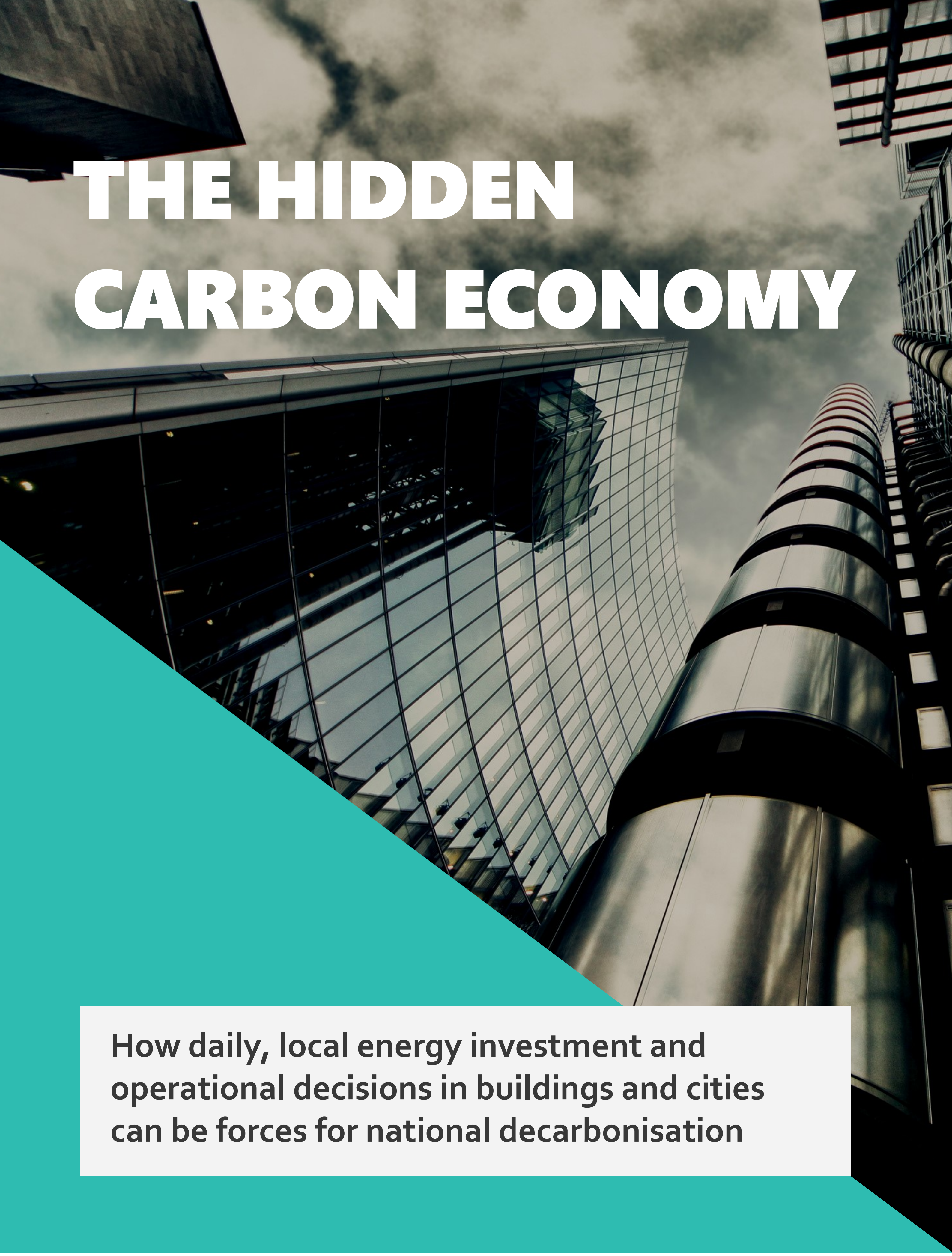
THE HIDDEN CARBON ECONOMY



How daily, local energy investment and operational decisions in buildings and cities can be forces for national decarbonisation

ENERGYUNLOCKED

About the Carbon Flex Project

The report summarises the findings of the Carbon Flex project 2020-2021. It is increasingly clear that electrification and the decarbonisation of energy systems are both key to future climate change mitigation when society will be operating on more carbon-free and renewable energy all hours of every day. But how to get there, the pace, the cost and who benefits most, are not yet certain. The Carbon Flex project assessed whether accounting for carbon in a more accurate or granular way would improve the local authority's business case for making investment decisions to electrify their own buildings and transportation. It builds on a two year 'FlexLondon' Mayor of London programme that identified barriers to adopting smart, flexible energy solutions. The Carbon Flex project set out a key hypothesis: ***If the carbon impacts of a local energy decision on the broader energy system could be measured, then the local investment and operational matching of those actions to renewable energy would be more likely to happen.*** The project assessed the data from Merton Council's buildings, before holding workshops and one-to-one discussions with industry, climate and finance stakeholders. This report sets out a roadmap for valuing these local actions. This phase of the project took place in London and future work will look to other cities in other countries to understand the scalability of the findings.

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Project Lead Partners

Molly Webb, Founder and Director, **Energy Unlocked**, www.energyunlocked.org

Aneysha Minocha, Founder and Director, **Quantenergy**, www.quantenergy.co.uk

Associate Partners

Laurence Watson, Ayrton Bourn, Clement Attwood, Dylan Johnson, **Future Energy Associates**

Gautham Krishnadas, Co-Founder/Director and Pierre Vogler-Finck, Advisor, **dTime**

Mark Bornhoft, Director & Founder, **EigenVentures Ltd**

Robert Friel, Managing Director, **Apteno Consulting**

Report design

Naomi Bennett, www.naomibennett.co.uk

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Rick Curtis, Programme Manager, Stephen de Souza, Strategic Programme Manager Energy and the Energy Team, Greater London Authority

Corin Freshwater-Turner, Energy Project Officer, Merton Council

Anneliese Allen-Norris, Policy and Programme Lead (Climate Change), Richmond and Wandsworth Councils

Shravan J. Joshi, Elected Member for Bishopsgate, and Simi Shah, Project Director-Innovation, City of London Corporation

Henry Richardson, Environmental Impact Analyst, and Laura Corso, Managing Director, WattTime

Oliver Corradi, CEO, and Markus Killendahl, Product Manager, Tomorrow and Electricity Map

Matthew Brander, Senior Lecturer in Carbon Accounting, University of Edinburgh Business School

