Institute (2023) Living Building Challenge (available online)
[67] UKGBC (2023) Renewable energy procurement (available online)
[68] SE4ALL (2023) Join the Movement for a 24/7 Carbon-Free Energy Future (available online)
[69] UK Net Zero Carbon Buildings Standard (2023) UK Net Zero Carbon Building Standard (available online)
[70] RE100 (2023) We are accelerating change towards zero carbon grids at scale (available online)

To expand the measurement of progress towards a 24/7 CFE future, the following simple actions could be adopted in future studies which calculate a 24/7 CFE score:

- **The 24/7 CFE Score currently starts with electricity as the baseline, so the value of electrification cannot be explicitly measured**. If we could take into account non-electrified heat and transport in the baseline, the electrification fuel switching benefits would appear in the score and would provide a better way of tracking true Carbon-Free Energy in London – and potentially other cities;
- **As a tracking tool, 24/7 CFE is valuable, but for investment decisions, the cost/tonne avoided metric should also be used**. This metric makes it possible to choose between two options, for instance a heat pump or solar panels, or both. In one use case, flexing the heat pump had slightly less impact than flexing absorption chillers. In tracking the potential scale-up of an intervention, consistent baseline data should be used to track if the expected impact is realised over time. This is because grid carbon intensity is changing annually as well as hourly, and using 2022 data vs 2019 already shows that grid decarbonisation is changing the carbon savings potential (usually reducing that potential, unless on-site solar can be fully self-consumed and exported).

5. Greater London Authority: An Enhanced Role for the GLA in Driving Flexibility and 24/7 CFE

London has a critical role to play in convening stakeholders, locally and nationally, to drive a 24/7 CFE vision that accelerates localised flexibility in the GLA and other Combined Authorities and regions, leads to an accelerated decarbonisation of the grid, and protects London from disruption and costs associated with the risk of low flexibility in the future. This includes an overall role exercising its convening power, focussing on data coordination, convening private sector and continuing to bring together the power of the M10 – soon the M12 – to bring forward an organised group to coordinate with policy-makers and regulators.[71] Ultimately, the GLA can play a key role in coordinating what is happening at the local level with policy and regulators in a more centralised role.



5.1 A Top Down- Bottom Up Coordinating Role

London has a critical role to play in convening stakeholders, locally and nationally, to drive a 24/7 CFE vision that accelerates localised flexibility in the GLA and other Combined Authorities and regions, leads to an accelerated decarbonisation of the grid, and protects London from disruption and costs associated with the risk of low flexibility in the future. Ultimately, the GLA can play a key role in coordinating what is happening at the local level, with policy and regulators in a more centralised role.

[71] Centre for cities (2022) Everything you need to know about metro mayors (available online)

London Wide Tracking, Modelling and Data Coordination

Many private sector companies are already engaging with the concept of 24/7 CFE within London of their own accord. In addition, this project has designed and agreed further London pilot studies that can take place in the short term, which will see several new assets flexing to a carbon signal. There is a very important continued role needed to coordinate, track, monitor and disseminate findings from these on-going carbon flexing activities across London. Without coordination, there is higher likelihood of slower uptake, repeating work and of negative unintended consequences.

This points to an important role for GLA in convening London stakeholders in 24/7 CFE activities. Key activities include below:

- Setting up a working group of key stakeholders including boroughs, private sector, London DNOs (Distribution Network Operators) (e.g. UK Power Networks) and others who can facilitate sharing of lessons learnt and data;
- Ensuring London-wide delivery programmes and pilots are using a common method for hourly /half-hourly carbon impact accounting – in particular the Mayor's energy efficiency fund (MEEF) and Local Energy Accelerator (LEA); [72] [73]
- As more flexing takes place, testing metrics and measures for how to record and report on 24/7 CFE within London;
- Acting as a bridge between flexing asset owners and regional/ national regulator and policy makers and identifying key regulatory and policy opportunities and challenges to collectively influence – such as a London role in the Future System Operator and funding for pilots.

Engage and Drive Leadership with M10

As well as the GLA, several M10 regions are actively supporting roll out of retrofit, LAEP and planning and flexible technologies. For example, Greater Manchester Combined Authority and their 10 local authorities have been working on developing a coordinated approach to deliver LAEPs across the whole combined authority region.[74]

By engaging on a 24/7 CFE approach within the M10, the GLA could raise awareness about 24/7 CFE across England, by sharing lessons learnt and any important sources of information (e.g. data, modelling results) within this group. Bringing together this group will be essential in order to collectively determine a way to engage with regulation and policy making in this area, particularly regarding LAEPs and the role of Combined Authorities in relation to the Future Systems Operator. The national government has a key role to play in creating an enabling environment (through regulation and investments) and provide the right incentives to support Combined Authorities and other actors' efforts to adopt 24/7 CFE approaches.

5.2 Leading by Example – Enhancing and Strengthening Existing Policies and Programmes

London has key powers over the critical elements necessary for a 24/7 CFE London, and overall for enhancing flexibility at a local level. It is already leading by example, using its powers to accelerate electrification, deployment of demand side flexibility measures, and funding and financing programmes to drive decarbonisation. In the future, it can build on this leadership and continue to integrate 24/7 CFE principles into all of its programmes and policies. In this future, flexibility will be integrated into the electricity networks from supply to consumption and the data and digital infrastructure, such as a digital spine and asset register, will facilitate the required data flows for this to be possible.

[72] GLA (2018) Mayor of London's Energy Efficiency Fund (Available online)
[73] GLA (2023) Local Energy Accelerator (available online)
[74] Greater Manchester Local Energy Market (2022) GM Wide Local Area Energy Plans (available online)

- **Accelerating electrification with 'smart' controls, and implementation of demand side flexibility measures**
- **Encouraging and incentivising flexing to a carbon signal**

A review of existing policies and programmes identified the potential for the GLA to use existing policies and programmes to better embed the above principles in order to accelerate 24/7 Carbon-Free Energy and overall demand side flexibility.

London Planning Policy and Guidance

As the strategic development plan for Greater London, the London Plan (2021)[75] informs decision making on planning applications across London and is a powerful tool to drive ambition in new builds across London. The Local Plans of all of London's 32 boroughs must show general conformity with the London Plan. The London Plan includes an overarching policy (Policy SI 2) which requires major developments to be net zero carbon and requires detailed energy strategies to be produced as part of major planning applications. In addition, the London Plan (and its supplementary guidance) includes policies which require or recommend adoption across some of the key technologies known for being vital for increasing flexibility and therefore facilitating the ability to adopt a 24/7 CFE approach. For both the uptake of technology and carbon flexing, the London Plan has the potential to drive 24/7 Carbon-Free Energy through two routes:

- **Updating future London plan and guidance to incorporate technology specifications:** The GLA can begin assessing how the London Plan can be updated in the future to drive the types of demand side flexibility measures required. As the GLA has recently refreshed the London Plan (2021) and relevant supplementary guidance, there are unlikely to be immediate opportunities – but future updates should be explored and prepared. The plan is supported by London Plan guidance documents to provide further information on specific topics, for example relevant guidance includes the Energy Assessment Guidance (2022)[76] and the London Heat Network Manual II (2021)[77]. Table 4 provides an overview of the policies relating to the flexibility technologies modelled as part of this project and identifies policy gaps where there is a lack of reference to those technologies or where guidance could be strengthened.
- **Issuing guidance to Local Authorities who might wish to exceed or complement the London Plan:** The GLA should support Local Authorities within London in adopting and integrating the progressive policies and guidance which already promoted uptake of flexibility technologies, as included in Table 4, into their Local Plans as they are renewed. The GLA should also communicate with Local Authorities where their Local Plans could go further than the existing GLA policy and guidance, filling the policy gaps identified in this report.

Table 4: GLA policy review for flexibility technologies

Flexibility Technology	Potential Updates	
EV smart-charging EV Vehicle to grid charging	The London Plan policy T6 (car parking) promotes the roll out of EV charging in new development but does not specify for smart and V2G charging. However, the Energy Assessment Guidance states that applicants for major developments are required to determine the potential to reduce peak demands through modelling and investigation of flexibility measures in their energy strategy (which references smart charge points as an example).	Refine guidance with more specific promotion of EV which are flex enabled such as smart charging and V2G.
Battery Storage (Behind the Meter)	LA's Energy Assessment Guidance outlines that applicants for major developments	Refine guidance and over time require explicit the need

[75] The Greater London Authority (2021) The London Plan (available online)
[76] The Greater London Authority (2022) Energy Assessment Guidance (Available online)
[77] The Greater London Authority (2021) London Heat Network Manual II (available online)

Smart Systems	are required to consider use of thermal and electrical energy storage, as part of a flexibility solution. However, it does not specify that they should consider behind the meter battery storage or smart system specifications.	for smart systems that manage multiple assets including thermal and electrical energy storage, which should include BTM storage

Local Area Energy Plans (LAEPs)

Across London, the GLA have already been supporting the delivery of several LAEPs which assess the whole energy system of a local area and set out evidence-based recommendations for change to guide energy system transition, developed through engagement with local energy stakeholders. These have been focussed in; Isle of Dogs and South Poplar Opportunity Area in Tower Hamlets, and the Old Oak/Park Royal Opportunity Area in West London. There are a few key actions the GLA should accelerate and implement to leverage the potential of LAEPs to drive demand side flexibility and a 24/7 Carbon-Free Energy approach:

- **Promote the benefits of LAEPs and expand the delivery of LAEPs across more London Boroughs:** Whilst the output of the LAEPs does not directly constitute enforceable policy or actions, they provide costed spatial energy plans, identify priority projects, and provide clear actions across a range of stakeholders that can help shape informed energy decision making in the area. For example, London Boroughs may use LAEPs as an evidence base for new policy when updating local plans, or for allocating budgets to projects. DSOs may use LAEPs as evidence for determining local flexibility service requirements, allocating budget, and discussing funding needs with Ofgem. Developers may also look to LAEPs to inform their energy decisions. As such, LAEPs offer opportunities to drive the deployment of locally considered demand-side flexibility and the GLA should continue to play an active role supporting the delivery of further LAEPs across London. Furthermore, GLA could encourage more boroughs to undertake LAEPs, and expand the potential of 24/7 Carbon-Free Energy principles across London.
- **Integrate 24/7 Carbon-Free Energy approaches and principles within a common LAEP methodology:** Currently, approaches and methodologies for developing LAEPs are not standardised, with those being delivered to date developed at different spatial scales, using varying data inputs and offering different types of outputs. The GLA is already exploring their role in standardising the methodology, data approach and outputs for LAEPs across London, making them as accessible, interpretable and comparable as possible for London Boroughs, DSOs and other energy stakeholders. Through this guidance and coordinated approach, the GLA could drive the need for flexibility and the concept of 24/7 Carbon-Free Energy as a core element of the LAEP. This could entail setting key methodology recommendations around types of flexibility technologies which must be considered, or the use of hourly/half-hourly cost and carbon intensity profiles. Where GLA is involved in the procurement of consultants to deliver a LAEP, these recommendations could become scope requirements. This guidance should focus on the priority principles of accelerating the necessary demand side flexibility technologies and also embedding carbon flexing approaches.

GLA S106 Carbon "Offset" Scheme

Currently in the London Plan for major development proposals, London developers must meet minimum on-site operational carbon requirements for new developments, and if they are unable to, they must make an 'offset' payment into local authorities 'carbon offset fund' administered under Section 106 legislation of the Town and Country Planning Act 1990[78]. The carbon offset funds are then deployed by individual local authorities to invest locally in carbon reduction measures, such as housing retrofit, in line with GLA's guidance[79].

There is potential for the Offset fund to incentivise and drive 24/7 Carbon-Free Energy in two ways:

- **Provide guidance and information to developers on the benefits of a 24/7 CFE approach, linked to reduced S106 payment:** The mechanisms are already in place in the London Plan which allow

[78] UK Legislation S106 Town and Country Planning Act (available online)
[79] Greater London Authority (2022) Carbon Offset Guidance (Available online)

developers to demonstrate the benefits of flexibility and demand-side management technologies in their energy management strategy, reducing their operational carbon. These reductions contribute to reducing the 'shortfall' in achieving net zero carbon, and therefore reducing the amount of S106 payment required. The GLA should clearly outline how using a 24/7 CFE approach can have a beneficial impact on reducing S106 payments, therefore incentivising uptake.

- **Using Carbon 'Offset' Funds to pilot and implement flexibility technologies and carbon flexing:** Another key role that the GLA S106 Carbon "Offset" Scheme could play locally is through funding technology which supports roll out of flexibility and demand side management as well as funding projects which actively apply carbon flexing to reduce carbon. The GLA Carbon offset guidance (2022)[80] outlines how the funding should be spent by London Boroughs, specifying that the main priority of the funding is to be spent on reducing demand in existing buildings including through energy efficiency measures and improving monitoring and operation, with other priorities included being: renewable energy, low carbon heat networks, whole building retrofit including smart metering.[81] Funding could prioritise local projects that incorporate both energy efficiency and demand side flexibility measures as well as those which actively carbon flex using these technologies.

GLA Group Pilots and Roll Out

The Greater London Authority group owns property and assets across London, including those related to the London Fire Brigade, Transport for London, Metropolitan Police Service and through the London Legacy Development Corporation. There is significant opportunity for the GLA group to lead by example in rolling out carbon flexing and demand side response technology in its own assets and supply chains.

As part of this project, The London Fire Brigade, Transport for London, Metropolitan Police Service and the London Legacy Development Corporation (LLDC) were all consulted, to understand if there were any immediate opportunities to pilot demand side response technology. Opportunities were identified within TfL, modelled in the use cases, and LLDC, as well as some barriers – including concerns over battery storage as a fire risk, and emergency vehicle services unable to adopt vehicle-to-grid charging to ensure availability of vehicles at all times.

Pilots going forward should aim to:

- **Trial what is possible at an asset level:** test what operational decisions will need to be taken to maximise flexibility, and how buildings can operate in practice to test assumptions about the maximum flexibility that can be achieved with assets of a certain type – building on initial findings in the use cases.
- **Test what data should be used:** For the system benefits, understanding which signals an asset or multiple assets are matching to will matter significantly. Testing different signals to assess what will have the greatest impact and which will have unintended consequences.
- **Test for alignment on carbon and other revenue mechanisms**: assessing the correlation between carbon intensity and power prices, which can inform how to structure reward mechanisms for future flexing,
- **Assess asset impact:** asset the asset level benefits of flexing energy use to avoid high carbon periods for asset owners,
- **Assess system impact:** assess the wider consequential benefits of assets flexing to a carbon signal, including reducing curtailment and/ or turning off high carbon generators.

To lead by example, GLA should continue to look for opportunities to expand its involvement in the London pilot, through GLA owned assets and disseminate findings, to further accelerate take-up and refinement of a

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[81] Greater London Authority (2022) Carbon Offset Guidance (Available online)

carbon flexing approach across GLA Group. The GLA can also use this as an opportunity for upskilling building owners and supply chain in the process, which can then help support future adoption of 24/7 CFE approach.

London Power Tariffs

London has created the innovative London Power energy supply company with Octopus, to offer affordable and green energy to London. With energy costs at a record high in the UK, London Power is not currently bringing on new customers. However, there is an opportunity for retail suppliers to become leaders in offering new green tariffs under a 24/7 CFE approach.

There has been significant criticism of existing green tariffs[82], provided in the market today, as they do not create additional renewable supply. Through London Power, London could pioneer a true green tariff and trial a new business model to provide guaranteed renewable power to homes and businesses. Being able to offer this may depend on how National Grid ESO takes forward their current CrowdFlex trials and Demand Flexibility Service (DSF) and whether there is scope to trial flexing to a carbon signal rather than specifically peak times.[83] [84] However, the impact would be significant if this approach could be trialled in London and expanded beyond.

Retrofit Accelerators

The GLA manage and run a number of programmes which are driving building scale decarbonisation on the ground. The GLA is driving Low Carbon Retrofit Accelerators across key areas for decarbonisation: 1) Retrofit Accelerator – Workplaces 2) Retrofit Accelerator – Homes 3) Social Housing Retrofit Accelerator.[85] As part of these programmes, GLA is driving delivery through the development of delivery units, supporting supply chains, administering training and guidance, bringing together working groups and more. Two avenues could be explored to pursue 24/7 CFE approach in relation to the existing retrofit accelerators:

- **Integrate demand-side management:** Current programmes focus primarily on energy efficiency with some demand-side measures supported, but over time could be expanded to include encouragement of 24/7 CFE and carbon flexing practices, particularly demonstrating an improved business through the associated carbon savings.
- **Programme expansion:** The GLA also could consider if there are any lessons learnt and potential expansion/ replication of such programmes for flexibility and carbon flexing specific technologies e.g. could methods of engagement with asset owners be used to leverage roll out of flexibility and demand side management technologies.

Local Energy Accelerator (LEA)

Local Energy Accelerator (LEA) is a £6m programme providing expertise and support to organisations to develop clean and locally generated energy projects.[86] This includes projects such as installing heat pumps, solar panels, batteries and EV charging.

When providing funding to roll out these flex enabling technologies, there is an opportunity for the GLA to promote (or require if possible) the adoption of comprehensive solutions which align with 24/7 CFE approach. For example, the City of London Corporation recently procured a study into the feasibility for demand-side flexibility, and the potential development of a smart-grid, at its Barbican and Guildhall sites through the LEA framework. One of the project's requirements is to develop an emissions assessment methodology to be utilised on future LEA projects and programmes that accounts for varied half-hourly grid carbon intensity, and how this can be used to incentivise demand-side flexibility deployment.

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[82] Climate Change Committee (2020) Corporate Procurement of Renewable Energy – Implications and Considerations (available online)
[83] National Grid ESO (2023) CrowdFlex (Available online)
[84] National Grid ESO (2023) Demand Flexibility Service (DFS) (Available online)
[85] GLA (2023) Low Carbon Accelerators (available online)
[86] GLA (2023) Local Energy Accelerator (available online)

Mayor's Energy Efficiency Fund (MEEF)

The Mayor of London's Energy Efficiency Fund (MEEF)[87] is a £500m investment fund established in 2018 by the GLA with funding from the European Commission. The fund aims to help achieve London's ambition of being a net zero carbon city by 2030, by addressing market failures in London's low carbon sector by providing flexible and competitive finance to enable, accelerate or enhance viable low carbon projects across London. As part of the MEEF funding mechanism, every fundable intervention must be able to demonstrate carbon benefit (for example applying carbon factor of solar panel installation). In isolation, many demand-side flexibility technologies have not traditionally had clear and adoptable carbon factors (e.g. battery storage, smart controls).

Through the citywide flexibility modelling, we found that technologies like battery storage and demand shifting through smart-controls could offer clear operational emissions savings, even when delivered in isolation. The MEEF could consider funding a trial project which would apply and test a carbon factor to these technologies and then assess the end carbon impact of the project. They could also encourage or specify that the trial project also apply carbon flexing and assess the carbon impact of the flexing as well as the technologies.

GLA Green Bonds

In February 2022, the London Mayor announced £90 million towards new green bonds, to be used to unlock over £500 million for zero-carbon projects.[88] The money from the GLA is used to leverage high-impact green investment opportunities across all London boroughs, with project examples including solar PV, heat pumps, and district heating networks.

The green bonds scheme could be another programme where GLA could advise, administer and monitor potential for flex enabled technologies and a 24/7 CFE approach to be embedded in relevant projects.

The Mayor's Business Climate Challenge and Climate Leaders

The Mayor's Business Climate Challenge (BCC) is a programme which supports businesses to reduce their energy consumption, to accelerate building decarbonisation efforts in London.[89] An extension of this programme is the London Business Climate Leaders, which sees the Mayor of London working with 11 prominent London businesses to push the boundaries of what they can do to achieve net zero, looking at innovative solutions. Many private sector companies are already exploring 24/7 CFE approaches to accelerate their way towards their own corporate net zero targets. Through these channels the GLA can accelerate private sector commitment by:

- **Champion 24/7 CFE approach:** use these channels to engage with more private sector companies, outlining what we know to date about 24/7 CFE and its benefits for both asset and system wide decarbonisation, which are demonstrated through the London citywide modelling.
- **Drive best practice standards and commitments**: champion the forthcoming UKGBC guidance on time-based matching along with 24/7 CFE principles, and also encourage signing up to the 24/7 CFE Compact to incentivise further commitments to 24/7 CFE.[90] [91] It is recommended that these groups are represented on the stakeholder working group that the GLA could convene on 24/7 CFE.

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[87] GLA (2018) Mayor of London's Energy Efficiency Fund (Available online)
[88] GLA (2022) Mayor announces £90 million towards new green bonds (available online)
[89] GLA (2023) The Mayor's Business Climate Challenge (available online)
[90] UKGBC (2023) Renewable energy procurement (available online)
[91] SE4ALL (2023) Join the Movement for a 24/7 Carbon-Free Energy Future (available online)

5.3 Learning from GLA for Other Cities

There are a number of critical learnings and implications for other cities around the world that may have similar powers to London. The C40 24/7 CFE White Paper has taken the Google methodology of 24/7 and translated it into principles for cities which include: Time matched procurement; local procurement; technology inclusive; enabling new generation; and ultimately maximising system impact.[92] In the paper, London is categorised as a Pioneer City, which includes characteristics of high availability of carbon-free energy, good financial resources and control over electricity system regulation – although London has low control over electricity system regulation.

The paper identified recommendations for Pioneers which shows the potential for 24/7 across London focussed on implementing demand side management measures and working with energy regulators. But beyond this, it is clear London has a number of powers it can use to support a 24/7 CFE approach. These findings could also be applicable to other cities, and include:

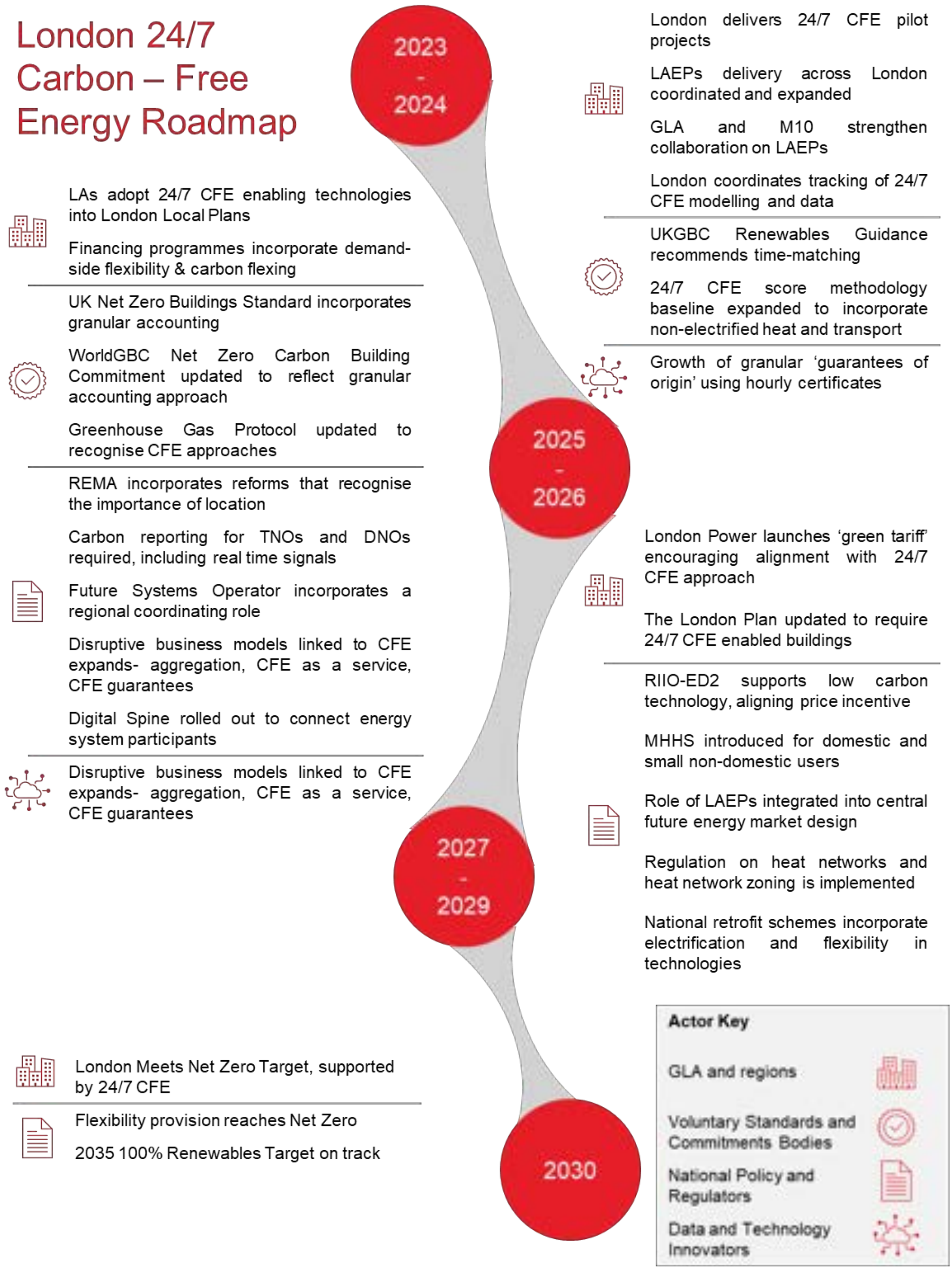
Learnings for C40 and Other Cities

Planning Powers	Specifying demand side flexibility technologies in planning policy.
Accelerators, Funding and Finance Programmes	Numerous cities provide accelerators for retrofit, and the London examples demonstrate there is a potential to tailor and update these to adopt demand side flexibility measures and encourage and incentivising flexing to carbon signals.
Convening and Influence	Cities like London have tremendous 'soft powers' and can use their influence and convening potential to raise ambition levels, set visions and establish strategic directions for stakeholders on 24/7 CFE.
Leading by Example with City Owned Assets	City operations represent a significant potential to pilot approaches, disseminate findings and champion best practice.
Locally Owned and Coordinated Energy Strategy	As cities increasingly seek to support local energy projects, there are critical roles to play in coordinating what technologies are implemented and how they're used, as well as using local power.

[92] C40 Cities (2022) 24/7 Carbon-free energy for cities: Opportunities, challenges and pathways for urban energy systems (available online)

6. The Roadmap

The pathway to a 24/7 Carbon-Free Energy system can be accelerated, and London has an essential role to play in supporting this, alongside policy-makers and regulators, data and technology innovators, and voluntary standards and commitments driving private sector action. The London 24/7 Carbon Free Energy Roadmap outlines the key steps to be taken at key intervals in time, paving the way for a 24/7 carbon-free future.



Appendix 1 – Citywide Scale Modelling Technical Report

ARUP
ENERGYUNLOCKED
Quantenergy

Citywide modelling technical report

London’s CFE performance today and what a 24/7 CFE future could look like for London in 2030

June 2023

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Executive Summary

This report examines London's current Carbon Free Energy (CFE) performance and the citywide potential for CFE-driven demand-side flexibility by 2030.

Currently, around 44% of London's hourly electricity demand is met with carbon-free supply. By 2030, this is expected to increase to 63% as a result of supply-side electricity grid decarbonisation. However, this number could be further increased by responding demand-side flexibility to carbon signals.

We projected the deployment of demand-side flexibility across London under two scenarios ('flex-enabled' and 'max-flex') and modelled the impact of operating this flexibility to maximise the matching of electricity demand with carbon-free supply. Table 0.1 shows the headline results. We found 4.1–7.8 GW of demand-side flexibility London-wide by 2030 and estimate that this flexibility could be used to avoid 5.6%–9.3% of London's electricity consumption emissions- in 2030. If London's guide price of £95/tCO_2 is used to estimate the value of the avoided carbon at a high-level, this equates to between £17m–28.5 m annually. This is in addition to the significant carbon benefits of electrification, and the wider economic benefits of demand-side flexibility's ability to reduce network reinforcement requirements.

Encouragingly, we found that responding to CFE signals could align well with other priorities for demand-side flexibility. In our CFE flex modelling results, 80% of major demand turn-down events occurred during typical electricity peak hours, while 81% of major demand turn-up events occurred outside these hours. These major turn-down/up events are defined as when London's total electricity demand in an hour was at least 2 GW lower/higher than without the operation of flexibility. Given the complementary nature seen here, we suggest that the carbon benefits offered by CFE flexing can be a valuable mechanism to incentivise immediate deployment of much-needed flexibility for London which can be leveraged for delivering on other priorities too.

We suggest that heat network operators and residential buildings will be a priority to engage; our results show these buildings contribute the most to avoided emissions in the 2030 flex scenarios. Under ambitious targets for the future electrification of heat, electrified thermal storage is expected to be the most impactful demand-side flexibility technology.

	2030 no flex	2030 CFE flex enabled	2030 CFE max flex
CFE score	62.9%	65.5%	67.2%
Emissions reductions (compared to 2030 no CFE flex)	-	5.6% (180 ktCO_2 p.a.)	9.3% (300 ktCO_2 p.a.)
Maximum flex response	No flex operation modelled	4.1 GW	7.8 GW
Number of hours in 2030 with >3GW flex response	No flex operation modelled	600	1,600
Heat pump, district heating, EV, and PV deployment	According to Accelerated Green targets		
Energy storage, DSR, smart-charging and V2G deployment	No flex operation modelled	According to typical projections in the literature	According to maximum projections in the literature

Table 0.1: 2030 citywide CFE flex modelling results for London (Accelerated Green is the Mayor of London's preferred energy transition pathway for London to reach net zero by 2030, developed by Element Energy)

Glossary

Term	Definition
BEIS	Department of Business, Energy and Industrial Strategy (now DESNZ)
CFE	Carbon Free Energy
COP	Coefficient of Performance
DESNZ	Department for Energy Security and Net Zero
DFES	Distributed Future Energy Scenarios
DLUHC	Department for Levelling up, Housing and Communities
EV	Electric Vehicle
FES	Future Energy Scenarios
GLA	Greater London Authority
ICCT	International Council on Clean Transportation

Term	Definition
kW/MW/GW	Kilowatt/megawatt/gigawatt – units of power
kWh/MWh/GWh	Kilowatt-hour/megawatt-hour/gigawatt-hour – units of energy
LAEP	Local Area Energy Plan
LBSM	London Building Stock Model
National Grid ESO	National Grid Electricity System Operator
Ofgem	Office of Gas and Electricity Markets
PV	Solar Photovoltaics
UKPN	UK Power Networks
V2G	Vehicle-to-grid

1. Introduction

1. Introduction

We have examined the potential for citywide adoption of a 24/7 CFE approach for demand-side flexibility to contribute to London's decarbonisation ambitions

This report sits in a wider programme of work being completed by Arup, Energy Unlocked and Quantenergy on behalf of the GLA and C40 Cities. The programme entails development of an implementation roadmap for driving the deployment of demand-side flexibility and uptake of a 24/7 Carbon Free Energy (CFE) approach in London. It also involves the design of a pilot project to demonstrate the potential for 24/7 CFE flexing and to examine key considerations.

Why do we need demand-side flexibility?

Demand-side flexibility refers to the changing (i.e., increasing, reducing or shifting) of grid electricity consumption in response to a signal. Demand-side flexibility is expected to play an important role in enabling London's transition to net zero by helping to match electricity demand with variable renewable supply, reducing the need for dispatchable fossil fuel generation.

As London seeks to rapidly electrify heating and transport to achieve its decarbonisation goals, the capacity of electricity networks will experience increasing pressure; demand-side flexibility will be one of London's key levers for managing constraints on these networks, reducing works and disruption to London's economy and facilitating the increased deployment of low carbon technologies.

What is a 24/7 CFE approach?

A '24/7 Carbon Free Energy (CFE)' approach – the concept that every kilowatt-hour of electricity demand should be matched with carbon-free electricity supply for every hour of the day, every day of the week– has been championed by companies with ambitious goals for energy procurement to go beyond matching annual electricity consumption to annual renewable production. The approach measures performance, and progress towards 24/7 CFE, through measuring a 'CFE Score', the average percentage of electricity consumption matched to carbon-free supply on an hourly basis over a year.[1]

Extending this approach to demand-side flexibility sees buildings flex their electricity consumption in response to carbon signals to maximise their CFE score. The approach recognises, and measures, the benefits of this kind of operation.

What is the aim of the citywide modelling?

This report's citywide modelling aims to examine the extent of the opportunity for CFE-driven flexibility in London by 2030. It also identifies key opportunities and considerations to inform the wider programme of work, such as the implementation roadmap.

To do this, the report first explores the CFE performance of London now and in 2030 without the operation of demand-side flexibility, modelling the various electricity demands of London's buildings to hourly level.

Then, 2030 projections of London's demand-side flexibility capacity are defined and a high-level mapping exercise is performed to distribute capacity to borough-level.

Finally, the operation of this flexibility capacity is modelled to maximise CFE matching in 2030. The results are examined to inform the assessment of the extent of the opportunity and the key considerations.

2. London's CFE performance today

2. London's CFE performance today

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To calculate London's current CFE score, we performed hourly citywide electricity demand modelling and considered distributed solar PV and the CFE proportion of grid supply

Developing a baseline CFE score for London

To gauge London's current performance, and the progress needed to achieve its aim of 24/7 CFE, we developed an estimate of London's 'CFE score' as a city.

CFE score is a measure of the percentage of electricity consumption matched to carbon-free electricity supply on an hourly basis over a year. Google have developed a methodology for calculating CFE scores which considers contracted PPAs and the CFE proportion of grid supply as the options to match demand with CFE supply at each hour of the year. For a citywide score, we considered local solar PV generation rather than PPAs. Therefore we define CFE score as:

$$CFE\ score = \frac{Embedded\ CFE + Consumed\ Grid\ CFE}{Total\ demand}$$

A score of 100% would mean every kilowatt-hour of electricity consumption is matched to carbon-free supply in every hour of the year. To estimate London's citywide score, three hourly profiles were required:

1. The electricity demand of London's buildings
2. The electricity generation of distributed solar PV
3. The CFE proportion of grid supply

At each hour, any solar PV generation was matched to electricity demand. For the hour's remaining electricity demand, the CFE proportion of grid supply in the hour was used to determine how much was matched to carbon-free supply.

Floorspace-based energy demand modelling was performed to estimate the annual electricity demands of London's various building types. The London Building Stock Model (LBSM) provided floorspace data, to which we applied kWh p.a./m^2 benchmarks from DESNZ's National Energy Efficiency Data-Framework (NEED) and Building Energy Efficiency Survey (BEES).[2,3] These annual demands were distributed to hourly resolution using data from Octopus Energy, Ofgem and De Montfort University.[4] The building types from the LBSM included in the citywide demand modelling are shown in Table 2.1. The hourly demand profiles were uplifted slightly to ensure demand profiles captured all demand before self-consumption of PV.

London's annual solar PV generation was estimated using several installed capacity and annual yield datasets. This was distributed to hourly resolution based on a profile of global tilted irradiation for a point.

The hourly profile for the CFE proportion of grid supply was taken from National Grid ESO historical generation mix data for the grid in the London region.[5] Solar, hydro, wind, and nuclear were considered to contribute to the average grid CFE percentage at each hour.

Results of the analysis are presented on the following page and more details on the components of this modelling are provided in the technical appendix.

Domestic	Non domestic
• Flats • Terraced houses • Other domestic (i.e., detached and semi-detached houses)	• Community • Education • Hospitality • Leisure • Medical • Office • Retail • Warehouses/Stores

Table 2.1: LBSM building types included in the citywide demand modelling

2. London’s CFE performance today

We estimate that London’s CFE score was 44% in 2022 and 24% in 2019, with supply-side decarbonisation driving the significant improvement; however, more progress is still needed

Baseline CFE score results

The hourly profiles for buildings’ electricity demands and distributed solar PV generation were developed for 2019, the most recent year of data in the LBSM.

Using National Grid ESO’s London region grid generation mix data for 2019 returns a CFE score of **23.5%**. This suggests that around a quarter of London’s hourly electricity usage in 2019 was carbon-free. Distributed solar PV generation only contributes 0.1% to this score.

However, applying the grid mix data for 2022 to the same electricity demand and solar PV generation profiles returns a score of **43.8%**. Assuming that buildings’ electricity demands in 2022 are largely alike to 2019, this suggests that close to half of London’s hourly electricity usage in 2022 was carbon-free. Figures 2.1 and 2.2 visualise the hourly CFE matching contributing to the 2019 and 2022 scores with heatmaps; hours with the most CFE matching are shown in green, while those with the least are shown in black.

The improvement of score between 2019 and 2022 is highly encouraging and highlights the success of supply-side electricity grid decarbonisation over recent years. However, significantly more progress will be required for London to reach the goal of 100% 24/7 CFE. This will require further phasing out of dispatchable gas generation, making progress incrementally more challenging; in this context, demand side flexibility will be a fundamental lever for London to meet its goals and match every future kilowatt-hour with low-carbon supply. Today, no carbon-driven demand-side flexibility contributes to matching electricity demand to the grid’s CFE content.

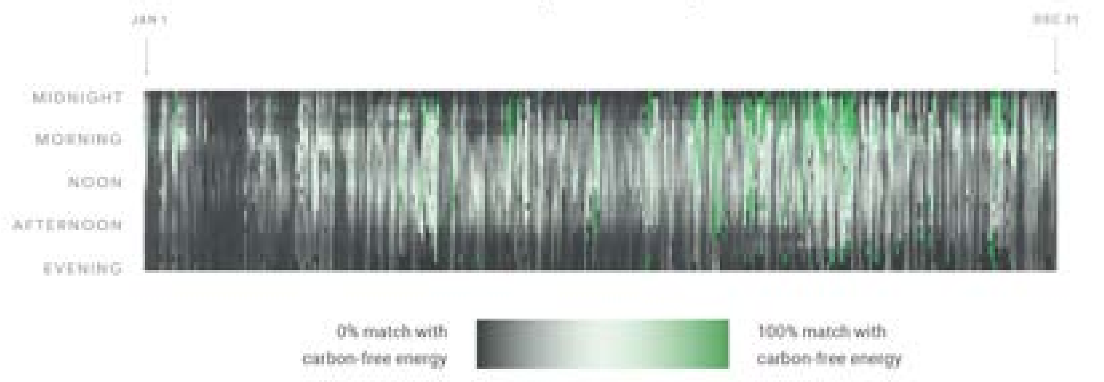

Figure 2.1: 2019 London hourly CFE matching (23.5% CFE)

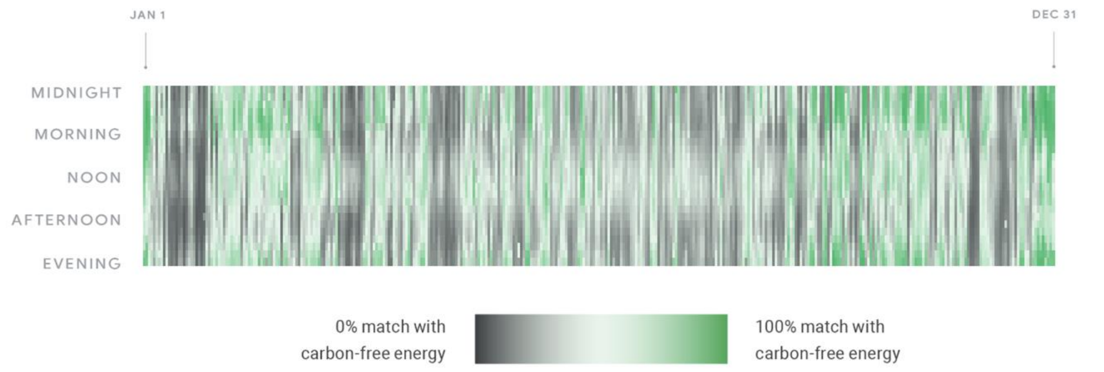

Figure 2.2: 2022 London hourly CFE matching (43.8% CFE)

3. London’s CFE performance in 2030

3. London's CFE performance in 2030

To develop an estimate of London's CFE score in 2030, we needed to account for changes to buildings' electricity demands due to the electrification of heat and transport

Developing a 2030 CFE score for London

To examine the citywide potential for demand-side flexibility to contribute to London's decarbonisation ambitions by 2030, we needed to first develop a picture of London's future CFE performance without the operation of CFE-driven flexibility.

Section 2 outlined the three hourly profiles contributing to the calculation of London's citywide CFE score: the electricity demands of London's buildings; the electricity generation of distributed PV; and the CFE proportion of grid supply. Significant changes to all these profiles are anticipated by 2030, caused by the electrification of heat and transport, deployment of rooftop PV, and the continued supply-side decarbonisation of grid electricity. To estimate London's 2030 CFE score, we needed to account for the changes to the baseline profiles.