Derik Broekhoff, Senior Scientist, Stockholm Environment Institute

Piyush Verma, Global Future Energy Leader, at World Energy Council

Alex Rathmell, Managing Director, at Energy Pro

Mikael A. Mikaelsson, Europe Lead on Net-Zero Innovation & Climate Change, Foreign and Commonwealth Office

Rick Parfett, Senior Climate Change Specialist, WWF-UK

Terri Wills, former CEO, World Green Building Council

Rachel Bravard, Founder & Managing Director, Vallard Limited

Elaine Trimble, Director, Cally Energy

Jake Verma, Senior Consultant, Energy Systems Catapult

Jeremy Yapp, Head of Flexible Energy Systems, and John Parsons, Director Digital, BEAMA

Matt Roderick, CEO, N3RGY

Tereza Borges, International Business Development Executive at Lumenaza, and CSO, N3RGY

Noah Miller, Carbon Solutions Lead, Advanced Infrastructure

Andrew Lam, Energy Policy Lead, Tesla

Robin Abraham, Head of Product, Kaluza

Simon Daniels, CEO, Moixa

Toby Ferenczi, Founder of Energy Tag and Director, Ovo Energy

Alistair Martin, Chief Strategy Officer, Andrew Langlands, Head of Account Management, and Claire Addison, Head of Regulation at Flexitricity

Vijay Natarajan, Co-founder & COO, qBots

Isabel Sunnucks, Project Manager, and Jo-Jo Hubbard, CEO, Electron

James Kelloway, Energy Intelligence Manager (Strategy and Regulation), National Grid ESO

Executive Summary

There is growing consensus that electrification of much of the energy demands from heating, transportation and industry – coupled with decarbonising electricity – will get us the majority of the way toward tackling climate change. This requires two key steps: first, to electrify the assets in buildings or transport; and second, to match energy demand to operate on a 'carbon-free' energy supply every hour of every day.

Cities present an unprecedented opportunity to test and scale this vision of matching demand to carbon-free energy to bring the vision of net zero closer. Many are motivated to decarbonise rapidly (over 1,800 have declared climate emergencies globally); they have a high concentration of assets and intersections where energy needs and uses interact; and they often have access to data that can be used to model the potential for impact and scale.

However, there are barriers to investing in the electrified technologies that provide 'matching' because of a lack of awareness, an uncertain business case and a lack of incentives. ***The Carbon Flex project sought to understand whether 'carbon flexing' could be a solution***, by modelling the addition of two potentially flexible technologies (heat pumps and batteries) in several buildings in a London borough, to explicitly and directly match their energy demand to carbon intensity of the electricity grid. The aim was to ensure that the building was using the most carbon-free electricity sources available at any given half-hour.

Our use cases show, when using these more granular carbon datasets, that by intelligently operating the heat pump and battery to reduce highest carbon energy consumption, the buildings can avoid up to **8%-13% more carbon**. This is achieved through flexing batteries for up to 4 hours overnight, and heat pumps for 4 hours day and night, to avoid the highest carbon intensity half-hourly grid electricity, at low cost, without impacting the energy services to the building occupants.

Buildings with rooftop solar	**...adding a battery**		**...adding a heat pump**	
Carbon Impact	**Option 1: Maximise using rooftop solar**	**Option 2: + flex to grid carbon intensity**	**Option 1: Maximise using rooftop solar**	**Option 2: + flex to grid carbon intensity**
Measured as footprint (scope 2) reduction in CO_2e	**18%**	**22%**	**9%**	**14%**
Measured as avoided CO_2	**1%**	**8%**	**9%**	**13%**

Scaling just the battery use case to similar buildings across the UK today would provide 175 MW of capacity on the demand side for carbon flexing and avoid the carbon equivalent of 10,000 homes' energy footprint. The future benefits in London, if the targeted solar rollout to 2030 also included **'carbon flexing' batteries would avoid 20,000 tonnes of CO_2**.

Barriers to Carbon Flexing

While there is significant interest from local government stakeholders to see this value realised, particularly if they have made commitments to achieving net zero in advance of their national grid being fully carbon-free, barriers remain.

1. Accounting for carbon today is limited by annualised carbon figures used in Scope 2, and a lack of clarity on calculating the benefits of avoided carbon. If we want to achieve decarbonisation we must measure carbon saved and avoided, not only energy kWh saved.
2. Carbon markets are limited in coverage and do not solve the challenge of aggregating many small actions at the end user level.
3. Price and carbon are not directly correlated, and kWh cost savings are no longer equivalent to decarbonisation in higher penetration renewable grids. Therefore, price does not provide enough value or incentive for end users to align their marginal choices with carbon performance.

City Actions

To achieve carbon flexing benefits, local governments can take three key actions:

1. Account for carbon impacts in two different ways - firstly, the familiar carbon 'footprint' savings at granular level, and secondly, based on the effect that carbon flexing will have on the wider system, measured in avoided carbon emissions.
2. Act on carbon using more granular time and location-based carbon intensity datasets to trigger carbon-avoiding optimisation at the site level and evaluate the results.
3. Attribute value by aligning existing policies and programmes either through voluntary commitments to carbon-free operations, or procurement levers that require reporting.

Moving to a more flexible energy system could provide cities with the means to avoid paying millions in offsets in 2030, because demand would dynamically match low carbon energy supply and individual entities such as buildings and cities could operate fully on renewable and carbon-free power. It also provides opportunities to avoid fossil fuel backup and baseload power, unlock significant cost savings, restore confidence in the ability of individual action to have a systemic impact, lead to an economy in avoiding carbon, and ultimately reduce the cost of decarbonising our grid. This offers wider benefits for equitable distribution of the benefits of electricity transition to every consumer, and job creation in retrofit and low carbon technology sectors.

Recommendations

Governments and standards can do more to support carbon flexing.

1 Carbon accounting needs to recognise the impact of carbon flexing

Improve Scope 2 granularity and introduce Scope 4 to capture avoided emissions benefits.

2 Create open and fair access to carbon flexing

Access to carbon flexing requires opening up data, ensuring standards will allow timely signals to hardware that can be 'flexed', and opening access to data platforms for all market participants.

3 Value carbon flexing performance to drive uptake

Targeted policies and programmes can require carbon reporting at a more granular level, incentivising carbon flexing directly, whilst utilising the learning to evidence market redesign to more accurately reflect carbon in every marginal decision that end users are making to electrify their own buildings or purchase renewable energy.

The above provides the evidence governments need, to push ahead with the sustained but consistent process of market redesign, fit for the **end goal of a global carbon-free energy system**. Users on the 'demand side' can hasten the role of governments by starting on the journey today, with the data we have at very low cost, and in cities – where it will benefit people most.

Report Contents

1. Introduction: Why Hidden Carbon is Worth Finding

Organisations and companies recognise that they have a role in decarbonizing electricity and electrifying heat, transport, and industry - and a few have even begun making commitments beyond 100% renewable energy procurement to 'operating on' carbon-free energy, driving them to electrify their own heating, transportation, and industrial demands. Google has committed to 24/7 carbon-free energy and Microsoft to operate 100% renewable 100% of the time. The UN has created a Go 24/7 Carbon Free coalition for those making these voluntary commitments.

The opposite is also happening. Some organisations, including local authorities, have no choice but to make decisions that are not about reducing carbon. This is because it is still cheaper on the margin to buy something like a gas boiler that is higher carbon than available technologies that electrify heat (such as heat pumps) or a diesel vehicle instead of the electric alternative. High carbon decisions are still being made because we have few forward-looking incentives on valuing electrification and decarbonisation of electricity in every procurement and energy system management choice that is made. Every year the decisions are delayed makes it more challenging for local areas to meet 2030 net zero targets, putting them in the untenable position of paying for politically unpopular offsets later.

We could turn these many decentralised decisions and asset investments by companies and local authorities into a force for decarbonisation, but not unless we start to incentivise them based on the carbon benefits they bring. As the market stands today, the risk is that these investments don't happen, or happen too slowly, and that once these assets are in place, that they are not used in a coordinated way to manage renewable energy, but instead increase peaks or cause unpredictability for energy system operators.

Leaving it to the market - as the market is structured today - is not working.

In the UK, we are just 2% of the way toward our 2030 targets for heat pumps and electric vehicles (EVs). That means huge uptake of new heat pumps and EVs needed every year over the next eight years to even begin to electrify at the scale required. This broader shift from pushing renewable energy to pulling it into every action means that societies should be focused on 'operating on' renewable energy, matching their demand every hour of every day to ensure these investments happen.

We could turn these many decentralised decisions and asset investments by companies and local authorities into a force for decarbonisation, but not unless we start to incentivise them based on the carbon benefits they bring.

1. Introduction: Why Hidden Carbon is Worth Finding

In the over 20 years that we have had an international framework to tackle climate change, the conversation has been about how we share the burden of reducing emissions. Countries, local governments, and companies have set targets but then ratcheted back their decarbonisation ambitions to fit the rules of today's energy markets, where a kWh is equal no matter what the carbon content of that kWh is, where it was generated and from what source. Even with initiatives that track and 'guarantee' the origin of renewable energy, the goal has been to increase new renewable generation, not to manage and operate assets in a system that is largely renewable, which causes entirely new challenges. The conversation about sharing the burden does not solve the negative 'externality' of carbon emissions that many small decisions and actions are contributing to today. They need instead to be turned into creating positive externalities of avoiding carbon.

But markets are hard to shift quickly, so we need to start now with what we can do today. We have carbon intensity per kWh data that lets us start operating on renewables as much as possible already. We can start with voluntary initiatives and targeted policies now, in order to build toward a total shift in valuing avoided carbon in how we operate across the board.

This report sets out a map to using carbon data today and valuing it through initiatives that can begin now. These actions can be done in parallel to the longer-term structural market changes that need to take place. Governments need to use the carbon data as a first step in valuing carbon explicitly - which is currently an 'externality' - even as they undertake the longer process of changing market prices and rules to properly 'internalise' carbon.

2. Vision: Unlocking a Hidden Carbon Economy

Today, the world is moving at pace towards renewable power generation – and this progress is considered one of the great success stories of the transition to net zero. In most countries, despite this progress, the use of high carbon gas or coal with carbon capture and storage (CCS) and expensive forms of power generation like nuclear is anticipated to be required long into the future - even beyond 2050 when the world must reach net zero. However, there is an alternative emerging that goes further than the traditional demand side approaches of energy efficiency and renewable energy procurement. Moving to a more flexible energy system – where (1) demand would dynamically match energy supply from wind and solar and (2) where individual entities, such as buildings and other infrastructure in cities, could operate fully on renewables – provides the opportunity to eliminate fossil fuel backup and baseload power. This unlocks significant cost savings, restores confidence in the ability of individual action to have a systemic impact, leads to an economy in avoiding carbon and ultimately reduces the cost of decarbonising our grid.

2.1 A New World of Electrified Energy Brings Challenges

Electricity generation around the world is rapidly shifting to renewable power. In 2020, 29% of the world's electricity was powered by renewables – a 2% increase from 2019.[1] This is expected to rise by another 8% in 2021. In the UK, 2020 was the first year on record when renewables generated more of its electricity needs (43%) than fossil fuels (38.5%).[2]

Yet the intermittency of this power still requires advanced economies like the UK to rely on expensive and largely fossil fuel based large scale generation long into the future to provide for enough backup power in case of low output from variable wind and solar power. Even with the dramatic increase of individuals, public and corporate entities actively choosing renewable power and taking significant action on energy efficiency – as well as the large-scale subsidies that governments like the UK provide to the renewable sector – the UK Climate Change Committee forecasts that still by 2050 combinations of nuclear plants and with CCS will be required.[3] These types of energy supply are more predictable and help maintain precise planned levels of supply at all times compared to 'variable' renewable energy which is weather and time-of-day dependent. There is often a fear that variable or intermittent forms of power will not be reliable enough for the energy needs in every cold winter or hot summer day in the future.

1 https://www.iea.org/reports/global-energy-review-2021/renewables

2 https://www.offshorewind.biz/2021/03/25/renewable-energy-outperforms-fossil-fuels-in-uk/

3 https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Electricity-generation.pdf, p 29

This concern is exacerbated by the anticipated advance of electrification. Mass electrification is required as the world transitions to net zero, which will significantly increase electricity demand. Continuing the UK example, the Climate Change Committee predicts that the electrification of surface transport (electric vehicles), buildings, and industrial processes will lead to over 200% increase in electricity demand between 2018 and 2050.[4] Growing demand from new technologies, such as heat pumps and electric vehicle fleets, coupled with the variability of renewables on the supply side, will present significant challenges to keep the grid 'stable' or balanced. This means, in order to ensure that we are building enough renewables to overcome intermittency, we either end up building and paying for much more capacity than would otherwise be needed or we end up using much more high carbon generation (with CCS).