Changes to the electricity demands of London's buildings

The Mayor of London's ambitious 'Accelerated Green' pathway for London's energy transition (see Figure 3.1 on the following page) targets mass electrification of heat and transport, and widespread fabric energy efficiency improvement of buildings.[6] New developments across London are also expected to be delivered between 2019 and 2030. This means the 2030 electricity demand profiles needed to consider:

- Large increases in the numbers of electrically-heated buildings
- High fabric energy efficiency in those buildings
- Large increases in the numbers of electric vehicles charging at buildings
- Electricity demands of new buildings

Increases in the numbers of heat pump- and heat network-heated buildings were aligned with citywide modelling completed by Element Energy for the Accelerated Green pathway.[7] We accounted for Accelerated Green targets for improved fabric energy efficiency when modelling the annual heat demands of these electrically-heated buildings. Electrically-heated buildings' annual heat demands were distributed hourly for different building types based on occupancy and temperature setpoint assumptions, and coefficients of performance (COPs) were applied to convert hourly heat demand to electricity demand for these buildings.

The total number of electric cars and vans in London by 2030 was also aligned to the Accelerated Green targets and all of these vehicles' charging loads were modelled. Vehicles' charging loads were assigned to different domestic and non-domestic building types. This analysis used assumptions used by the International Council on Clean Transportation (ICCT), accounting for varied levels of home charging availability in different domestic property types, and other high-level assumptions detailed in the technical appendix.[8] The hourly charging loads of vehicles at different building types (without flexibility operation) were based on profiles developed by National Grid ESO.[9]

The electricity demands of new developments delivered between 2019 and 2030 were also considered. Housing and commercial floorspace projections from the House of Commons and Department for Levelling Up, Housing and Communities (DLUHC) were used for this.[10,11]

Overall, these changes result in an increase to London's annual electricity demand of 10% between 2019 and 2030 in our modelling.

3. London's CFE performance in 2030

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We also needed to account for increases in the amount of rooftop PV generation, and continued supply-side electricity grid decarbonisation

Changes to distributed solar PV generation

The Accelerated Green pathway also targets widespread deployment of rooftop PV by 2030, leading to large increases in future distributed solar PV generation.

We developed the 2030 hourly distributed PV generation profile to align with Element Energy's modelling for the Accelerated Green pathway, which predicts 1,210 GWh of annual domestic generation and 227 GWh of annual non-domestic generation in 2030.

This represents an increase of over 10 times the amount of annual distributed PV generation between 2019 and 2030 in our modelling.

Changes to the CFE proportion of grid supply

Section 2 outlined the significant improvement in London's CFE score between 2019 and 2022 as a result of supply-side electricity grid decarbonisation.

Given the UK Government's commitment to fully decarbonise Great Britain's electricity supply by 2035, this supply-side grid decarbonisation is anticipated to continue, and the hourly CFE proportion of grid supply in 2030 is anticipated to increase.[12]

To account for this, and produce an estimate of the hourly average CFE percentage of London's electricity grid in 2030, we adjusted the proportion of solar, hydro, wind, and nuclear generation at each hour of the grid mix data for the London region in 2022 by changes to the contribution of each technology to annual national generation between 2022 and 2030 from National Grid ESO's most recent Future Energy Scenarios (FES) work.[13]

With a 2030 projection for the hourly average CFE percentage of London's electricity grid, we were able to also produce a projection of the hourly average grid carbon intensity in 2030, aligned to National Grid ESO FES projections.

More details on the components of the approach for developing the 2030 hourly profiles of electricity demand, PV generation and average grid CFE percentage are provided in the technical appendix.

Accelerated Green: London's pathway to 2030

In 2022, the Mayor of London selected a preferred pathway for London to reach net zero by 2030. Named the 'Accelerated Green' pathway, it prescribes highly ambitious deployment targets for interventions and electrified technologies. By 2030, the pathway targets:

- 2.2 million heat pumps installed
- 1.5 GW of rooftop solar PV deployed
- 460,000 domestic connections to district heat networks
- Reductions to the total heat demand of London's buildings of almost 40% through building fabric improvements
- 46% of car miles driven by electric vehicles

These will result in significant changes to the electricity demands of London's buildings.

Figure 3.1: Accelerated Green pathway summary

3. London's CFE performance in 2030

Under Accelerated Green electrification targets, we estimate London's 2030 CFE score to be 63%; this could be further improved through leveraging demand side flexibility

London's 2030 CFE score

With estimates of the hourly profiles for London's electricity demand, Solar PV generation, and average grid CFE percentage in 2030 assembled, an estimate of London's 2030 CFE score could be developed.

Under Accelerated Green electrification targets, we estimate London's 2030 CFE score to be **62.9%**, a significant improvement on the 2022 score which reflects further anticipated supply-side decarbonisation. The heatmap in Figure 3.2 visualises the hourly CFE matching for this modelling, with notably more CFE matching than Figures 2.1 and 2.2. Distributed solar PV contributes 1.1% towards this score.

This 2030 CFE score is without any kind of operation of demand-side flexibility. Widespread adoption of the 24/7 CFE approach could drive improvement to this score further, particularly as the technologies targeted in the Accelerated Green pathway, such as EVs and district heating, offer significant potential for demand-side flexibility.

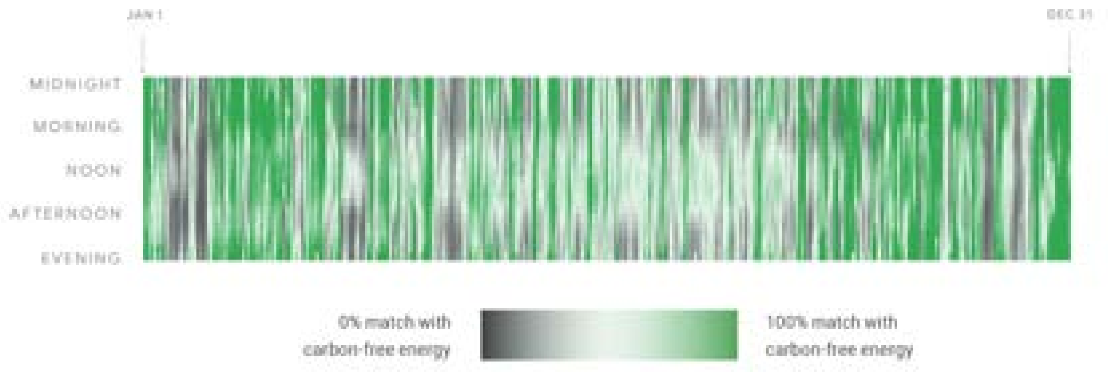

Figure 3.2: 2030 London hourly CFE matching (62.9% CFE)

Consideration of flexibility in this 2030 CFE score

Note that although Element Energy's analysis for the Accelerated Green pathway examines some demand-side response (DSR) at a high-level, **no demand-side flexibility operation is considered for this 2030 CFE score**. This allows a comparison to be made later between the CFE-flex scenarios and *not* operating demand-side flexibility at all. As Element Energy's consideration of DSR was at a high-level, and there are not specific deployment targets as part of the pathway, it does not translate into an hourly-resolution adjustment to the electricity demand profiles over the entire year (the granularity needed to develop the CFE score)

Figure 3.1: Consideration of flexibility in 2030 CFE score

4. Flexibility deployment by 2030

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4. Flexibility deployment by 2030

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For us to assess the potential impact of demand-side flexibility in 2030, we needed to define the relevant demand-side flexibility technologies for London and project their deployment

To assess the impact of CFE-driven demand-side flexibility to London in 2030 we needed to define the relevant technologies and project the deployment of their capacity by 2030.

Defining demand-side flexibility technologies

For London's buildings to engage in demand-side flexibility in 2030, they will need to be equipped with technology that enables them to flex their grid electricity consumption in response to signals. With the appropriate technology, there are ways to flex a building's grid electricity consumption for all its service demands:

- Unnecessary demands: These are demands which are not necessary for a building to meet – a building can flex its grid electricity consumption by shedding them (not meeting the demands). For example, turning off small power equipment on standby.
- Non-time-critical demands: These demands do not need to be met at a specific time, but rather within a certain time window – a building can flex its grid electricity consumption by meeting the demand at a different time within a required time window. For example, through smart-charging, a building could sufficiently charge an EV at the most desirable time it is plugged in overnight, rather than as soon as it is plugged in.
- Time-critical demands: These demands are the most critical and must be met at a specific time. For a building to flex its grid electricity consumption but still meet these demands, it must use energy storage, charged previously. For example, a building could meet time-critical IT server electricity loads through a battery, charged earlier in the day. Alternatively, a building could meet critical morning demands for hot water through a hot water tank, heated at an earlier time by a heat pump.

We developed a list of the most relevant technologies for London's buildings to facilitate the flexing of grid electricity consumption while meeting buildings' various types and categories of service demands. These are presented in Table 4.1 on the following page.

Projecting deployment of these technologies by 2030

While the Accelerated Green pathway prescribes specific targets for the deployment of heat pumps, district heating, EVs, and rooftop PV, it does not offer such targets for the demand-side flexibility technologies we define in Table 4.1.

Therefore, we defined two scenarios for the deployment of these technologies in London by 2030 for every building type considered:

- 'Flex-enabled', based on typical values in the literature
- 'Max-flex', based on maximum values in the literature

The projections for each technology under the two scenarios are detailed in Table 4.2. These projections draw from and build on literature including the National Grid FES 2022; UKPN Distributed Future Energy Scenarios (DFES) 2022; Flexibility in Great Britain by Imperial College and the Carbon Trust; Octopus Energy flexibility trial findings; and DESNZ and Ofgem's Smart Systems and Flexibility Plan 2021.[14,15,16,17] Further detail is provided in the technical appendix.

4. Flexibility deployment by 2030

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Relevant demand-side flexibility technologies for London include battery storage, thermal storage, smart EV charging, vehicle-to-grid, and other smart load shifting

Technology	Category	Description
Behind-the-meter (BTM) battery storage	Energy storage	Perhaps the most flexible of these technologies, batteries store electrical energy for use at another time. Stationary batteries can charge from the grid or on-site PV generation and discharge to meet any of a building's electrical loads, whether time-critical or not. Lithium-ion batteries are the most common form of stationary battery storage. These batteries can respond almost instantly to a signal and are highly efficient, minimising energy losses through the storage process. However, they can be expensive (although prices are widely anticipated to continue reducing over the coming decade) and can present fire risks in urban environments.
Thermal storage	Energy storage	With electrical heating technologies like heat pumps, a thermal store can heat up and load the grid at an earlier time to supply space heating and/or hot water at another time. Hot water tanks are a common and inexpensive form of thermal storage, although some buildings may not have space available for a tank. District heat networks' large energy centres provide vast amounts of thermal storage to flex, removing the need for space in individual properties. A building's inherent thermal inertia is also a form of thermal storage – a building can be heated slightly earlier to respond to a signal.
EV smart-charging	Non-time-critical demand shifting	Often EVs will be plugged in for more time than needed to sufficiently charge their batteries. Smart-charging sees EVs batteries charged at the most desirable times in a given plugged in period, rather than as soon as plugged in. Smart-charging is only relevant for chargers that see vehicles plugged in for extended periods – i.e., home chargers rather than public fast chargers. Regulations now require new private charge points to be enabled for smart functionality.[18]
EV vehicle-to-grid (V2G)	Energy storage	Through bi-directional chargers, V2G extends the smart-charging concept to see vehicles use energy in their batteries to supply back to meeting a building's electrical loads, or back to the grid, at times over the period it is plugged in for. A vehicle engaging in V2G over a period would still need to charge its battery sufficiently over the time period. Similarly to smart-charging, V2G is only relevant for chargers with vehicles plugged in for extended periods. V2G is less mature than other technologies, still undergoing commercialisation.
Smart shifting of appliances and cooling demands	Non-time-critical demand shifting	Through smart systems deployment in appliances and building management systems, other non-time-critical electrical loads can also be shifted to other times, while unnecessary loads can be shed through use of these controls.

Table 4.1: Demand-side flexibility technologies considered in citywide modelling

4. Flexibility deployment by 2030

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We assembled two scenarios for the deployment of London's demand-side flexibility technologies by 2030: 'flex-enabled' and 'max-flex'

Technology	Value	2030 'Flex enabled' projection	2030 'Max flex projection	Notes
Behind-the-meter battery storage	Domestic installed capacity	88 MWh	190 MWh	Assumed to be Lithium-ion. Note that figures include behind-the-meter only; larger supply-side batteries were out of the scope of this study.
Behind-the-meter battery storage	Non-domestic installed capacity	380 MWh	820 MWh	Assumed to be Lithium-ion. Note that figures include behind-the-meter only; larger supply-side batteries were out of the scope of this study.
Thermal storage	Domestic installed capacity (decentralised)	11 GWh	25 GWh	Note that figures only refer to electrified thermal storage (i.e., thermal storage heated by a heat pump or resistance heater).
Thermal storage	Non-domestic installed capacity (decentralised)	7 GWh	17 GWh	Note that figures only refer to electrified thermal storage (i.e., thermal storage heated by a heat pump or resistance heater).
Thermal storage	Heat networks installed capacity	30 GWh	30 GWh	Note that figures only refer to electrified thermal storage (i.e., thermal storage heated by a heat pump energy centre).
EV smart charging	Demand shiftable to another hour during active window	60%	80%	Applied to aggregated profile. Assumed active window is 17:00-07:00. Assumed to only be available for cars with home charging (~50% of cars) and vans charging at non-domestic premises overnight.
Vehicle-to-grid	Proportion of EVs that participate in V2G during active window	4%	7%	Assumed active window is 17:00-07:00. Assumed to only be available for cars with home charging and vans charging at non-domestic premises overnight. 70% of total participating EV battery capacity is assumed to be available.
Smart shifting of appliances and cooling demands	Domestic demand shiftable to another hour	7%	19%	Applied to aggregated profile. Demand must be shifted within a maximum of 4 hours earlier/later.
Smart shifting of appliances, and cooling demands	Non-domestic demand shiftable to another hour	5%	10%	Applied to aggregated profile. Demand must be shifted within a maximum of 4 hours earlier/later.

Table 4.2: Demand-side flexibility deployment assumptions for London by 2030

4. Flexibility deployment by 2030

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We mapped the London-wide projections of demand-side flexibility technologies to borough-level

Spatially mapping 2030 demand-side flexibility technologies

In addition to projecting the deployment of demand-side flexibility technologies citywide by 2030 (see Table 4.2) for each building type, we performed a high-level mapping exercise to distribute London-wide capacity to borough-level. The spatial mapping of future flexibility will be crucial for its role in helping to manage local electricity constraints that arise from electrification of heat and transport; the mapping exercise presented here helps to provide an initial indication of where different types of capacity may be most available in 2030, which can be further built on in studies like Local Area Energy Plans (LAEPs).

The mapping exercise leveraged LBSM data on the numbers and floorspaces of each building type in each borough, 2021 Census data on the distribution of heating types in each borough, and other datasets to distribute capacity across boroughs. For example, domestic battery and thermal storage capacities were distributed based on the number of domestic units, with houses (terraced and other) weighted twice as heavily as flats (based on analysis of English Housing Survey data), while heat network thermal storage was mapped based on the distribution of existing London heat networks, based on the Census data.[19,20] Full details of the distribution methodology for each technology are provided in the technical appendix.

Figures 4.1–4.7 across the following pages present this spatial mapping for the core 2030 flex-enabled deployment scenario. Labels in these maps show each borough's total 2030 capacity, while boroughs are coloured based on their capacity normalised per domestic or non-domestic unit.

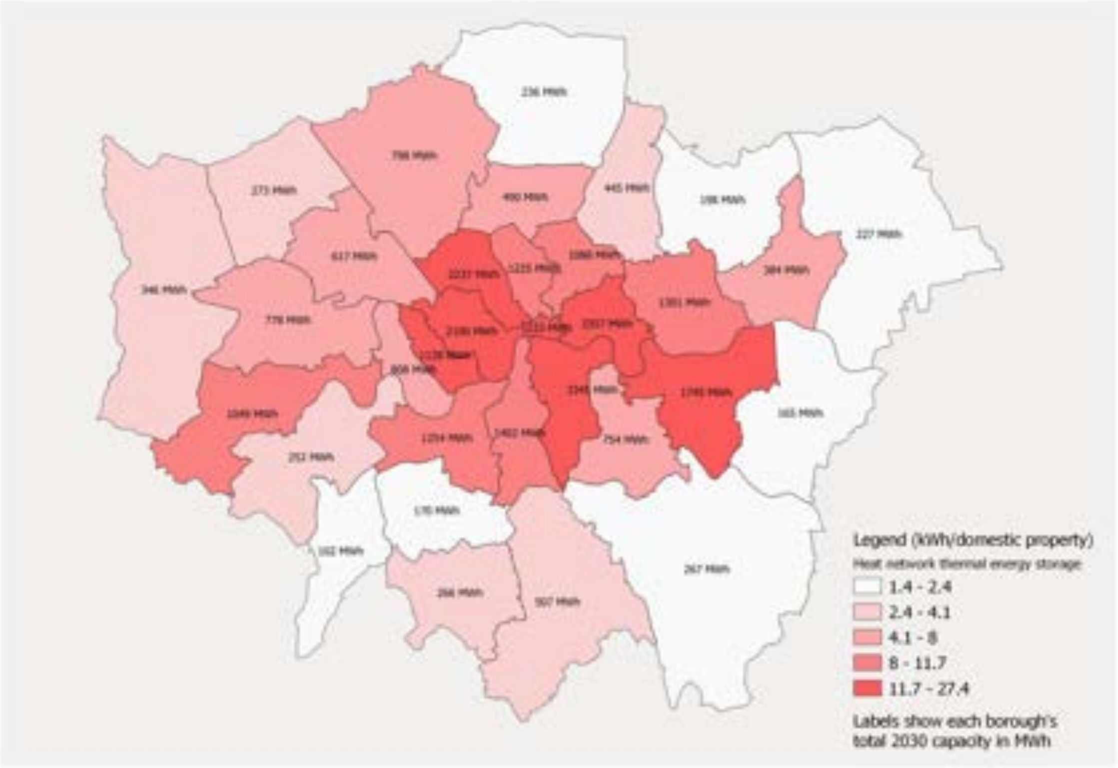

Figure 4.1: Electrified heat network thermal storage capacity (2030 flex-enabled)

4. Flexibility deployment by 2030

2030 demand-side flexibility deployment mapping: decentralised electrified thermal storage

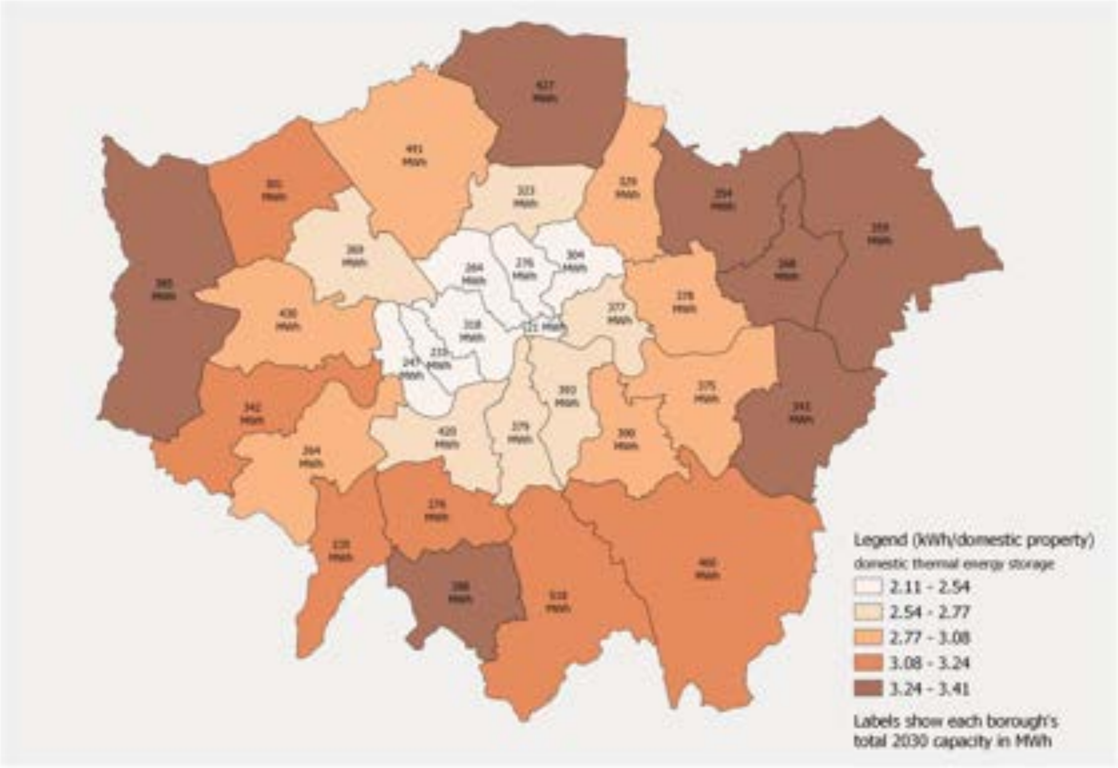

Figure 4.2: Domestic decentralised electrified thermal storage capacity (2030 flex-enabled)