2.2 Flexibility is Seen as a Solution

Flexibility is seen as a solution to these challenges. It can come from different sources on either (a) the 'supply side' - in the form of large-scale storage (batteries) or interconnectors - or (b) the 'demand side'- in car batteries or heating systems in buildings. Demand side flexibility is seen as a potentially more cost-effective route to decarbonisation if we expand its use beyond current demand side response programmes - i.e. when buildings turn their energy demand on or off for short periods of time -- because it relies on using the buildings we already have, or new technologies like electric vehicles, more effectively. By using technologies 'smartly' we won't need to build as much upstream production or flexibility capacity. Working together, supply side and demand side flexibility can balance and stabilise an energy system, creating more stability by matching variable renewables with demand and ensuring we utilise existing capacity as much as possible.

200%
The increase in electricity demand expected in the UK to 2050 as we electrify heat and transport

[4] https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Electricity-generation.pdf, p. 38

Flexibility for energy industry experts

Definitions of flexibility vary,[5] but generally refer to some amount of electricity or thermal energy that can be stored or shifted in time, to be used when most needed, therefore avoiding the creation of additional energy capacity. The broadest definitions include heating and sector coupling – a large focus in countries with district heating systems that are also using gas.

According to the International Energy Agency, flexibility is "the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply".[6]

UK regulator Ofgem defines flexibility as "modifying generation and/or consumption patterns in reaction to an external signal (such as a change in price) to provide a service within the energy system".

Demand response

'Demand response' is provided by energy customers, usually large industrial or commercial sites, that can reduce or shift the time of their electricity usage in response to market signals, time-based rates, or other forms of financial incentives. As distinct from energy efficiency, demand response can be a 'turn up' demand service, or 'turn down', depending on the need of the system operator. Already in use today in some energy markets, this is the most common form of demand side flexibility today. In the UK, criticism that demand response has largely been provided by diesel generators being turned on as backup to a site, or indeed to directly provide 'turn up' services, has spurred efforts to ensure that low carbon alternatives are able to compete to provide similar services.

Technologies and Business Models enabling Flexibility

Technologies that can deliver 'supply side' flexibility: Interconnectors, flexible gas plants, large scale battery storage, long duration energy storage (such as hydro power).

Technologies that can deliver 'demand-side' flexibility: Demand response in buildings, 'behind the meter' or distribution network connected battery storage, electric vehicles 'smart' charging, electric heating such as heat pumps, or communal heat solutions.

Business models or approaches that are increasingly seen to deliver flexibility: Community energy projects (particularly if they include solar + batteries), sector coupling, virtual power plants, peer-to-peer energy trading, energy-as-a-service, digital energy 'platforms', Distributed Energy Resources Management (DERMs), electric fleet management and shared electric mobility services.

[5] Lund, P.D., Lindgren, J., Mikkola, J. and Salpakari, J., 2015. Review of energy system flexibility measures to enable high levels of variable renewable electricity. Renewable and Sustainable Energy Reviews, 45, pp.785-807.

[6] https://www.iea.org/reports/status-of-power-system-transformation-2019

The Carbon Trust and Imperial College London's modelling shows that deploying flexibility across the heat, transport, industrial and power sectors in Great Britain can reduce the cost of achieving net zero by £9-16 billion per annum in 2050, primarily by reducing the need for 10 GW of nuclear generation (or more than three Sizewell C size plants) and 50 GW wind generation (the equivalent of 41 Hornsea offshore wind farms). Furthermore, in a fully electric scenario, an additional 90 GW of gas fired power plants could be reduced at peak times with flexibility.[7]

£9-16 billion per annum in 2050

The cost reduction for achieving net zero if we deploy flexibility across heat, transport and power sectors.

This potential is exciting to experts, but is flexibility being enabled by the daily decisions to purchase or operate buildings and mobility solutions?

2.3 The Decarbonisation and Demand-side Flexibility Disconnect

If we could use demand side flexibility to match demand to renewable energy supply, then cities present the best opportunity to test and scale hourly matching because they are huge demand centres; they are motivated to decarbonise rapidly (over 1,800 have declared climate emergencies globally);[8] they have a high concentration of assets and intersections where energy needs and uses interact; and they often have access to critical use data that can be used to model the potential for impact and scale.

And cities are home to businesses, individual consumers, large and small corporations, who, as the race to net zero accelerates, are looking to contribute by minimising their own carbon footprint and taking actions which, they hope will contribute to the larger scale systemic change that is needed to reach net zero. They are doing this in numerous ways, including implementing energy efficiency measures – such as building retrofits and purchasing renewable energy through 'green tariffs' offered by energy suppliers or Power Purchase Agreements.

Yet, unfortunately, these well-meaning actions are not necessarily delivering the value they should and nor are they necessarily contributing to flexibility. What may be counterintuitive is that the widely accepted tools for decarbonisation – energy efficiency and renewable energy procurement – are becoming less useful and less impactful as the grid decarbonises. Why? This is because they do not necessarily result in matching the demand to the supply of renewables.

7 https://publications.carbontrust.com/flex-gb/analysis/
8 https://www.ren21.net/report-renewables-in-cities-2021/

The intermittency of renewables means that the carbon intensity of the grid mix changes on an sub-hourly, hourly, daily and seasonal basis. In a power system with high solar and wind generation, a sunny afternoon or a windy morning would lead to excess renewable generation, potentially lowering the carbon intensity to zero at those times of day. Conversely, a calm and cloudy day could lead to greater reliance on other forms of supplied power, such as a gas power plant, increasing the carbon intensity of the grid on that day. Even when battery storage is utilised to help even out the intermittency and rely on less on gas or coal, high carbon intensity of the grid at the time of battery charging can lead to high carbon emissions attributed to the power used from storage.