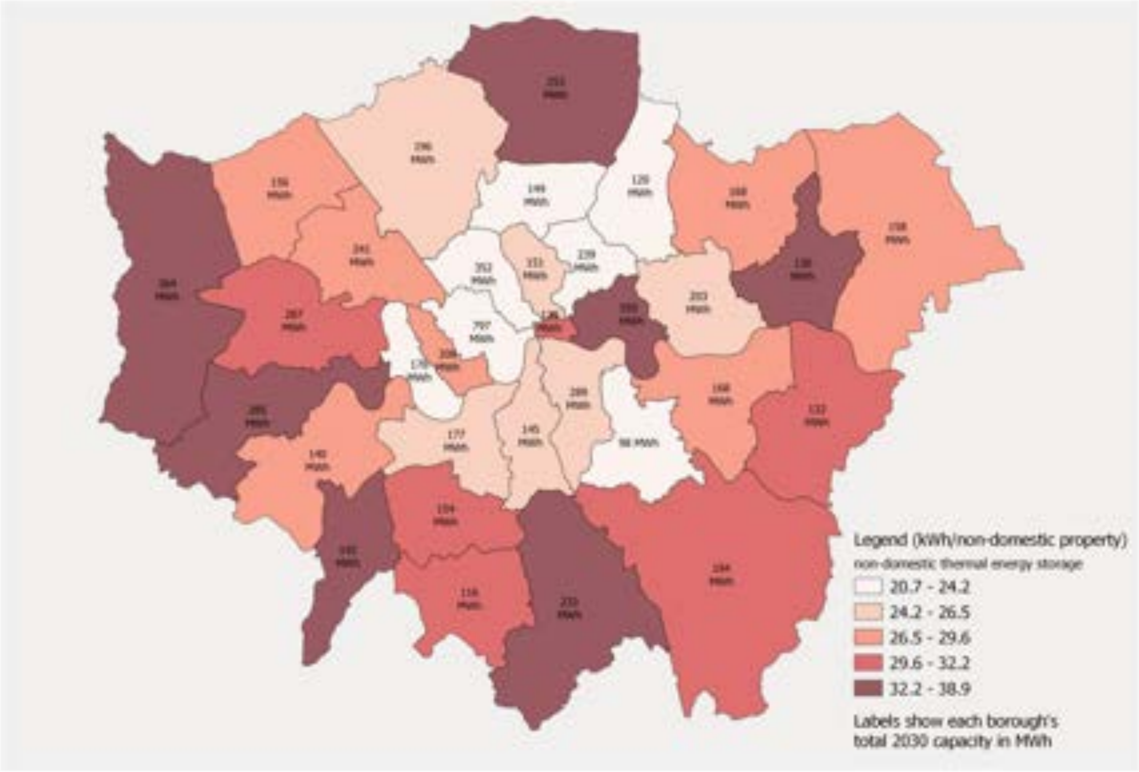

Figure 4.3: Non-domestic decentralised electrified thermal storage capacity (2030 flex-enabled)

4. Flexibility deployment by 2030

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2030 demand-side flexibility deployment mapping: behind-the-meter battery storage

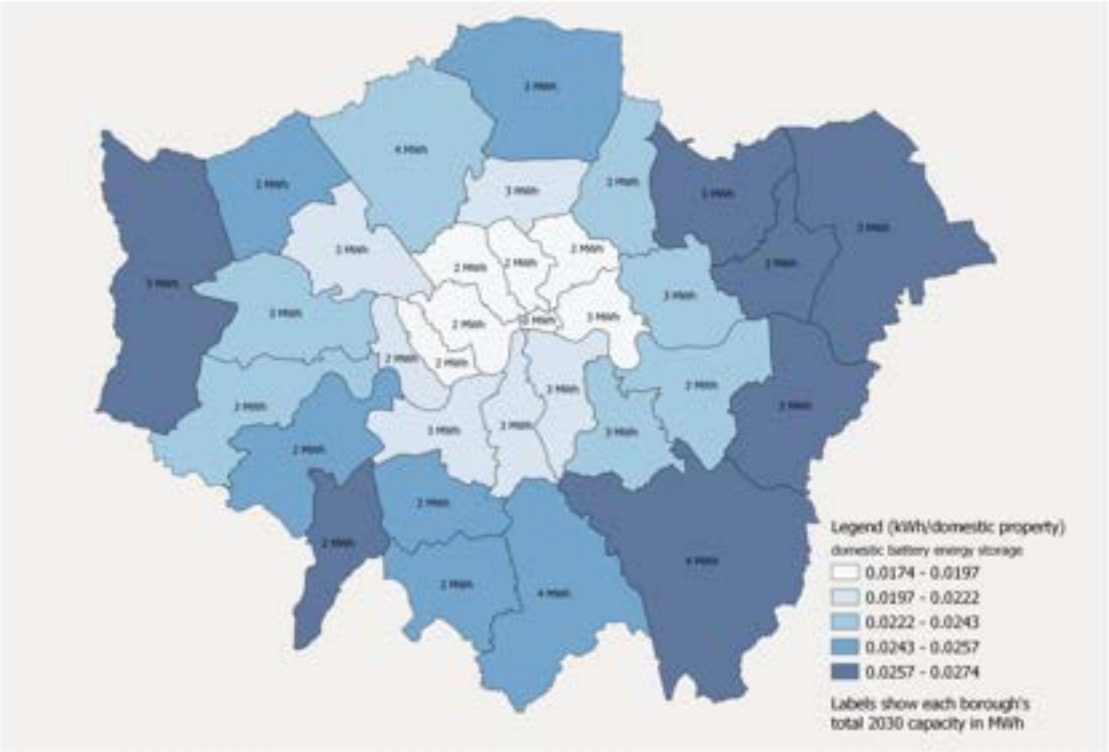

Figure 4.4: Domestic behind-the-meter battery storage capacity (2030 flex-enabled)

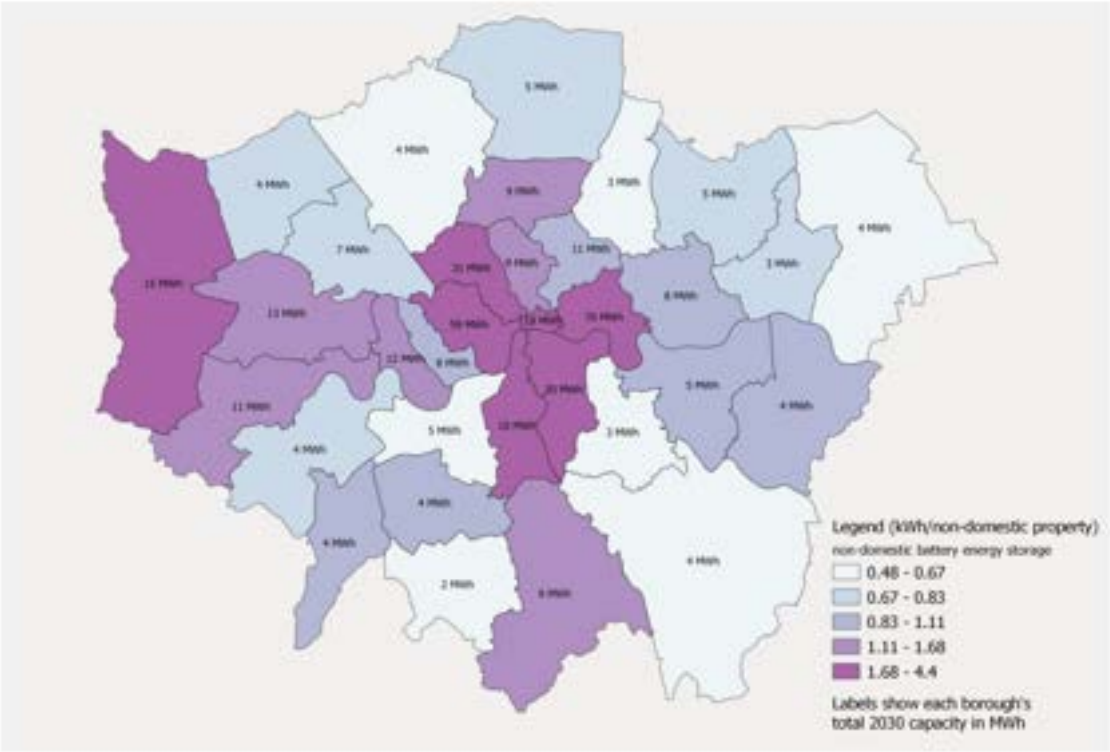

Figure 4.5: Non-domestic behind-the-meter battery storage capacity (2030 flex-enabled)

4. Flexibility deployment by 2030

2030 demand-side flexibility deployment mapping: home charging EVs and V2G

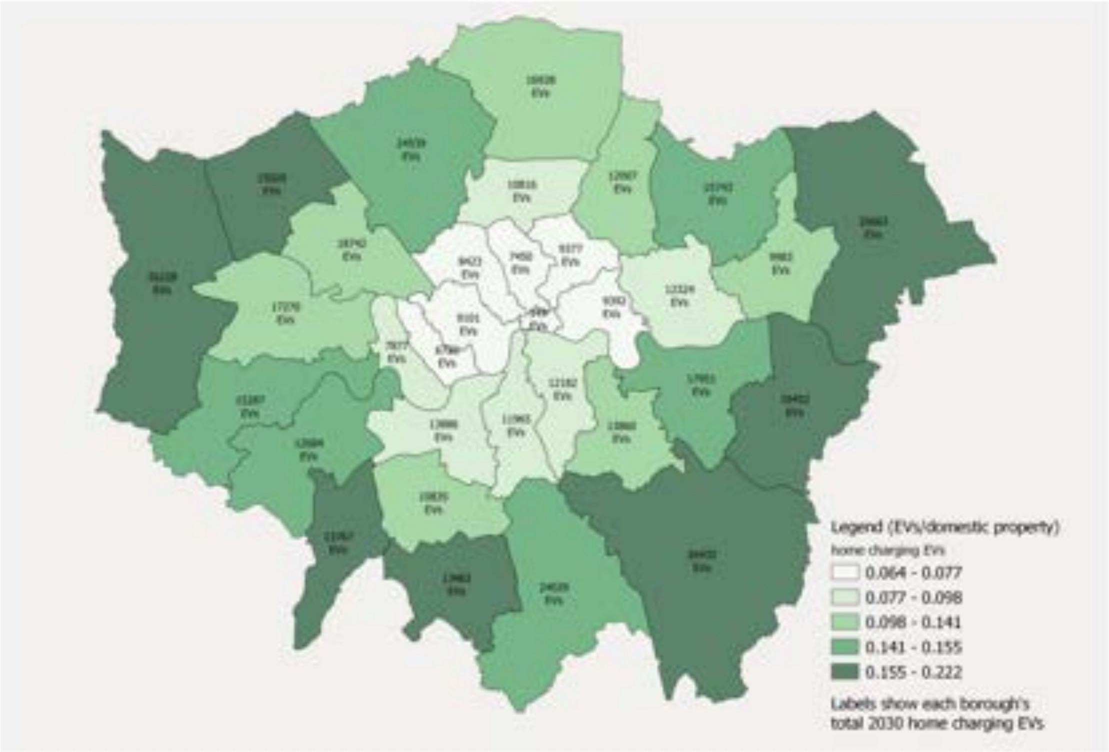

Figure 4.6: EVs with home charging access (2030 flex-enabled)

Figure 4.7: V2G battery capacity available during active window (2030 flex-enabled)

5. Driving 2030 flexibility with CFE

5. Driving 2030 flexibility with CFE

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We modelled the impact of driving London's 2030 demand-side flexibility with CFE; to do this, we first needed to model shifting EV charging loads, and appliance and cooling loads

With the hourly profiles and technology projections developed over Sections 3 and 4, we had everything required to examine the potential impact of widespread adoption of a 24/7 CFE approach for London's demand-side flexibility in 2030.

We explored a 2030 future in which all of London's demand-side flexibility responds to the hourly average grid carbon intensity, modelling the impact of optimising the operation of London's flexibility to maximise CFE matching. While it is unlikely that all of London would be totally engaged in CFE matching rather than other activities and services, the analysis aims to explore the maximum extent of the opportunity.

This involved two steps: modelling the shifting of non-time-critical demands, prior to optimising the operation of energy storage technologies.

Shifting non-time-critical demands

As outlined in Section 4, EV smart-charging and smart shifting of appliances and cooling demands present ways to shift non-time-critical electricity demands in 2030. To model this shifting to maximise CFE matching in 2030, we iterated through each hour of the 2030 EV charging electricity demand profiles and the appliances and cooling electricity demand profiles for the 2030 building stocks of the building types considered.

While iterating through, the average grid carbon intensity in a given hour was compared to the grid carbon intensity of other hours within the shifting window assumptions for the technology. If a different hour within the window offered a lower carbon intensity, demand was shifted from the given hour to the hour with lowest carbon intensity. Limits on the amount of demand that could be shifted from one hour to another followed the assumptions outlined for the two technology deployment scenarios in Section 4.

Figures 5.1 and 5.2 show the results of performing this demand shifting for the EV charging demands and the appliances & cooling demands of London's flats over a 24 hour period in 2030. The dashed grey line shows the average hourly grid carbon intensity. The pale blue lines show electricity demand without shifting. The dark blue lines show electricity demand after shifting. These examples clearly show how electricity loads on the grid are shifted from when the carbon intensity is high to when carbon intensity is low.

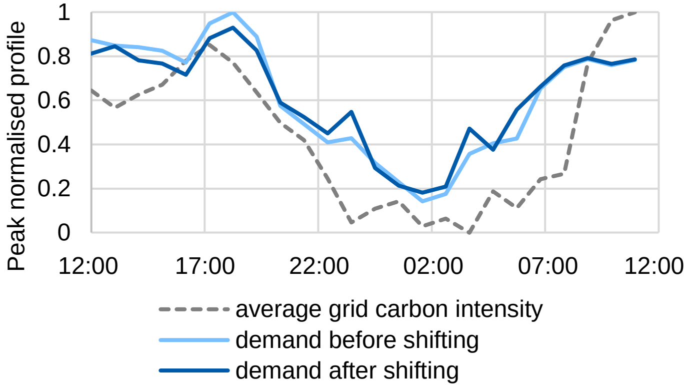

Figure 5.1: Shifting of London's flats' appliances and cooling electricity demand for 24 hours in 2030

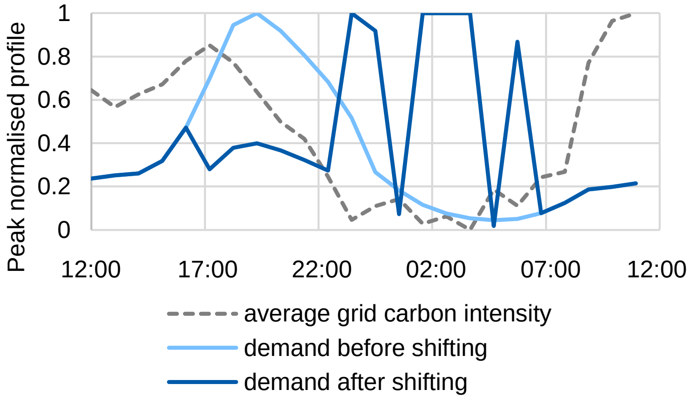

Figure 5.2: Shifting of London's flats' EV charging electricity demand through use of smart charging for 24 hours in 2030

5. Driving 2030 flexibility with CFE

We then developed a simplified linear optimisation model of London's electricity system to optimise the operation of the demand-side storage technologies

Modelling the operation of storge technologies

For shifting grid electricity consumption for time-critical service demands, Section 4 outlined the different types of energy storage expected to be available to London's 2030 buildings: behind-the-meter battery storage, thermal storage (decentralised and in heat networks), and vehicle-to-grid.

To model the operation of these storage technologies in 2030 to maximise CFE matching, we developed an hourly linear optimisation model using the Calliope open source energy systems modelling framework.[21]

This model developed a simplified representation of London's electricity system; each of the eleven building types considered were represented as a node, with these nodes joined together by a distribution network node (as visualised in Figure 5.3). The following features were defined for each building stock node:

- The 2030 hourly profiles for electrical heat, EV charging, appliances, lighting and cooling electricity demands (post-shifting where relevant)
- Hourly PV generation profiles
- The capacity of each storage technology, according to the 2030 deployment scenarios
- Other relevant constraints for the storage technologies – for example, roundtrip efficiencies, storage losses, and active time windows (for V2G); see the technical appendix for more detail

The linear optimisation model then found the operation method for the storage technologies that met all the hourly demand profiles in a way that minimised annual grid electricity consumption emissions within the technical constraints defined for the technologies. If desirable, electricity supply from V2G, batteries or PV could be supplied from one building stock node to another through the distribution network node, although this entailed losses. The 2030 average grid carbon intensity profile was used to drive the optimisation. PV generation was treated as emissions-free in the model.

Figure 5.4 shows an example output of the model optimising the operation of heat pumps with thermal storage for London's flats over 24 hours in 2030. The model selects the hours with the lowest carbon intensity to charge the thermal stores, which are used instead of heat pumps in the highest carbon intensity hours.

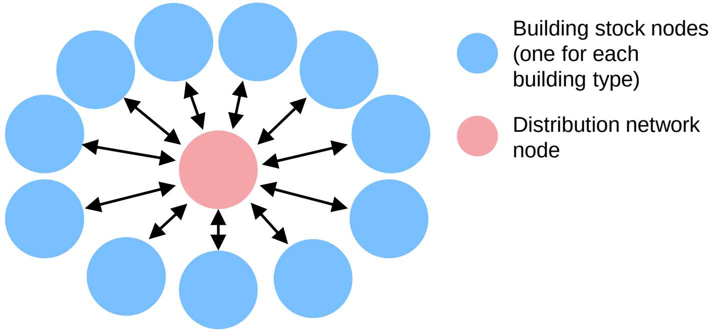

Figure 5.3: Simplified representation of London's electricity network for the optimisation modelling

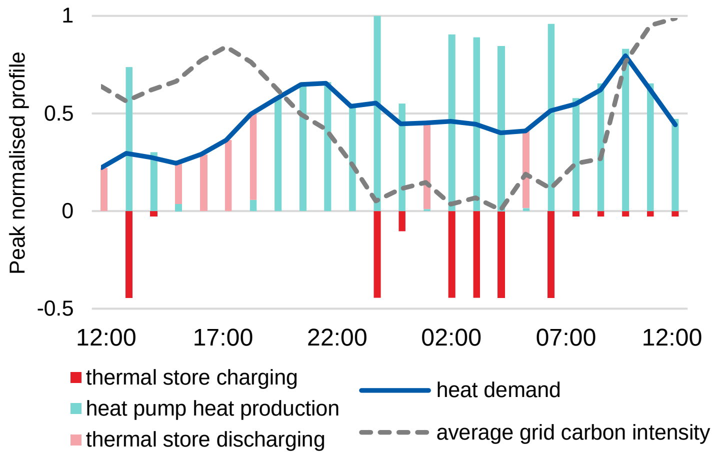

Figure 5.4: Optimising the operation of heat pumps and thermal storage for London's flats in 2030; charging of thermal stores is shown as negative, while discharging is shown as positive here

5. Driving 2030 flexibility with CFE

Our modelling suggests that London could avoid up to 9.3% of its electricity emissions through flexing to CFE; demand-side flexibility could provide up to 7.8 GW of capacity

2030 citywide CFE flex modelling results – 1/2

The results of the 2030 citywide demand-side flexibility modelling described in the preceding pages are presented in Table 5.1. These results show a clear emissions benefit to widespread CFE matching through demand-side flexibility, with grid electricity emissions reductions of between 5.6–9.3% depending on the flexibility deployment scenario. This translates to between 180–300 ktCO_2 p.a. savings and substantial increases to London's 2030 CFE score.

Table 5.1 also presents the maximum flex response observed in each flexibility deployment scenario; this is defined as the maximum difference in London's total grid load between the 2030 no-flex scenario and the 2030 CFE flex scenarios. Our modelling suggested a maximum response of between 4.1–7.8 GW depending on the scenario. To put this into context, 1 GW powers around 700,000 homes, and current annual procurement of flexibility by UKPN is in the hundreds of megawatts.[22] For between 600-1600 hours a year, at least 3 GW of flexible capacity is utilized in our modelling, which is the size of a Hinkley Point C plant.[23]

These gigawatts of demand-side flexibility present a number of opportunities beyond maximising CFE matching, such as managing network constraints and reducing costs and disruption to London's economy from network reinforcements. Setting out enabling mechanisms to achieve the deployment of this flexibility, while avoiding any unintended consequences from uncoordinated operation of gigawatts of flexibility, will be crucial for London as it seeks to electrify heat and transport.

	2030 no flex	2030 CFE flex enabled	2030 CFE max flex
CFE score	62.9%	65.5%	67.2%
Emissions reductions (compared to 2030 no-flex)	-	5.6% (180 ktCO_2 p.a.)	9.3% (300 ktCO_2 p.a.)
Maximum flex response	No flex operation modelled	4.1 GW	7.8 GW
Number of hours in 2030 with >3GW flex response	No flex operation modelled	600	1,600
Heat pump, district heating, EV, and PV deployment	According to Accelerated Green targets		
Energy storage, DSR, smart-charging and V2G deployment	No flex operation modelled	According to typical projections in the literature	According to maximum projections in the literature

Table 5.1: 2030 citywide CFE flex modelling results for London

5. Driving 2030 flexibility with CFE

Years before 2030 might offer even greater opportunities for CFE flexing; while deployment of flexible capacity will have made less progress, the grid will be more carbon intensive

2030 citywide CFE flex modelling results – 2/2

Figure 5.5 shows the hourly CFE matching heatmap for the 2030 CFE max-flex scenario. Given the marginal increase of CFE score from 62.9% to 67.2%, the differences between this heatmap and that for the 2030 no CFE flex heatmap (Figure 3.2) appear fairly minimal. This is despite the significant gigawatts of flexible capacity presented by the scenario, and the 9.3% of avoided emissions.

It is possible that a point prior to 2030 could offer greater opportunities for a 24/7 CFE approach to improve London's CFE performance. While less deployment of demand-side flexibility will have occurred in earlier years, the average carbon intensity of the electricity grid in the London region will be higher. The emissions reduction opportunities presented by a more carbon-intensive grid could outweigh the more limited deployment of flex capacity. Figure 5.6 visualises this concept. The idea highlights the role of a 24/7 CFE approach to incentivise demand-side flexibility deployment in immediate years.

A note on distributed solar PV in the optimisation modelling

Note that while our model considered distributed solar PV generation as carbon-free supply in its optimisation, no hour contained excess PV generation at the citywide building stock level; all PV generation was utilised even under the 2030 scenario with no CFE flexing. This means that, to optimise London's citywide CFE performance, demand shifting and storage technologies only responded to the average grid carbon intensity in our results. This would be different for a building/asset with times of excess PV generation looking to maximise its individual CFE performance.

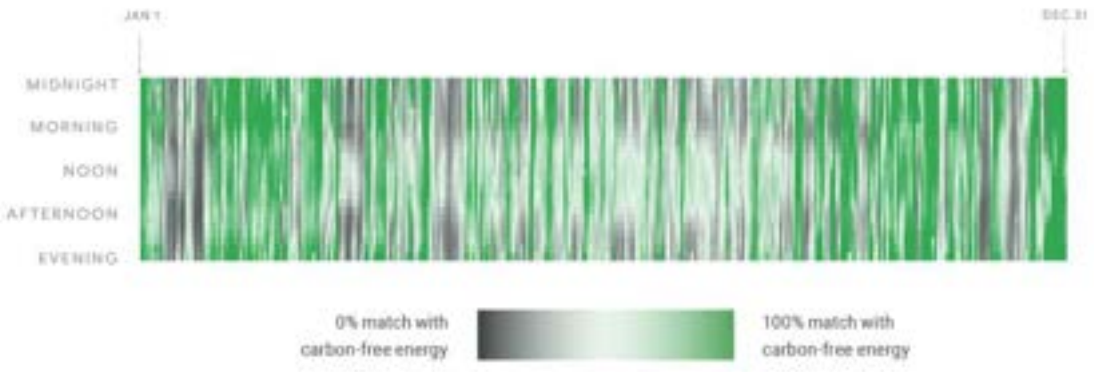

Figure 5.5: 2030 London hourly CFE matching in 'max-flex' scenario (67.2% CFE)

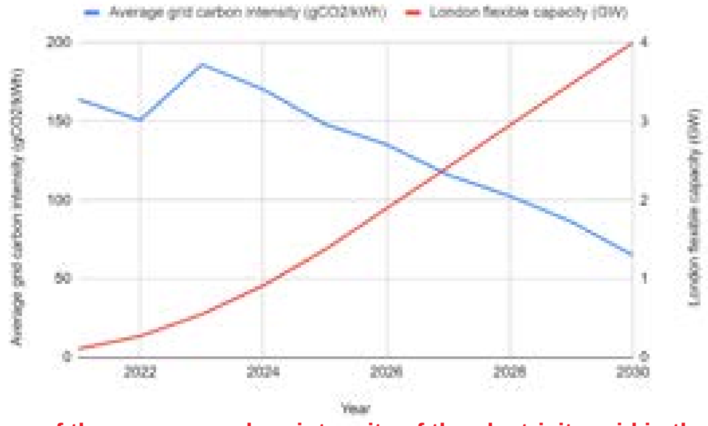

Figure 5.6: Projections of the average carbon intensity of the electricity grid in the London region and London's demand-side flexibility capacity

5. Driving 2030 flexibility with CFE

Widespread flexing to CFE could align well with other flexibility priorities like managing network peaks, although care must be taken to protect against unintended consequences

Alignment with other flexibility priorities

The histogram in Figure 5.7 shows the number of times a flex response of over 2 GW was observed for each hour of the day over the 2030 modelling. Encouragingly, these results suggest that flexing to CFE could align well with other priorities like the need to manage network constraints; 80% of demand turn-down events over 2 GW occur during the typical electricity network peak hours of 07:00-11:00 and 17:00-21:00, while 81% of demand turn-up events over 2 GW occur outside of these peak hours. Given the complementary nature seen here, we suggest that the emissions benefits offered by the 24/7 CFE approach can be a valuable mechanism to incentivise immediate deployment of flexibility which can be leveraged for delivering on other priorities too.

However, as can be seen in Figure 5.7, it should be noted that a substantial number of demand turn-up events of over 2 GW were observed in the morning and evening peak hours. While these events may offer opportunities to increase CFE matching, they could put pressure on networks during constrained times. For large scale CFE-driven flex, signals will need to be carefully coordinated to protect against this.

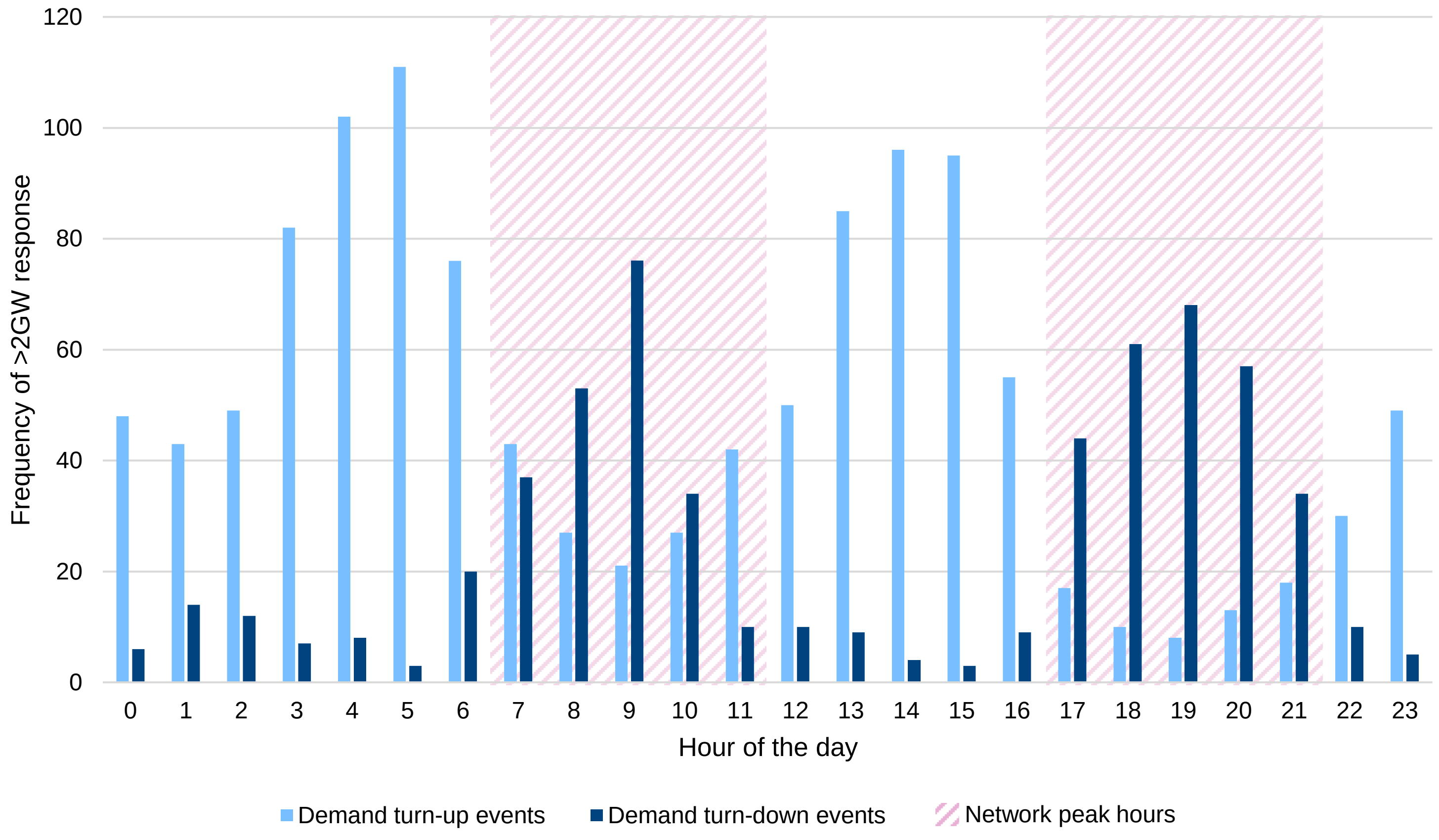

Figure 5.7: Histogram showing the temporal distribution of flex response events greater than 2 GW observed in the modelling of the 2030 flex-enabled scenario; note that demand-turn up refers to an increase in demand and demand turn-down refers to a decrease

5. Driving 2030 flexibility with CFE

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Thermal storage is expected to make the largest impact out of the technologies considered in 2030; residential buildings offer the most opportunities for CFE flex emissions savings

Priority demand-side flexibility technologies

Figure 5.8 shows the contribution of each demand-side flexibility technology to the 180 ktCO_2 p.a. avoided under the 2030 CFE flex-enabled scenario.

Under Accelerated green electrification targets and our flex-enabled deployment projections, our modelling suggests that thermal storage will provide over half of the emissions savings from flexing to CFE. Thermal storage from heat networks provides a notable amount of this contribution. With large centralised stores operated by single operators, heat networks' flexibility can be easier to leverage than distributed technologies. Electrified heat network operators are therefore a priority to engage. Around half of heat networks' contributions were assigned to domestic properties, with the other half assigned to non-domestic building types.

Priority building types

The emissions avoided results discussed previously refer to London's entire building stock. However, as shown in Figure 5.9, the impact of flexing to CFE varies across building types. The results suggest residential buildings offer the most opportunities for avoiding emissions, while retail and office buildings offer the least.

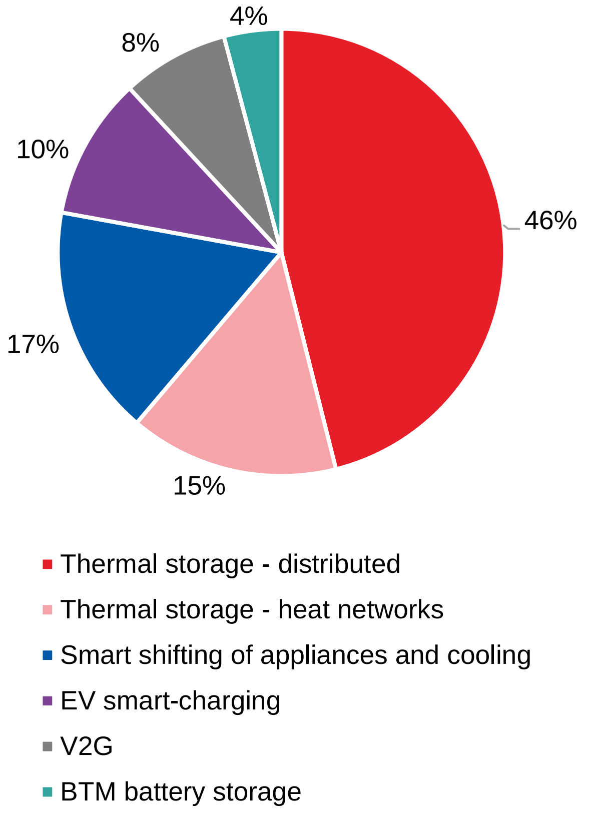

Figure 5.8: Contribution by technology to citywide annual grid emissions avoided under the 2030 CFE flex-enabled scenario

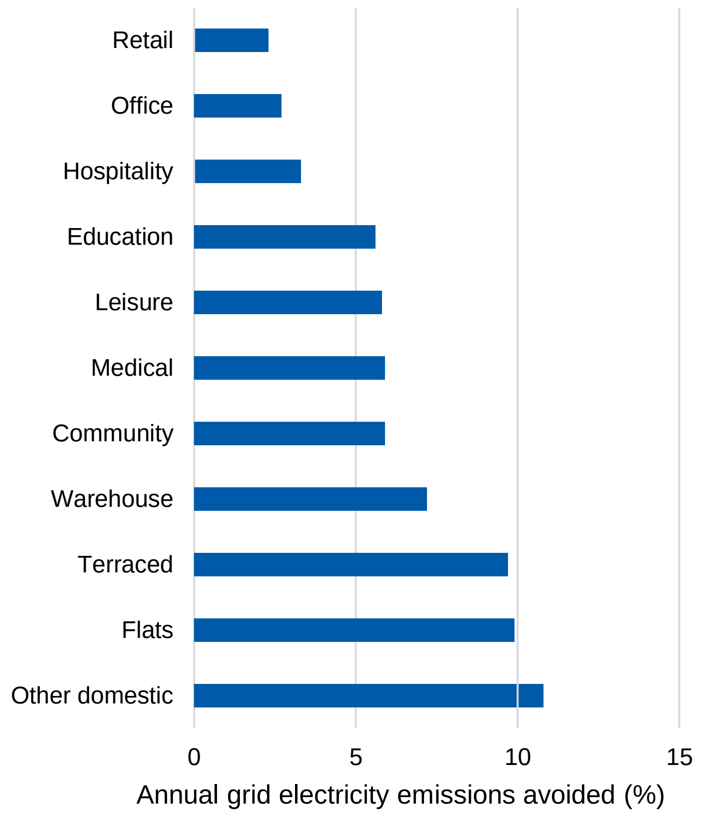

Figure 5.9: Annual building emissions avoided by building type under the 2030 CFE flex-enabled scenario

5. Driving 2030 flexibility with CFE

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As a 24/7 CFE approach to demand-side flexibility scales up, signals may need to be carefully coordinated to ensure emissions benefits are realised at system level

Potential unintended system emissions consequences

The CFE flex modelling and emissions reduction figures presented in this section have all been based around the future grid average carbon intensity signal, using the overall mix of generation in the region at each hour. Under the 24/7 CFE approach, it is anticipated that organisations will use this type of signal for their carbon accounting and will therefore respond to this signal when engaging in carbon-driven demand-side flexibility.

However, there could be ‘unintended consequences’ at a system level, where the net result of turn-ups and turn-downs in electricity demand will not lead to low carbon outcomes. For instance, if significant loads in London turn up unexpectedly to wind generation at 8pm, what could happen? Previously curtailed wind generation could begin to be utilised, or a gas-fired plant could be required to turn on to meet the increased demand. This assessment is referred to as the consequential impact.

The best data we have for the historic consequential impact assessment is the ‘marginal’ carbon intensity; we can observe what overall grid marginal factors were (i.e., the change in generation that took place). These can be very hard to forecast. While, for a given hour, defining what the marginal generators are, and what their carbon intensity is, can be challenging.

Data scientists at Advanced Infrastructure provided us with an estimate of hourly marginal carbon intensity for 2030. Using this to measure the consequence of demand-side flexibility operation in our 2030 CFE flex scenarios, we observed a small net increase in consequential system emissions for both of the CFE flex scenarios (as shown in Figure 5.11), despite seeing reductions to emissions when considering the grid average carbon intensity (Figure 5.10). This analysis suggests that if all of London attempts to maximise their CFE score, there could be undesired emissions impacts.

This is an important issue to track as more buildings adopt a 24/7 CFE approach and it highlights the central importance of coordinating signals carefully and having transparency of data used for system control decisions. However, we believe it should not temper the short-term role of a 24/7 CFE approach as an incentive to drive forward flexibility deployment; consequential impacts will not be substantial until large scale up of the approach, while very significant uncertainty also exists over the future marginal intensity profile used in the analysis.

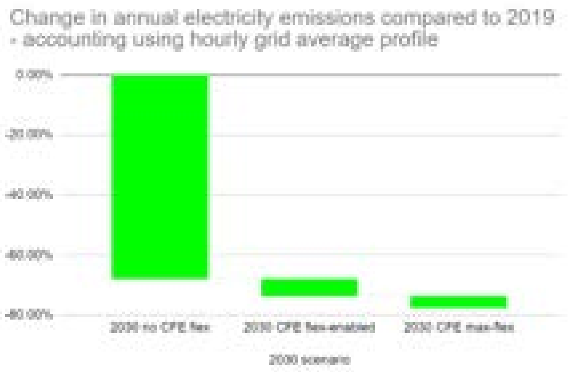

Figure 5.10: Emissions impacts of London 2030 CFE flex scenarios compared to 2019 baseline, accounting using the hourly grid average carbon intensity profile

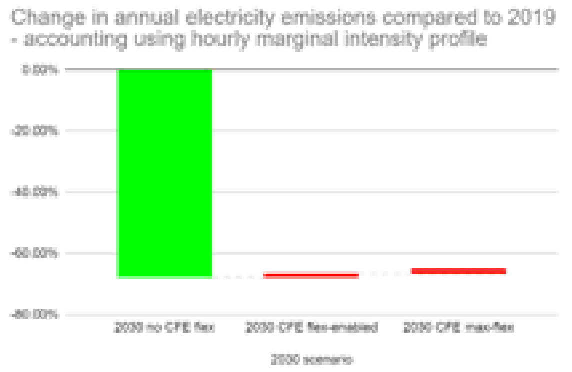

Figure 5.11: Emissions impacts of London 2030 CFE flex scenarios compared to 2019 baseline, accounting using the hourly marginal grid carbon intensity profile

6. Reflecting and next steps

6. Reflecting and next steps

This report has presented the vast amounts of flexibility that could exist in London by 2030 and the extent of the opportunity for CFE flexing; some limitations to the analysis exist

This report's analysis has presented the extent of the opportunity for a 24/7 CFE approach to demand-side flexibility in London in 2030. Our analysis has projected up to 7.8 GW of demand-side flexibility London-wide by 2030; leveraging this could avoid up to 9.3% of London's electricity usage emissions in 2030.