Demand side efficiency and flexibility are underutilised today for decarbonisation. Though energy efficiency projects are the most popular emissions reduction activities, following the 'efficiency first' principle, accounting for 65% of the nearly 7,000 responses to CDP they make up just 23% of the total reported impact (in terms of tonnes of CO2 savings).[9] Furthermore, if these actions are taken at the wrong times, their system – or grid-level – impact will be minimal. A study of 4,000 retrofit projects in California demonstrated that while individually they were saving carbon, in aggregate, they still increased load during the evening peak, just when solar power is no longer available. Efficiency is often assumed to reduce peak demand, because it reduces kWh, but this is not necessarily the case. It could be more efficient to have a heat pump, but thousands of houses with heat pumps could create an early morning 'peak' just when no sun or wind is available. In other words, efficiency does not necessarily change the fact that we have peaks, or when they are, and may not necessarily support increased decarbonisation if peaks require fossil fuel backup without other solutions to build flexibility into the system.

Efficiency is often assumed to reduce peak demand, because it reduces kWh, but this is not necessarily the case.

Uncertain business case for flexibility

Wouldn't the need to solve challenges in grid management lead to more demand-side flexibility and therefore more decarbonisation? Unfortunately, the energy markets alone are not sufficient to drive this effect. In London, during a recent programme to identify 1 GW of demand side flexibility to scale up by 2050, several challenges were highlighted. Energy cost reduction alone and even payments for flexibility from national grid or local network operators – particularly if the cost of energy was not a large part of the business overhead – was not sufficient incentive for local authority stakeholders to invest in these projects, because stakeholders had other business objectives and priorities or previous experience that made them wary of adopting new technologies or allowing external companies to automatically control the operations of systems like heating in buildings.

[9] https://static1.squarespace.com/static/556c3a68e4b056fbbd35d60c/t/5a608f81ec212d0970f60bd4/1516277636332/EnergyLeaders_Unlocked.pdf

FlexLondon - A Mayor of London programme 2018-2020

Through the FlexLondon project running from 2018-2020, Energy Unlocked worked with the Greater London Authority to identify potential projects that would put London on a path to 1 GW of flexibility in London and identify potential for scale, and thereby outcompete diesel being the primary demand response resource. In fact, much of the supply side flexibility in UK markets comes from fossil fuel plants and generators, which continues to be the case. Low carbon demand side alternatives are slow to emerge. The project sought to understand the barriers to rapid development of low carbon alternatives, and how to overcome them.

By working with London, it was possible to understand if building owners, developers and climate policy leads in boroughs understood how flexibility would help them meet their own, and London's, climate and environmental goals, while also meeting the needs of both the end user and wider energy system. The project explored the potential of domestic and non-domestic consumers to use solutions ranging from smarter control of existing energy-using appliances and heating systems, through to thermal or electrical storage and local generation, and into Energy-as-a-Service or Heat-as-a-Service.

eMobility

- ✓ Enhanced usage of street cabinets for resilience and grid flexibility through battery upgrades
- ✓ Scale up opportunity – utilisation of existing assets enabling transport electrification

Social Housing Heat

- ✓ Electric Storage Heating optimisation
- ✓ Flexible charging to meet user demand for heat
- ✓ Impact on fuel poverty
- ✓ Scale up opportunity for 160,000 homes (1.2-1.6 GW)

Solar + Clean Storage

- ✓ Storage & flexibility for buildings with Solar PV
- ✓ carbon reduction & enhanced self-consumption
- ✓ Reduced grid reliance and flexibility provision
- ✓ Scale up opportunity across London Boroughs (1.5 – 2.2 GWh/annum)

Diesel Generator Replacement

- ✓ Decarbonisation of backup supplies for offices
- ✓ Local Air Quality improvements
- ✓ Future Proofing for businesses
- ✓ Flexibility resource

The project identified four replicable use cases which could be used to deliver new flexibility immediately. These demonstrate a subset of the possibilities that are available to a city. The project also identified the wider benefits these projects can bring to a city, such as increasing energy resilience on-site, meeting carbon targets and improving air quality.

While the opportunity for scale and achieving benefits was significant, the FlexLondon programme showed that barriers remained, including lack of awareness of the opportunity, insufficient comfort with control and automation technologies on site, the uncertainty of the business case for financing energy 'flexibility' and that energy cost reduction alone was not sufficient incentive for local authority stakeholders to invest in these projects.

More information: https://www.london.gov.uk/what-we-do/environment/energy/flexlondon

Even though new regulatory and policy frameworks are starting to come into place to let the smaller distributed energy resources like those found in cities to be valued in energy markets, these are not yet overcoming consumer barriers. The uncertainty of the longer-term business case, the complexity of today's value chain and the existing systems that were built around other 'supply side' sources of flexibility mean that the pace of deploying demand side flexibility and the scale of it are uncertain.

Policy and regulatory frameworks are coming, but not yet clear how implementation will deliver pace and scale of demand side flexibility, hurting the business case

Currently, in the US, Australia, the UK and Europe, there are signs the policy environment and regulatory arrangements are changing to allow demand side flexibility to be utilised more. In Australia, the spot market has moved to 5 minute settlement to encourage batteries and demand response.[10] In Europe, the Renewable Energy and Electricity Markets Directives are encouraging 'energy communities' to play a role in providing grid services such as network cost sharing and balancing.[11] In the US, the federal energy regulatory commission (FERC) order 2222 opens up the wholesale market to smaller scale distributed energy resources (DERs) like batteries.[12] In the UK, Distribution Network Operators have begun to procure changes in demand from aggregators of flexibility. This still includes diesel generators but in future could increasingly include battery storage or demand side response instead. Code changes in 2021 make smaller loads available for aggregation into National Grid's balancing mechanism, meaning that 1 MW of services could come from hundreds, or thousands of smaller loads coordinated together.[13]

Lack of motivation and other incentives

FlexLondon results showed that users and purchasers of solar and batteries, EVs or heat pumps which could potentially be managed as a flexible resource for national decarbonisation were not necessarily motivated to do so. A body of work is emerging which looks at consumer drivers and motivations[14] for adopting technologies such as batteries with solar panels, which may contradict grid needs. Consumers may be seeking increased autonomy and may not trust third parties to control their buildings or vehicles. Alternatively, incentives are lacking. For example, Ofgem's recent review of EV owners showed that most do not see the value of 'smart charging' to off-peak times -- one form of flexibility -- because the value of purchasing the vehicle and avoiding the costs of petrol is so great, the additional value of a few pence saved on their electricity price in nighttime hours is comparatively small.[15]

[10] https://www.aemc.gov.au/rule-changes/five-minute-settlement
[11] https://www.raponline.org/wp-content/uploads/2020/12/rap-community-energy-January-2021.pdf
[12] https://www.ferc.gov/media/ferc-order-no-2222-fact-sheet
[13] https://www.current-news.co.uk/news/elexon-welcomes-ground-breaking-code-modification-that-enables-small-assets-to-enter-bm
[14] https://userstcp.org/
[15] https://www.ofgem.gov.uk/publications/one-four-consumers-plan-buy-electric-car-next-five-years-according-ofgem-research

So why not make matching to carbon more explicit?

FlexLondon findings were the starting point for the Carbon Flex project, which assessed whether accounting for carbon would improve the local authority's business case for making these investment decisions beyond energy cost-saving benefits alone. It used a 'carbon flexing' approach - or flexing energy demand dynamically to a carbon intensity signal – to assess the potential.

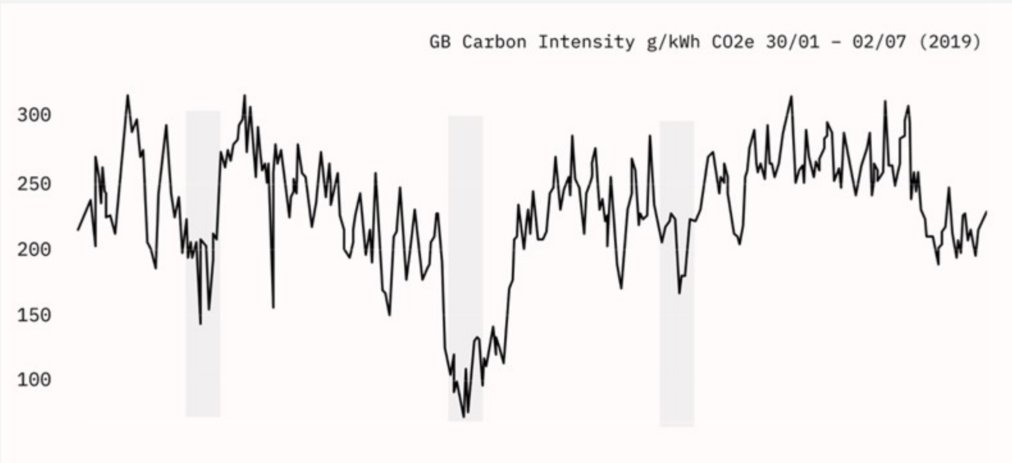
2.4 The Potential for Carbon Flexing

In the race to decarbonise, the policy focus for many countries – the UK included – has been on the production of low carbon and renewable power generation. However, to increase flexibility and to ensure full decarbonisation of the grid, there must be a shift from a singular focus on generation to utilisation. Better understanding and working with the variability of the increasingly decarbonised and renewable generation system will ensure that energy use is not only made more efficient but also more carbon effective by matching use with low carbon intensity.

Definition: Carbon flexing

An approach matching of demand to carbon intensity of electricity, daily, hourly or moment to moment. Matching grid-connected demand to the lowest carbon intensity times is possible in countries where there is mix of renewable and fossil fuel in the electricity mix to support more rapid electrification and decarbonisation of electricity. A broader definition includes timely matching to carbon intensity in any geographical area where there are high vs low carbon alternative sources of energy (including for heating or transportation).

In the figure below showing two weeks of Great Britain's grid carbon intensity in 2019, using at the grey hours significantly reduces the carbon emitted to serve energy demand. Automated optimisation could yield further benefits by matching deferrable or shiftable demand to carbon intensity across the minutes, hours and days.



The vision of the energy industry is that consumers could regularly be paid for adjusting their energy use - for plugging in an electric vehicle at times when the grid is willing to pay for a service of charging the battery – a reflection of the battery's value to the system (for services like balancing or frequency regulation). Equally possible is that organisations could be plugging in electric vehicle fleets or residential vehicles ***en masse*** at the wrong times resulting in system responses that may not be low carbon - that is, a high carbon balancing plant may need to be turned on to compensate for the additional demand.

Even small-scale individual actions could be linked in a new (currently hidden) economy trading in the value of eliminating carbon at a system level.

What is required in the future is a way to ensure that demand always matches renewable supply in every location – and this essentially means operating on clean energy. By better matching demand with renewable supply and combining that increased demand side flexibility with low carbon storage, the baseload and backup currently provided by fossil fuels can be minimised. If appliances, households, buildings, cities or companies could find ways to ensure that their demand use – hour by hour – is matched directly with low carbon energy or excess renewable supply, then they would be not only contributing to the necessary flexibility in the power system, but they would also be operating on clean energy. And if every appliance, every household, every building, every city and every company was operating on clean energy hour by hour, there would no longer be the need for high carbon and highly inefficient back-up power. The power of individual actions would lead to the system-wide change that the traditional actions of energy efficiency and renewable procurement on their own cannot do, and a new economy trading in the value of eliminating carbon at a system level could emerge which would further stimulate and incentivise flexibility and decarbonisation.

Ultimately, carbon flexing occurs when the signal for the matching of demand and supply is not price alone but comes from a 'carbon signal' reflecting the carbon content of each unit of energy delivered at a given time in any given place. If the carbon avoided through this carbon-signalled flexibility could then be valued by policies and programmes, then there would be the incentive for local buildings, cities, communities to take the necessary actions to build towards an agile decarbonised system, ultimately eliminating the need for the blunt instruments of large-scale power generation.

The use cases developed for Carbon Flex show potential for matching demand with supply using carbon intensity data - carbon flexing. There is also evidence from large scale projects in California and by large companies like Google and Microsoft that this is the direction of travel. However, carbon flexing isn't happening today as a matter of course due to carbon accounting, electricity pricing, and other mis-matched incentives.

3. The Opportunity: Scaling Carbon Flexing

3.1. Use Cases Prove the Carbon Value

Increasingly there is a value attached to carbon reduction for cities and businesses as it delivers a city's environmental targets and objectives, funds can be made available to reduce carbon, and increasingly citizens, investors and consumers are demanding it. As part of Carbon Flex, data was taken from four buildings within Merton Council – including a school, adult care centre, library and archive to model the potential site and system level impacts of carbon flexing.

Methodology

The use cases took the approach of modeling the avoided carbon value of an action to four buildings in London that already have rooftop solar, to add one of three potentially 'flexible' technologies - a battery, heat pump or electric vehicle charge point. In each case the new technology operated according to either (Option 1) a logical operational scenario that, for instance, is designed to reduce cost, or (Option 2) flexing these technologies specifically to match the lowest carbon intensity.