We have found that, at a high-level, the operation of demand-side flexibility to CFE signals could align well with other flexibility priorities to manage network constraints; in our modelling results, we observed that the vast majority of major demand turn-down events occur during morning and evening peaks. This supports the concept of the 24/7 CFE approach being a valuable mechanism with which to incentivise faster deployment of much-needed flexibility in London; the emissions benefits of CFE flexing can engage actors that may not be interested otherwise, while the resulting flexible capacity can be leveraged for other priorities too.

Our findings suggest that heat network operators and domestic buildings will be a priority to engage. In a highly electrified future, thermal storage is expected to be the most impactful demand-side technology. The analysis has also highlighted the importance of carefully coordinated signals and open, transparent and available data to prevent unintended consequences regarding network constraints and national balancing actions that could be carbon-intensive.

Limitations

Some limitations exist to our analysis, including:

- Only considering maximising CFE scores: The modelling results present analysis on the maximum extent of the opportunity rather than a forecast for 2030. We modelled London's projected demand-side flexibility capacity seeking only to maximise CFE scores; it is highly unlikely that London's buildings would only engage in responding to carbon signals and not other activities and services.
- No consideration of costs or constraints during operation modelling: Our modelling of the operation of demand-side flexibility was based entirely on carbon intensity and did not consider costs or network constraints when determining how to operate technologies. While the results show gigawatts of citywide demand turn-up at times, electricity networks in 2030 may not be able to facilitate this magnitude of response. This again relates to the analysis presenting the maximum extent of the opportunity rather than a forecast. Note that, unlike the modelling of flexibility operation, through the literature review undertaken, our projections for capacities of flexible technologies by 2030 do implicitly consider costs and other factors.
- Citywide flex modelling was limited to 2030: Modelling CFE-driven flex in the years before 2030 was not in this work's scope. As mentioned in Section 5, it is possible that a point before 2030 could offer even greater potential for CFE-driven flex. While the deployment of flexibility capacity may be more limited prior to 2030, the higher carbon intensity of the grid could offer more opportunities for flexing to CFE. Having an indication of the timing of peak CFE flex potential could help to gauge the timeframe in which 24/7 CFE can be leveraged as an incentive to drive demand-side flexibility deployment.
- Supply-side low carbon flexibility: Consideration of low carbon flexibility on the supply side was not in this work's scope but can offer significant further CFE opportunities for London.

6. Reflecting and next steps

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Despite some limitations, the citywide modelling has provided valuable insight; further work should seek to build on the findings

Limitations continued

- EV analysis: Modelling the future electricity demands of all of London's buildings is challenging and requires some high-level assumptions to be made. Of these demands, EV charging loads were some of the hardest to determine. The analysis aligned the total number of electric cars and vans to the Accelerated Green pathway. Electric cars were assigned to domestic or non-domestic premises based on home charger availability. Electric vans were assigned to charge at non-domestic premises. Smart-charging and V2G were only considered for home-charging cars and electric vans at non-domestic premises. This doesn't capture the flexibility potential of electric buses, and perhaps underestimates the flexibility potential of commercial fleets.
- Other flex opportunities not considered in this work: Data centres have large electricity demands that could be flexed through time and/or location shifting methods (such as Google's methodology to shift computationally demanding, non-urgent tasks to times/locations where grid carbon intensity is projected to be the lowest). However, almost no data centres currently engage in these practices, which conflict with operators' primary purpose to serve customers with constant reliable computing power; data centre participation in flexibility is highly uncertain and potentially very limited. Information on data centres can also be challenging to retrieve. Industrial processes can also offer significant potential for flexibility but are very site specific, making them challenging to generalise across a city's building stock; we have tried to capture this at a high-level through modelling the ability of non-domestic buildings to shift up to 10% of their aggregated appliances and cooling electricity demand.
- Uncertainty over projections of future hourly carbon intensity: it should be noted that there is significant uncertainty when projecting future carbon intensity to hourly resolution; our methodology for these projections has attempted to capture how different rates of deployment for different types of generation supply technologies will impact the future hourly profile differently. As mentioned previously, the future hourly marginal profile is particularly difficult to forecast.

Next steps

Despite these limitations, the analysis offers valuable insight and should be built on in further work.

Future Local Area Energy Plans (LAEPs) can play a significant role in building on the work by considering hourly variations in carbon intensity in their assessments. LAEPs should also seek to build on the high-level flexibility capacity mapping of this report to examine the potential capacity of demand-side flexibility more locally, comparing this to any anticipated constraints to identify local opportunities for flexibility. Distribution System Operators (DSOs) like UKPN can leverage this analysis from LAEPs to help them plan their procurement of flexibility services. The assumptions, projections, and data presented in this report can form a valuable starting point for future LAEPs' considerations of demand-side flexibility.

This work's findings also inform considerations for the proposed future CFE pilot project. Heat network operators would represent particularly valuable pilot participants.

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Technical Appendix

Technical Appendix

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Components of the 2019 baseline modelling of building electricity demands, distributed PV generation, and grid CFE profile

Component	Units	Source(s)
Total floorspace of each building type	m^2	London Building Stock Model
Appliances, lighting and cooling electricity demand benchmarks – domestic	kWh p.a./m^2	NEED
Appliances, lighting and cooling electricity demand benchmarks – non-domestic	kWh p.a./m^2	BEES
Proportion of electrically heated properties for each building type	%	Census data
Heat demand benchmarks – domestic	kWh p.a./m^2	NEED
Heat demand benchmarks – non-domestic	kWh p.a./m^2	BEES
Appliances, lighting and cooling electricity demand hourly profile shapes - domestic	Hourly % of annual demand	Octopus Centre for Net Zero Faraday API
Appliances, lighting and cooling electricity demand hourly profile shapes - non-domestic	Hourly % of annual demand	Ofgem and De Montfort University
Heat demand hourly profile shapes - domestic	Hourly % of annual demand	CIBSE weather data and Arup occupancy and temperature setpoint assumptions
Heat demand hourly profile shapes - non-domestic	Hourly % of annual demand	CIBSE weather data and Arup occupancy and temperature setpoint assumptions
Heat pump COP	Fraction	Assumed to be typical of air source (2.8)

Component	Units	Source(s)
Resistance heating efficiency	%	Assumed to be 100%
Solar PV installed capacity	kW	Ofgem FiT and SEG datasets, UKPN embedded capacity register
Solar PV annual yield rate	kWh p.a./kW	Data from various London systems gives 820 kWh p.a./kW
Solar PV hourly generation profile shape	Hourly % of annual generation	Global tilted irradiance of a typical panel in central London
Hourly grid CFE percentage profile	Hourly grid CFE %	National Grid London Region grid mix data (including solar, wind, hydro and nuclear contributions)

Technical Appendix

Components of the 2030 modelling of building electricity demands, distributed PV generation, and grid CFE profile

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Component	Units	Source(s)
Total floorspace of each building type	m^2	London Building Stock Model + new floorspace from House of Commons and DLUHC data
Appliances, lighting and cooling electricity demand benchmarks – domestic	kWh p.a./m^2	NEED w/ 5% reduction for increased efficiency
Appliances, lighting and cooling electricity demand benchmarks – non-domestic	kWh p.a./m^2	BEES w/ 10% reduction for increased efficiency
Number of heat pumps for each building stock type	Number	Accelerated Green analysis
Number of electrified heat network connections for each building stock type	Number	Accelerated Green analysis, assuming connections post-2021 are electrified
Heat demand benchmarks – domestic	kWh p.a./m^2	NEED w/ 37% reduction for increased efficiency (aligned to Accelerated Green)
Heat demand benchmarks – non-domestic	kWh p.a./m^2	BEES w/ 39% reduction for increased efficiency (aligned to Accelerated Green)
Appliances, lighting and cooling electricity demand hourly profile shapes - domestic	Hourly % of annual demand	Octopus Centre for Net Zero Faraday API
Appliances, lighting and cooling electricity demand hourly profile shapes - non-domestic	Hourly % of annual demand	Ofgem and De Montfort University
Heat demand hourly profile shapes - domestic	Hourly % of annual demand	CIBSE weather data and Arup occupancy and temperature setpoint assumptions

Component	Units	Source(s)
Heat demand hourly profile shapes - non-domestic	Hourly % of annual demand	CIBSE weather data and Arup occupancy and temperature setpoint assumptions
Decentralised heat pump COP	Fraction	Assumed to be typical of air source (2.8)
Heat network heat pump COP	Fraction	Assumed to be typical of higher temperature secondary heat (3.8)
Resistance heating efficiency	%	Assumed to be 100%
Total number of electric cars and vans	Number	Accelerated Green targets
Average mileage of a car/van	Miles p.a.	MOT data (8000 miles)
Mileage to EV charging demand conversion	kWh/mile	ICCT study (0.29 kWh/mile)
EV charging demand profile shapes	Hourly % of annual demand	NGESO FES 2019
Annual solar PV generation – domestic and non-domestic	kWh p.a.	Accelerated Green analysis
Solar PV hourly generation profile shape	Hourly % of annual generation	Global tilted irradiance of a typical panel in central London
2022 grid share of renewable generation technologies	Hourly grid %	National Grid London Region grid mix data
2022-2030 change in renewable generation technologies' annual generation share	% change	NGESO FES 2022

Technical Appendix

Flexibility technology deployment: assumptions and sources for ‘flex-enabled’ projections

Technology	Value	Source(s)	Notes
Behind-the-meter battery storage	Domestic installed capacity	2022 UKPN DFES Residential Battery Build BNEF	Based on UKPN domestic battery storage DFES projections for 2030 – using high scenario and uplifting for parts of West London not included in projections. Assumes average 2 hour capacity.
Behind-the-meter battery storage	Non-domestic installed capacity	2022 UKPN DFES BTM Batteries - IRENA	Based on UKPN I&C battery DFES projections for 2030 – using high scenario and uplifting for parts of West London not included in projections. Assumes average 2 hour capacity.
Thermal storage	Decentralised installed capacity (domestic and non-domestic)	DECC_TES.pdf nz2030 Element Energy NZ2030 Census 2021: how homes are heated in your area ONS	Takes total existing numbers of thermal stores and assumes continued sales in line with BEIS analysis. Nationwide figures scaled to London based on number of homes, with houses weighted twice as heavily as flats. Stores are assigned to domestic/non-domestic properties based on the share of domestic/non-domestic building stock. Only thermal stores with electric heating are included, with this determined based on analysis using Census data and Accelerated Green heat pump deployment projections. Domestic thermal stores are assumed to be 10 kWh (~200L hot water tank); non-domestic store sizes take this value and uplift it based on the increased average floorspace of each non-domestic building type.
Thermal storage	Heat networks installed capacity	Element Energy NZ2030 Census 2021: how homes are heated in your area ONS	The number of heat network connections were aligned with Accelerated Green targets. Only electrified heat networks were included. For this, it was assumed that all heat network connections post-2021 would be electrified. Electrified heat network thermal storage capacity was then sized to be able to meet the total heat demand of its connections on a peak winter day.
EV smart charging	Demand shiftable to another hour during active window	Smart systems and flexibility plan 2021 Flexibility_in_GB_final_report Future Energy Scenarios 2022 | ESO	Various assumptions for smart-charging shiftability exist in the literature. 60% represents a typical value; towards the high end of National Grid ESO FES assumptions but lower than BEIS and Carbon Trust/Imperial assumptions.
Vehicle-to-grid	Proportion of EVs that participate in V2G during active window	2022 UKPN DFES Future Energy Scenarios 2022 | ESO	The highest V2G participation rate assumed in 2030 in the UKPN DFES was 16%. Taking a participation rate of half of this (8%, which aligns well with NGESO FES assumptions for Consumer Transformation), and applying the DFES assumption that 45% of V2G EVs are available at peak, results in a rate of 4%
Smart shifting of appliances and cooling demands	Domestic demand shiftable to another hour	OE-NGESO Domestic Scarcity Reserve Trial Results Smart systems and flexibility plan 2021	7% is based on Octopus trial results (core scenario), assuming 1.5kW/household diversified peak load. The +/- 4 hours shifting horizon is based on assumptions in the BEIS flexibility study.
Smart shifting of appliances, and cooling demands	Non-domestic demand shiftable to another hour	Smart systems and flexibility plan 2021 Ofgem_DSR_Survey Flexibility_in_GB_final_report	5% is a typical value based on a number of sources on shiftability potential and deployment by 2030. The +/- 4 hours shifting horizon is based on assumptions in the BEIS flexibility study.

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Technical Appendix

Flexibility technology deployment: assumptions and sources for 'max-flex' projections

Technology	Value	Source(s)	Notes
Behind-the-meter battery storage	Domestic installed capacity	Future Energy Scenarios 2022 | ESO 2022 UKPN DFES	Based on NGESO FES distributed battery projections, scaled down to London and assuming 70% are behind-the-meter (based on analysis of UKPN projections). Assumes average 2 hour capacity.
Behind-the-meter battery storage	Non-domestic installed capacity	Future Energy Scenarios 2022 | ESO 2022 UKPN DFES	Based on NGESO FES distributed battery projections, scaled down to London and assuming 70% are behind-the-meter (based on analysis of UKPN projections). Assumes average 2 hour capacity.
Thermal storage	Decentralised installed capacity (domestic and non-domestic)	Smart systems and flexibility plan 2021	Similarly to the high scenario assumptions in the BEIS flexibility study, this assumes that every property has the equivalent of a 200L hot water tank (~10 kWh, assuming a supply temperature of 65ºC and an ambient temperature of 20ºC). The size of each non-domestic property thermal store was based on uplifting the 200L domestic store size by the difference in average property floorspace between each non-domestic building type and domestic properties.
Thermal storage	Heat networks installed capacity	Element Energy NZ2030 Census 2021: how homes are heated in your area ONS	No change from 'flex-enabled' projections.
EV smart charging	Demand shiftable to another hour during active window	Smart systems and flexibility plan 2021 Flexibility_in_GB_final_report Future Energy Scenarios 2022 | ESO	Various assumptions for smart-charging shiftability exist in the literature. 80% represents a maximum value seen in the sources.
Vehicle-to-grid	Proportion of EVs that participate in V2G during active window	2022 UKPN DFES Future Energy Scenarios 2022 | ESO	The highest V2G participation rate assumed in 2030 in the UKPN DFES was 16%. Applying the DFES assumption that 45% of V2G EVs are available at peak to this value results in the 7% participation value
Smart shifting of appliances and cooling demands	Domestic demand shiftable to another hour	OE-NGESO Domestic Scarcity Reserve Trial Results Smart systems and flexibility plan 2021	19% is based on Octopus trial results (high scenario), assuming 1.5kW/household diversified peak load. The +/- 4 hours shifting horizon is based on assumptions in the BEIS flexibility study.
Smart shifting of appliances, and cooling demands	Non-domestic demand shiftable to another hour	Smart systems and flexibility plan 2021 Ofgem_DSR_Survey Flexibility_in_GB_final_report	10% is a high value based on a number of sources on shiftability potential and deployment by 2030. The +/- 4 hours shifting horizon is based on assumptions in the BEIS flexibility study.

Technical Appendix

Flexibility spatial mapping – capacity distribution methodology

Technology	Capacity distribution methodology
Electrified heat network thermal storage	Based on each borough's share of properties currently connected to a heat network out of the London total, using the 2021 Census dataset.
Decentralised electrified thermal storage	Based on the number of domestic units in each borough, with houses (terraced and other domestic) weighted twice as heavily as flats. This is based on analysis of English Housing Survey data on hot water tank ownership in different property types. The total number of decentralised thermal storage installations in each borough was then split between domestic and non-domestic properties based on the domestic/non-domestic share of the total borough building stock.
Domestic behind-the-meter battery storage	Uses the same distribution methodology as decentralised thermal storage (weighting houses twice as heavily as flats) based on the assumption that areas containing homes with significant space for hot water tanks are more likely to have significant space for battery storage systems.
Non-domestic behind-the-meter battery storage	Based on each borough's share of London's total non-domestic electricity demand.
V2G and smart-charging	V2G and smart-charging was assumed to only be available for electric vans at non-domestic premises and electric cars with home charging at domestic premises. Numbers of electric cars and vans were aligned to Accelerated Green. 80% of electric vans were assigned to the Medical and Warehouse building stock types, based on the assumption that these building types are the most likely to have fleets of electric vans charging at their premises. The other 20% were shared across other non-domestic building types based on the number of each building stock type's number of properties. The vans were distributed to each borough based on the borough's share of London's non-domestic building stock, accounting for the increased weighting of Medical and Warehouse buildings. Total numbers of electric cars owned by Flats, Terraced, and Other Domestic building stock types were developed for 2030 based on EV buyer assumptions. These were distributed to boroughs based on each borough's share of the number of properties of each building type out of the London total. Home charging availability assumptions for each domestic building stock type were then applied to the numbers of cars owned by each domestic property type in each borough to produce the number of EVs with access to home charging in each borough.

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Technical Appendix

Citywide flexibility optimisation modelling – technical constraints

Technology	Constraint	Value	Units	Source(s)	Notes
Behind-the-meter battery storage	Roundtrip efficiency	85	%	Storage-costs-technical-assumptions-2018.pdf (publishing.service.gov.uk) Fact Sheet | Energy Storage (2019) | White Papers | EESI	Based on Lithium-ion
Behind-the-meter battery storage	Storage losses (self-discharge)	2.5	%/month	Lithium-Ion Battery - Clean Energy Institute (washington.edu) Module supplier datasheets	Based on Lithium-ion
Thermal storage – decentralised	Storage losses (self-discharge)	2	%/hour	EASE_TD_HotWater.pdf (ease-storage.eu) DECC_TES.pdf (publishing.service.gov.uk)	Based on sources ~25% of stored energy lost in 12 hours
Thermal storage – heat networks	Storage losses (self-discharge)	1	%/hour	EASE_TD_HotWater.pdf (ease-storage.eu) DECC_TES.pdf (publishing.service.gov.uk)	Assumes larger heat network thermal stores lose energy half as quickly as smaller decentralised stores
Distribution network	Losses	6	%	Ukpn-business-plan-2015-2023.pdf (ukpowernetworks.co.uk) What are Losses? - SP Energy Networks	Applied to electricity flows between building stock type nodes in the optimisation model
EV chargers	Efficiency	90	%	A comparison of electric vehicle charging efficiency | IEEE Conference Publication | IEEE Xplore	Assumes Level 2 charging
EV chargers	Power	7	kW	Electric Car Charging | EDF (edfenergy.com)	
Decentralised heat pumps	COP	2.8	-	See notes	Assumes decentralised heat pumps are air source
Centralised heat network heat pumps	COP	3.8	-	See notes	Assumes heat network heat pumps utilise higher temperature secondary heat (e.g. waste heat from a data centre)
Smart-charging and V2G	Active window	17:00-07:00	Time	Arup assumption	
V2G	EV battery size	75	kWh/EV	Global EV Outlook 2020 (windows.net)	Of participating V2G vehicles, only 70% of this battery capacity was considered available

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Appendix 2 – Use Cases key Findings Summary

C40 Cities

24/7 Carbon-Free Energy for London

Use Cases for 24/7 CFE London- TfL buildings

Reference: Appendix Final

20th June 2023

Contents

1. Introduction

In order to assess the potential flexibility of actual buildings in London today with some added electrification, the team assessed detailed use cases with half hourly data. Outreach to stakeholders within the GLA Group, boroughs and the private sector resulted in up to 5 use cases that would be suitable to move to pilot stage, and for two of these, the team undertook two detailed bottom-up models of actual changes to technology in the buildings that would increase the potential for – or be a prerequisite for – flexibility. The remaining use cases are being developed separately in the pilot, and they would not require technology change.

Two buildings within TfL's portfolio were selected because they had very detailed data available, and they both would need to answer key questions about how to decarbonise in the near future. One of the buildings (Palestra) has a combined heat and power plant on site and building operators will need to decide the timing for upgrading to heat pumps. The other (Pier Walk) is seeking to replace gas-fired heating and hot water with lower carbon alternatives.