Alignment with GHG reporting standards

Review of GHG Protocol Standards was conducted to attempt to fit best into the current reporting. Two years (2019 and most of 2020) of half hourly invoicing and energy demand data from the buildings was used, along with half hourly carbon intensity datasets (not annual figures).

The applicability of marginal carbon intensity data was also assessed based on an extensive literature review on the role of marginal carbon intensity factors, showing they are more accurate for assessing impacts of potentially 'flexible' technology decisions and actions (See Appendix C). The analysis used one of the marginal intensity datasets (from WattTime) for the detailed use cases and compared Electricity Map (by Tomorrow) and WattTime's marginal datasets for the purposes of understanding price and carbon correlation. Accounting guidance[16] has since been produced by WattTime and Tomorrow.

It was clear that the UK expects a gradual decrease in carbon intensity of electricity over the coming decade, but this annual assumption would have required a separate analysis given the half-hourly assessment undertaken here. Instead, the work chose to illustrate the value of matching demand to carbon intensity at a granular level, to understand the carbon value of investment today in assets / technologies that could be controlled specifically for grid flexibility needs in future (such as capacity, management of constraints, frequency response or balancing).

[16] https://www.watttime.org/app/uploads/2021/08/GHG-Frameworks-WhitePaper-Tomorrow-WattTime-202108.pdf

3. The Opportunity: Scaling Carbon Flexing

Each use case resulted in:

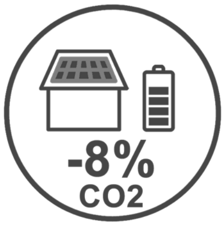
The Footprint analysis at the site level (using Scope 2 emissions accounting) added new granular half hourly average carbon intensity of the grid mix for the most accurate accounting of a dynamically controlled technology such as those selected.

An "Avoided Emissions" Analysis, which assesses the effect of the product's installation and operation to half hourly marginal carbon intensity data (which evaluated the potential of the action taken to purchase the technology, and operate it on renewables, from the perspective of the 'energy system'). Marginal emissions datasets at the half hour or hour are used to measure the impact of small changes to the system, because they show the specific power plant that is being used to serve the demand rather than the average grid mix at that time and are advised to be used for avoided emissions assessments (see later section).

Costs. Each use case also showed the high-level payback expected from the installation and operation of the new technology. The carbon price that was assessed for the battery use case provides a rough view of the scale of carbon pricing for avoided carbon emissions that would be required to incentivise a local authority decision-maker to execute the purchasing decision (to reduce payback to under 15 years).

The findings show that the carbon case for electrification and operating on renewables is clearly in the national interest, but purely judged on costs, the return on investment for the end user is low, and therefore the carbon benefits may not happen. There are several reasons why the UK user is not able to align their purchasing and operational actions with system-wide decarbonisation, highlighted in the next section, and a set of proposed actions that would allow us to faster value this hidden carbon economy.

Use Case 1: A battery is added to existing solar



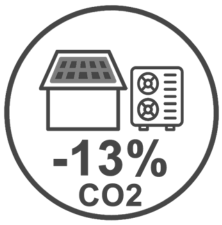
The first use case, modelled on Merton's four buildings, shows that with carbon flexing local decisions can have system-wide impacts which ultimately could contribute to avoiding the need for large scale fossil fuel plant generation and cost savings that can be redirected towards more critical net zero infrastructure.

In buildings with existing solar, of which there are roughly 34,000 installations on similar buildings in the UK (own analysis from national databases of solar installations) adding a battery and optimising to store excess energy for use when solar isn't

operational could provide 5.6 additional tonnes of carbon footprint savings on-site beyond the solar itself, and 2 tonnes of avoided emissions at no extra cost to the site if it the battery discharged not just when the energy was needed but specifically discharged to avoid the highest carbon times. This equates to 8% more avoided emissions system impact than if the battery discharges without the carbon signal.

Overall, the figures demonstrate that there is additional impact on system decarbonisation; however, it isn't likely these actions will take place unless they are valued for the carbon impact they have at scale (see scale up figures below). The value of the battery to support system balancing17 alone would not have created enough financial value to significantly reduce payback times of the battery. Adding a carbon incentive of £400/tonne would reduce a more-than-20-year payback to under 15 years.

Use case 2: Adding heat pump to buildings with existing solar



The Carbon Flex project also modelled the same buildings but instead of adding batteries, heat pumps were added to replace gas boilers in meeting the heat demand. In this case, most of the carbon footprint savings (64%) or avoided carbon (39%) impact accrue from 'fuel switching' away from gas to a lower carbon intensity electricity source, as would be expected. However, the costs to the site annually are 17% higher than they would have paid otherwise, making the business case very challenging.18 In this case, once heat pumps are installed, they could also be optimised to either use the on-site solar first (self-consumption) or carbon flex to lowest carbon intensity times (when using grid- provided electricity). If the heat pump shifts 4 hours of its consumption to cleaner hours up to 13% more avoided carbon benefit to the system is possible. This could be increased if it is possible to aggregate building heating demands to optimise across many buildings, as would be the case with distributed energy resources management solutions or communal heating or energy systems.

[17] In this case, Firm Frequency Response and UK Power Networks flexibility payments were modelled.

[18] Cost modelling was completed before the gas price volatility in the UK started in autumn 2021.

3. The Opportunity: Scaling Carbon Flexing

Summary Findings

Buildings like these that already have solar and go on to electrify heat would achieve carbon savings from fuel switching by 64% and avoid emissions by 39% but would increase operating costs by 17% (this was modelled before higher gas prices in September 2021). In the case of the heat pump, the value of 'carbon flexing' to the system is 6% if self-consumed solar alone is used and up to 8% if the heat pump responds to a grid carbon intensity signal. Flexing batteries to operate on renewables saves the site carbon and avoids 8% more carbon than simply optimising the battery only for solar self-consumption. In both cases, ***if this avoided carbon could be valued*** - either through market-wide policies like a carbon price or through a more consistent way to recognise avoided carbon value in today's GHG reporting -- the purchase and operation of these assets would be more likely to happen.

Table 1: Summary table Carbon Flex use cases

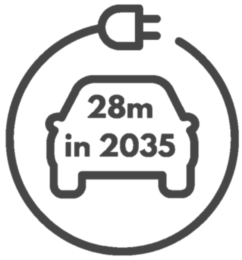
Annual savings and avoided emissions of carbon flexing to a building with installed solar, calculated based on 2019 data.