2. Key Findings

- The fuel switching benefits of 29-40% carbon savings from replacing heating systems with heat pumps,
- Carbon savings of an additional 3-5% annually is possible from flexing electricity to match to carbon intensity (for all heating loads and shifting 50% of chiller and central plant loads). This does not include thermal storage which would provide additional flexibility,
- Modelling on the existing CHP plant at the Palestra site in London shows that an annual 20- 32% carbon savings over the baseline is achievable. This could allow existing assets to be maximised for annual carbon savings before full replacement, saving embodied carbon and costs (particularly while electricity prices are so high),
- As we electrify more loads in buildings, different electrical loads will require optimisation according to their daily and seasonal uses (ie: lighting and servers are inflexible but chillers can be pre-chilled without compromising comfort; heating provides flexibility in winter but not summer),
- In the use cases, the flexibility that achieved the most carbon benefit was from the chiller and central plant loads - this is because these are heavily air conditioned buildings. But in buildings without AC, this is likely to flip around and more flexibility will be available from heat. Both the buildings we modelled also had hot water tanks (thermal storage) which is beneficial for maximising flexibility potential,
- Annual costs increase because electricity consumption increases (and with today's prices electricity is more expensive than gas):
    - Palestra would see an annual utility cost increase of £739,257 from replacing the CHP plant
    - Pier Walk would see an annual utility cost increase of £29,352 by adding heat pumps
- Could this annual price increase be mitigated by a carbon incentive? When applying a guide price of £95/tonne:
    - Palestra has an annual potential of electrification of 811 tonnes, worth £77,045
    - With carbon flexing, an additional 62.7 tonnes, £5,957
    - Pier Walk has an annual potential of 213.7 tonnes, worth £20,302
    - With carbon flexing, an additional 34.7 tonnes, worth £3,297
    - These benefits, if monetised, could provide some relief from increased electricity costs before prices change (gas is still much cheaper than electricity)
- Consequential analysis is one way to shows potential impact on the system:
    - In using this approach, electrification will increase emissions at the margin, because we have to assume that any added electrification uses the 'marginal' plant which is currently higher

carbon than average grid intensity. This would change if electrification was able to reduce curtailed wind power, for instance, and would be using wind power on the margin
    - Carbon flexing reduces the negative impact of the increased marginal emissions by just a very small percentage (1%)
    - This finding is useful in driving a portfolio approach where matching decarbonised supply with demand, where sites or local areas can combine efficiency, flexibility and storage alongside electrification and decarbonised supply.

The pilot is critical to understand if the modelled potential is going to be practical. There may be specific site conditions and equipment operational constraints that may need to be accounted for - which have not been modelled in this iteration.

2.1 High level results summary- Palestra

What is included in the baseline:

- For the attributional assessment, what's included is the emissions from gas and electricity except 75% of the hours of server load (because it is grid-reliant rather than CHP reliant and non-flexible)
- Baseline for the consequential assessment is electricity only without 75% of the hours of the server load (there is no marginal factor for gas)

The following sections outline what options are included in the modelling.

2.1.1 Option 1: Replace CHP with Heat Pumps

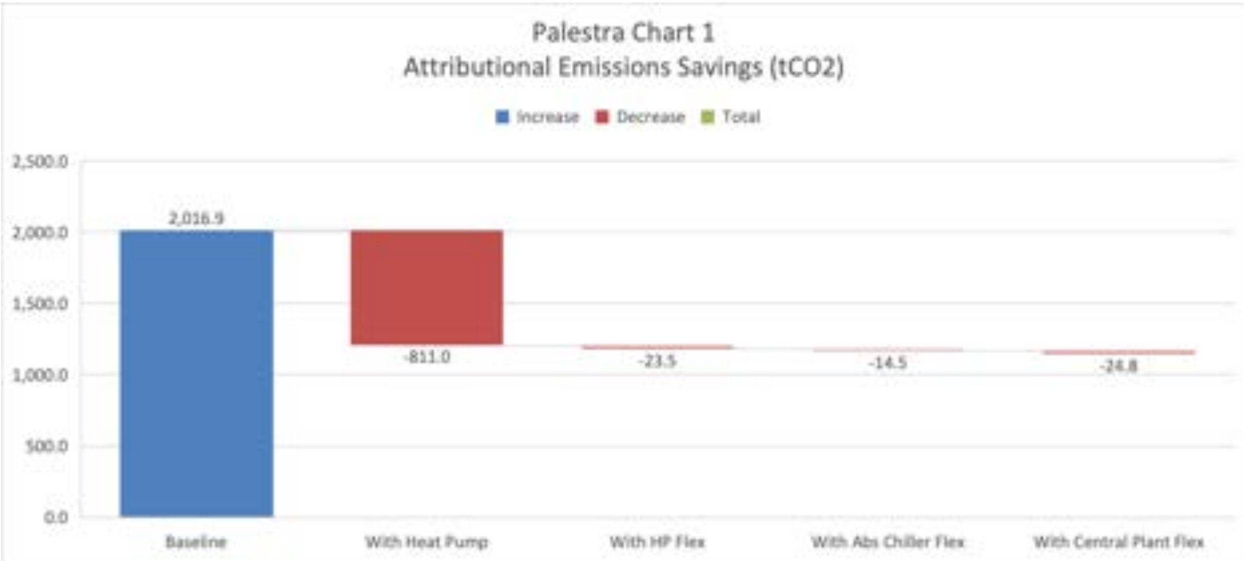
Site impacts:

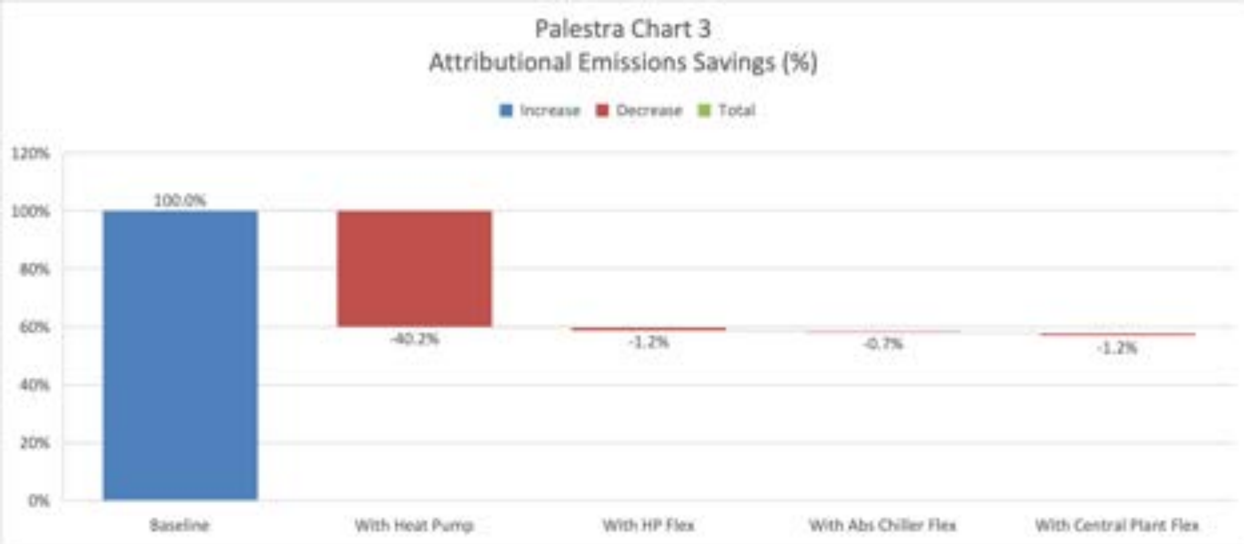
- Replacing the CHP with heat pumps led to a 40% reduction in carbon emissions,
- Carbon flexing added a further 3.1% annual emissions reduction:
    - Flexing the heat pump led to a further 1.2% carbon reduction
    - We used the absorption chiller electricity equivalent consumption from the grid and modelled the flexibility potential to the average grid carbon intensity for a further .7%
    - Shifting some of the central plant load increases the flex potential by 1.2%

System impacts:

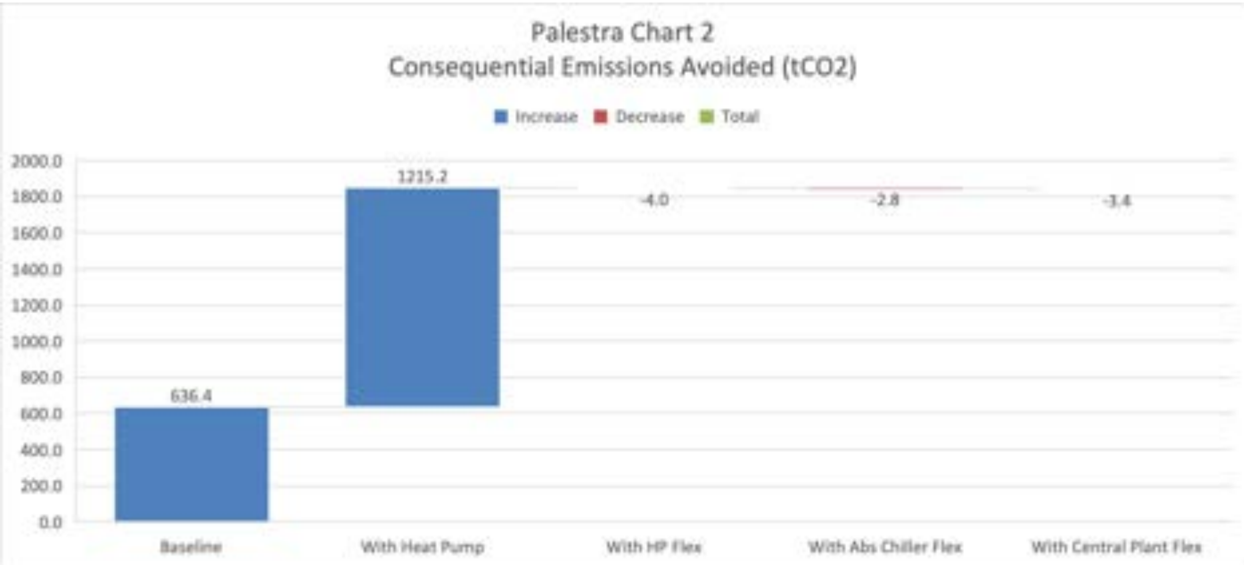
- Measured as the consequence to the grid, electrification drives up emissions (because it is assumed with Consequential Life Cycle Assessment that each new kWh is using a marginal plant that is higher carbon than the average) - see charts 2 and 4 below.
- Carbon flexing mitigates the increase in emissions by just 1.5%.

Total **Building Loads Without Servers**		**Carbon Saved / Avoided**				
	Baseline	**With Heat Pump (Switch from CHP)**	**With HP Flex**	**With Abs Chiller Flex**	**With 50% Central Plant & Miscellaneous Loads Flex**	**Total Avoided**
tCO2 (avg)	2,016.9	811.0	23.5	14.5	24.8	873.7
% Saved (avg)		40.2%	1.2%	0.7%	1.2%	43.3%
tCO2 (marginal) emissions	636.4	1,851.6	1847.7	1844.8	1841.4	
tCO2 (marginal) avoided		-1215.21	4.0	2.8	3.4	-1205.0
% Avoided (marginal)		-190.9%	0.6%	0.4%	0.5%	-189.3%

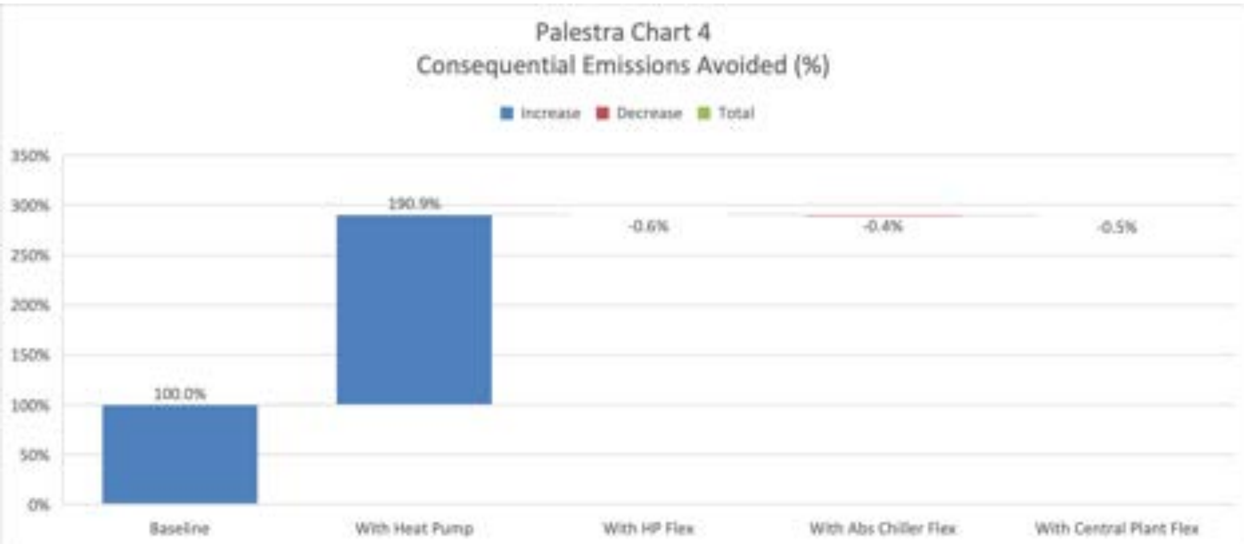




Palestra Chart 3
Attributional Emissions Savings (%)
Increase
Decrease
Total
120%
100%
80%
60%
40%
20%
0%
100.0%
-40.2%
-1.2%
-0.7%
-1.2%
Baseline
With Heat Pump
With HP Flex
With Abs Chiller Flex
With Central Plant Flex



Palestra Chart 2
Consequential Emissions Avoided (tCO2)
Increase
Decrease
Total
2000.0
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
636.4
1215.2
-4.0
-2.8
-3.4
Baseline
With Heat Pump
With HP Flex
With Abs Chiller Flex
With Central Plant Flex



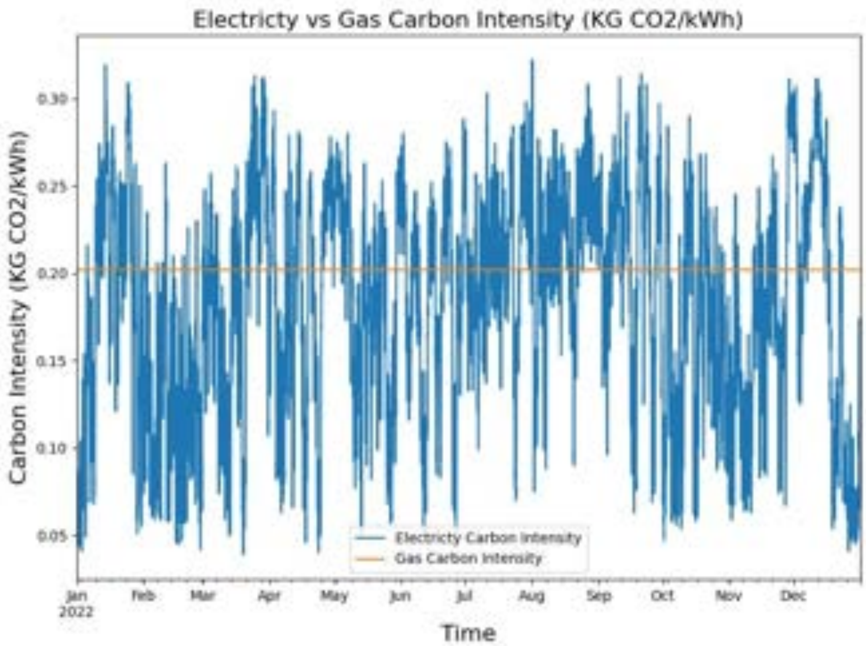
Palestra Chart 4
Consequential Emissions Avoided (%)
Increase
Decrease
Total
350%
300%
250%
200%
150%
100%
50%
0%
100.0%
190.9%
-0.6%
-0.4%
-0.5%
Baseline
With Heat Pump
With HP Flex
With Abs Chiller Flex
With Central Plant Flex

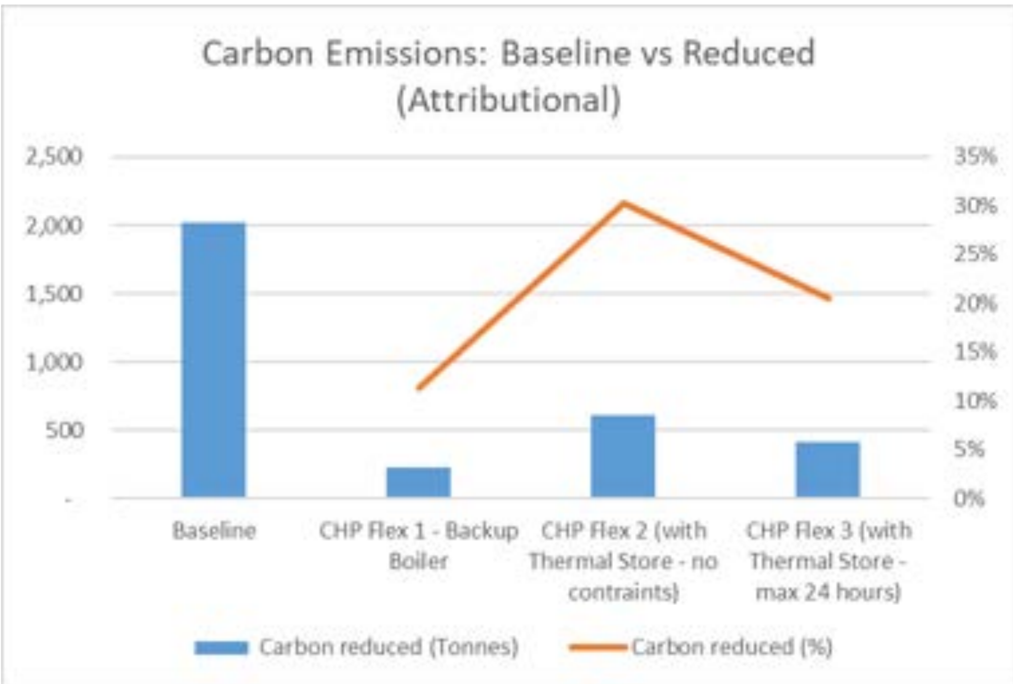
2.1.2 Option 2: Existing CHP 'Carbon Flexing' Potential

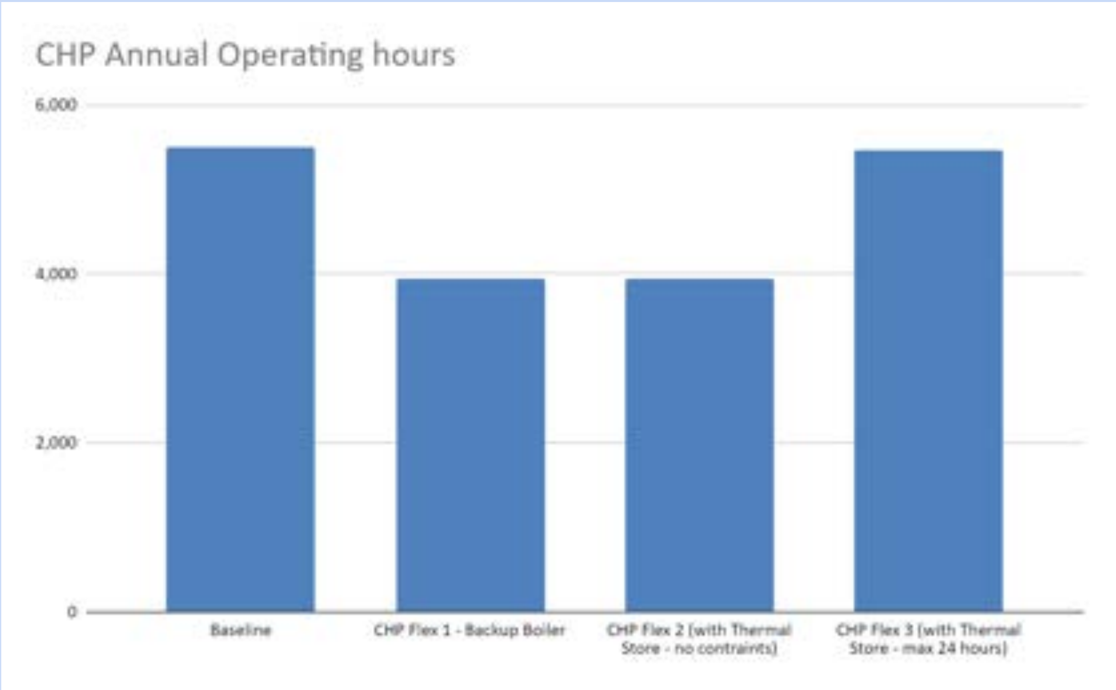
For the Palestra building, further modelling for the pilot is underway to review the impact of running a CHP when the electricity carbon intensity is higher than the Gas carbon factor, and vice versa, switching to grid consumption when electricity carbon intensity is lower than the Gas carbon factor. This could allow existing assets to be maximised for annual carbon savings before full replacement, saving embodied carbon and costs (particularly while electricity prices are so high).

Site impacts:

- Flexing the CHP to ensure that it was utilised when carbon intensity of the grid was high led to a 20-30% reduction in carbon, compared with the 40% reduction in carbon emissions from replacing with a heat pump
- The CHP operating hours were reduced







	CHP Annual Operating hours
Baseline	5,498
CHP Flex 1 - Backup Boiler	3,934
CHP Flex 2 (with Thermal Store - no constraints)	3,934
CHP Flex 3 (with Thermal Store - max 24 hours)	5,471

2.2 High level results summary Pier Walk

What is included in the baseline:

- For the attributional assessment, all the gas and electricity except all server loads,
- For the consequential, electricity only without servers (there is no marginal factor for gas),

What is included in the modelling:

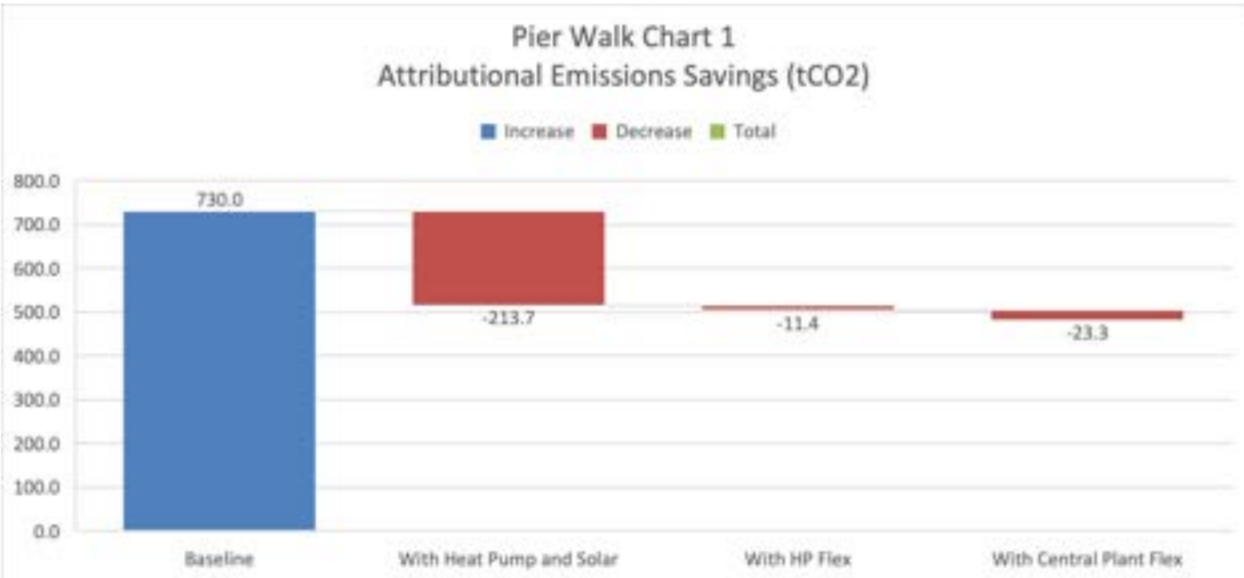
Site impacts:

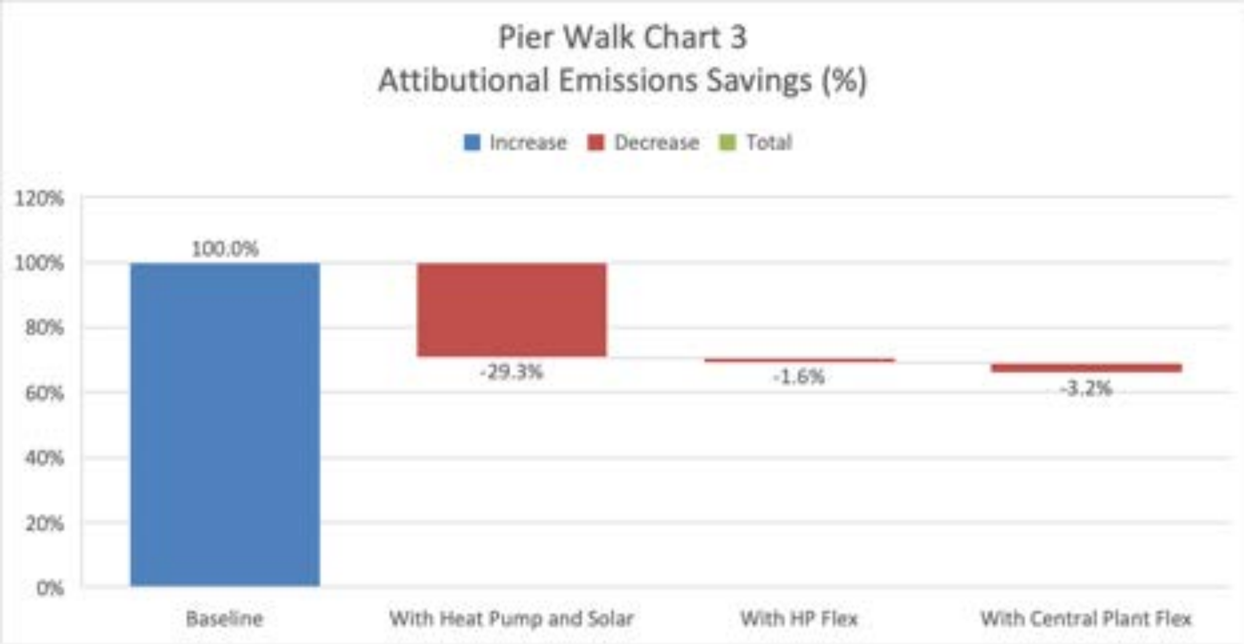
- Solar and heat pump only, because there was no potential for EV charging on site
- Significant benefit of 29.3% CO_2 reduction from gas-fired boilers and adding solar
- Carbon flexing adds 4.8% carbon savings annually
  - Carbon flexing of the pump adds 1.6% carbon reduction
  - Carbon flexing of the central plant adds an additional 3.2%

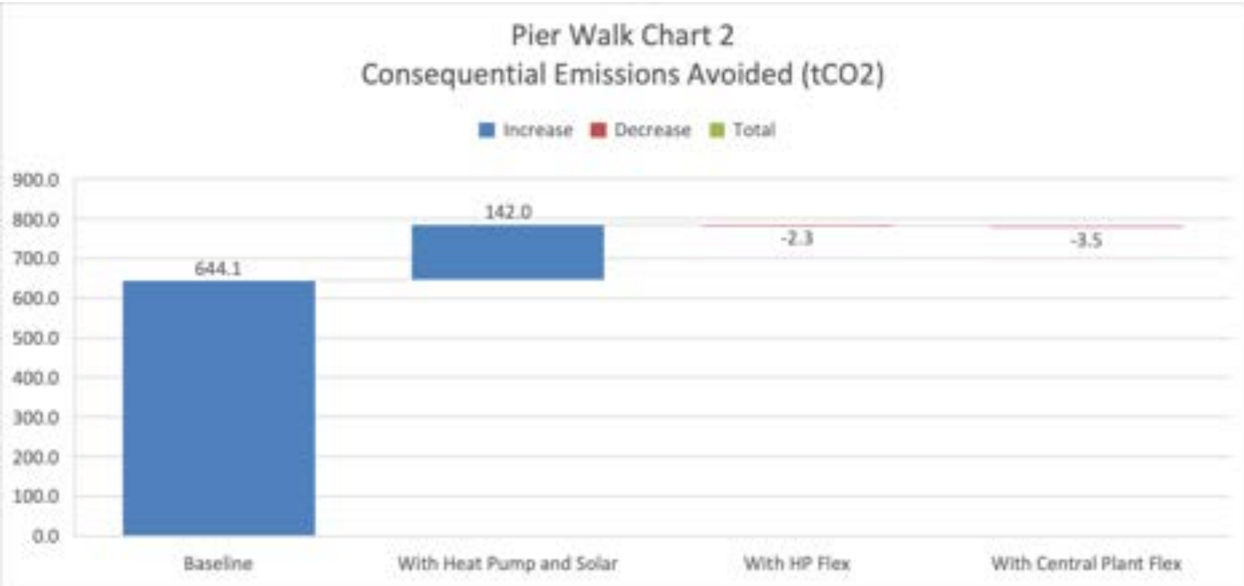
System impacts:

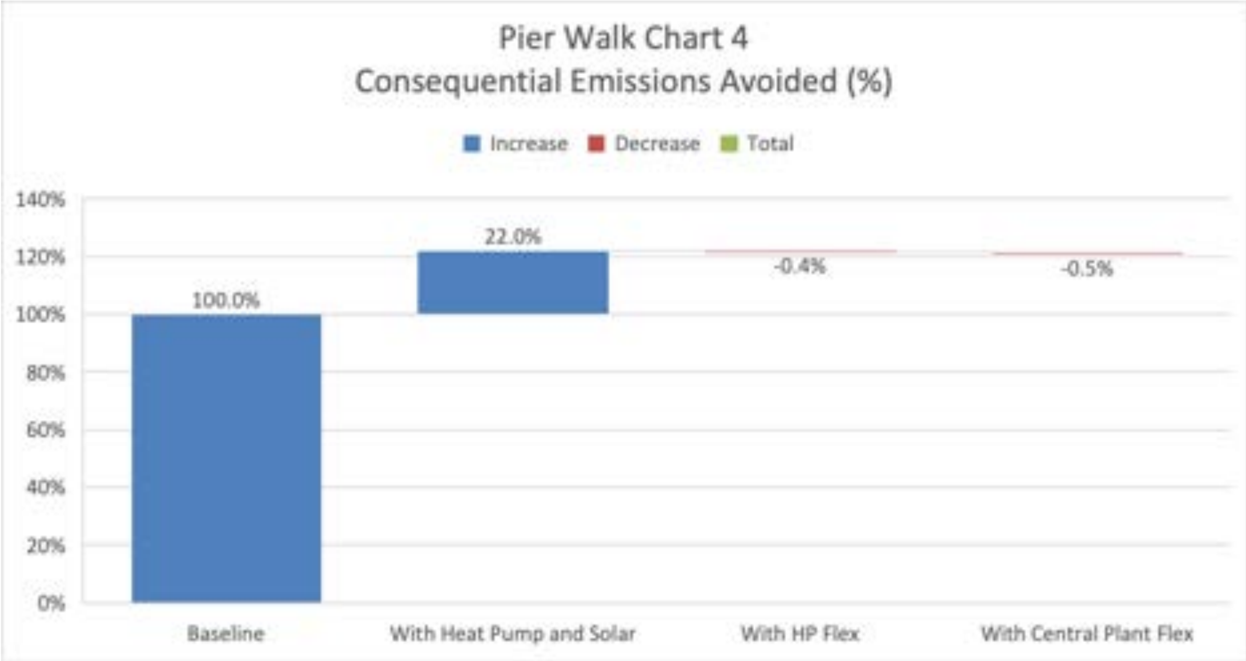
- Measured as the consequence to the grid, electrification drives up emissions (because it is assumed with Consequential Life Cycle Asssessment that each new kWh is using a marginal plant that is higher carbon than the average) - see charts 2 and 4 below,
- Carbon flexing mitigates the increase in emissions by just 1%.

Total Building Loads Without Servers		Carbon Saved / Avoided			
	Baseline	**With Heat Pump and solar (switch from Gas boilers)**	**With HP Flex**	**With 50% Central Plant & Miscellaneous Loads Flex**	**Total Avoided**
tCO2 (avg) -Gas & Elec	730.0	213.7	11.4	23.3	248.4
% Saved (avg)		29.3%	1.6%	3.2%	34.0%
tCO2 (marginal) emissions	644.1	786.1	783.8	780.3	
tCO2 (marginal) avoided		-142.0	2.3	3.5	-136.2
% Avoided (marginal)		-22.0%	0.4%	0.5%	-21.1%



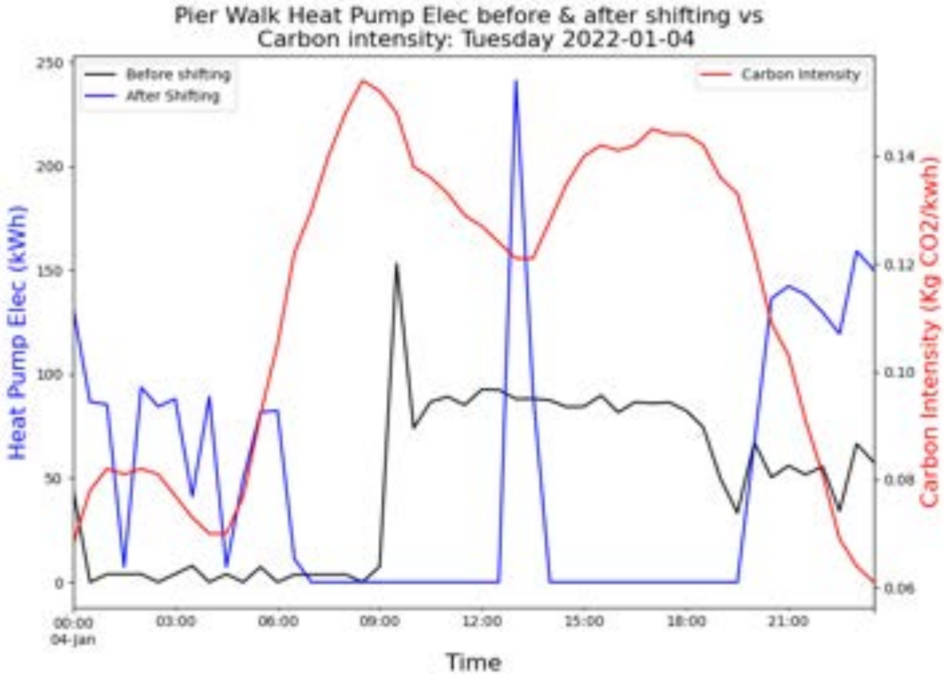

Pier Walk Chart 3
Attibutional Emissions Savings (%)
Increase
Decrease
Total
120%
100%
80%
60%
40%
20%
0%
100.0%
-29.3%
-1.6%
-3.2%
Baseline
With Heat Pump and Solar
With HP Flex
With Central Plant Flex

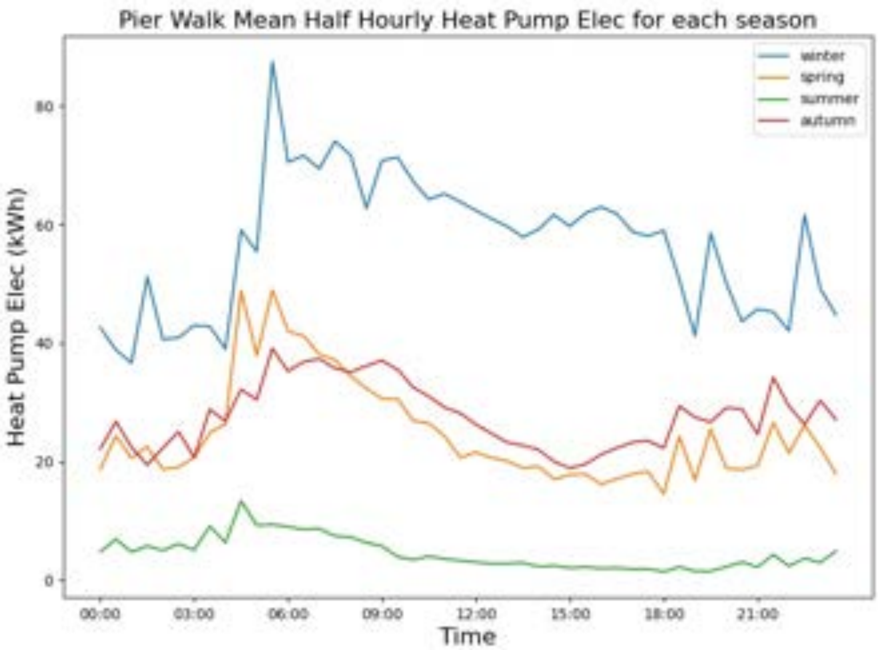

Pier Walk Chart 2
Consequential Emissions Avoided (tCO2)
Increase
Decrease
Total
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
644.1
142.0
-2.3
-3.5
Baseline
With Heat Pump and Solar
With HP Flex
With Central Plant Flex


Pier Walk Chart 4
Consequential Emissions Avoided (%)
Increase
Decrease
Total
140%
120%
100%
80%
60%
40%
20%
0%
100.0%
22.0%
-0.4%
-0.5%
Baseline
With Heat Pump and Solar
With HP Flex
With Central Plant Flex

2.3 Carbon Flexing - Illustrations

Charts showing the effects of shifting demand within a 24 hour period to match to low carbon times and the seasonal changes that will make flexibility very different depending on the time of year and weather. (More charts are available upon request).





3. Methodology - Modelling and Carbon Flexibility

3.1 Pier Walk

The team modelled the installation of a solar PV system and a commercial heat pump (to replace current gas usage). There were not enough parking spaces available for electric vehicle charging to be included. The commercial heat pump size was derived based on the demand required in the building, using the Quantenergy database of products and algorithm to select the suitable product.

Three potential areas on the roof for solar PV panels (see image below) were available, with a combined area totaling 253m2. Using the Quantenergy solar PV algorithm, 45,318 kWh of energy could be generated from the available roof space. Given the relatively high building grid electricity demand, there was insufficient excess solar for the installation of a battery storage system and hence was not considered.

3.2 Palestra

The team modelled the installation of a heat pump (to replace the current CHP) as there was no available roof space for solar PV installation and not enough parking spaces for electric vehicle charging.

To calculate the baseline, the following formula was used:

- 2022 baseline = 2022 grid electricity import + 2022 grid gas import
- 2022 grid elec import data and gas data were not separately provided, so the breakdown was estimated
- 2022 total elec building demand = 2022 grid elec import + 2022 CHP elec output + 2022 renewable elec generation
- 2022 grid electricity import = 2022 total elec building demand - 2022 CHP elec output - 2022 renewable elec generation
- 2020 renewable generation was 37,018 which was only 0.6% of 2022 total elec consumption. Because 2022 renewable generation data was not available, assumed 2022 renewable elec generation =0
- 2022 grid electricity import = 2022 total elec building demand - 2022 CHP elec output

To model a HP replacing the CHP we used the formula:

- 2022 grid elec import no CHP + 2022 grid gas import no CHP

- (2022 total elec building demand + 2022 absorption chiller elec equivalent) + (old 2014 grid gas import because this pre-dated the CHP installation)

3.2.1 Carbon flexibility

We considered three shiftable building electricity loads with the potential to flex and respond to a carbon signal:

1. Heatpump
2. Absorption Chiller (Palestra only)
3. Central Plant & Miscellaneous Loads

For all three loads, national grid carbon intensity was used as the signal. Maximum flex/shiftable load was considered within a given day i.e. how the half hourly profile could be shifted so to minimise the total carbon emissions for a given day with the constraint that the sum of the load across the day would remain the same.

For a given day consisting of 48 half hourly periods, in the 24 half hourly periods with the highest carbon intensity, the loads are set to zero and instead added onto the loads in the 24 half hourly periods with the lowest carbon intensity. In this way the loads in the highest carbon intensity period are reduced to zero and shifted to the periods of lower carbon intensity. This assumes that the heating and cooling loads are indeed shiftable to such degrees, which is the case for both Pier Walk and Palestra since both sites have sufficiently sized hot water (DHW) buffer vessels. We also assumed that 50% of the Central Plant & Miscellaneous Loads were shiftable due to the fact a significant proportion of the load comes from Metered Refrigeration Plant Chillers and HVAC.

3.2.2 CHP Flexibility at the Palestra

We considered three possible ways to shift the operation of the existing CHP to lower carbon emissions in response to grid carbon signals:

1. CHP replaced by backup boilers
2. CHP replaced by thermal store - no constraints
3. CHP replaced by thermal store - max 24 hours