Buildings with rooftop solar	**...adding a battery**		**...adding a heat pump**	
Carbon Impact	**Option 1: Maximise using rooftop solar**	**Option 2: + flex to grid carbon intensity**	**Option 1: Maximise using rooftop solar**	**Option 2: + flex to grid carbon intensity**
Measured as footprint (scope 2) reduction in CO_2	**18%**	**22%**	**9%**	**14%**
Measured as avoided CO_2	**1%**	**8%**	**9%**	**13%**

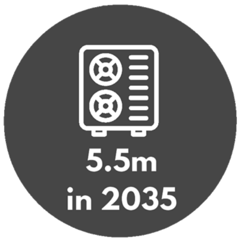
3.2. The Potential and Momentum

The electrification of heat, and the carbon flexing of heat pumps and batteries creates significant carbon value at scale, and there is some momentum created by the actions of several major firms and regional entities. Even just a few percentage points in annual avoided emissions through very low-cost optimisation to carbon signals can kickstart higher levels of avoided carbon we urgently need to meet near term targets and avoid longer term disruption to society and economies.

The Potential Scale of Carbon Flexing from Decentralised Technologies



In the future, there is significant potential to scale carbon flexing and flexibility due to the numbers of decentralised and potentially 'smart' technologies that will be rolled out across buildings and cities. On-site solar is expected to be deployed further along with the potential for 28 million EVs to be on the road in 2035 and 5.5 million heat pumps in homes 2030.[19] Future proofing these for carbon flexing and flexibility is a huge opportunity, as the capabilities developed today provide us with more options for a carbon-free electricity system tomorrow.



If existing and future 'smart resources' were technically enabled to operate in response to a carbon signal, the flexible capacity can avoid the need for power plants at no additional cost - using signals to optimise based on carbon rather than price alone. Recent modelling by Bloomberg New Energy Finance has shown that smart charging 85% of electric vehicles would mean the UK would never need to build another fossil fuel power plant.

In the Carbon Flex use cases, the site benefits may seem small, but when scaled, the aggregate potential really matters.

Figure 1: 'Carbon Flexing' Value Scaled up to the UK

Scaling up to the existing 34,565 similar buildings in the UK with solar already installed, measured in avoided tonnes CO_2

	Tonnes CO_2	Equivalencies	
	18,423	40 GWh of gas plant CO_2	10,000 homes energy-related CO_2
	124,814	286 GWh of gas plant CO_2	72,000 homes energy-related CO_2

Applying the use case findings to the 34,000 similar solar installations across the UK, and assuming a battery was added to each installation and was simply discharging overnight to avoid the building using electricity at the highest carbon times, 18,000 tonnes would be additionally avoided at no extra cost after the battery is installed, and the system impact would be the equivalent of 40 GWh of annual avoided emissions from a typical gas plant in the UK, or the equivalent of avoiding the annual energy emissions of 10,000 average homes. Heat pumps would avoid significant system emissions from electrification alone (avoiding gas emissions equivalent of (745,890 tonnes CO_2) and 124,814 additional tonnes CO_2 from carbon flexing for four hours a day. It is useful to note that the batteries add 173 MW of flexible capacity on the demand side.

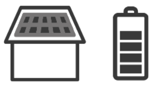
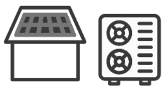
[19] https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf

3. The Opportunity: Scaling Carbon Flexing

If we scale up the 'carbon flexing' decarbonisation impact the buildings have on the electricity system, we begin to see the power of the hidden carbon economy which no individual site would see as very large, but in aggregate, provides immediate carbon value at no additional cost.

If we scale up the impact the three use cases in the London context to show the city role in supporting the electrification of heat and transportation and 'flexing' to carbon signals, these interventions provide low-cost additional benefits to the grids they are connected to.

Figure 2: London's Hidden Carbon Economy to 2030 (Measured in tonnes CO_2 avoided)

	2021 If scaled to existing commercial and industrial buildings with solar	**2030** If the target for 1 GW of solar in buildings in London in 2030 was reached
	860	20,000
	5,825	144,000

Just taking London's potential and rolling forward to the targeted 1 GW solar adoption in 2030, If these were distributed as 25 kW solar panels with 5 kW carbon flexing batteries, the additional avoided carbon flexing value would be **more than 20,000 tonnes CO_2** annually in 2030, though electricity grid decarbonisation is expected to reduce this potential (as the grid would have lower carbon intensity overall). As the grid decarbonises it would be able to use the 200 MW provided by these batteries for grid services as well including avoiding longer term carbon impacts of building more supply side generation and flexibility. **Heat pumps** combined with the 1 GW of distributed solar capacity provides a **carbon flexing value of 144,000 tonnes CO_2 avoided**.

This does not consider the projected update of heat pumps in homes, or the value of avoiding gas with electrification in the first place, both with over 60% expected decarbonisation benefit to the properties.

Momentum is building as large entities embrace operating on renewables

These use cases show the hypothetical potential of carbon flexing. But momentum is building in reality – with the State of California and Google embracing carbon flexing at scale and other related initiatives pushing toward more real time accounting for renewable energy.

In California, analysis of the Self Generation Incentive Program (SGIP) conducted by the Public Utilities Commission[20] showed their storage incentive increased emissions by 700 tonnes of CO_2, because batteries were being charged at higher carbon (though low-price) times. For this reason, California is now using carbon signals in 5-minute intervals to allow storage to be optimised based on GHG factors as well as price to continue to bring down emissions.[21] Increasing flexibility to not only balance demand and supply but also support optimal use of the lowest carbon power will be important for future decarbonisation.

In addition to the State of California, first Google and then Microsoft extended their existing commitments to procure 100% renewables by going further and committing to operate on 100% renewables by 2030. To do this, they will focus on ensuring that each hour of consumption is fully matched by carbon-free electricity generation which will require greater efficiency, greater use of renewables storage, procuring more renewables to generate greater capacity than their average usage, as well as matching their demand-response strategies to carbon intensity, not just pricing. They go even further under their approach that ***'the grid is the ultimate goal'***[22] and aim to procure more carbon-free electricity in regions where overall the grid carbon intensity is high to ensure they are maximising avoided emissions.

The use cases within London as well as the initiatives undertaken by California and Google demonstrate that there is sufficient opportunity, motivation, and momentum towards carbon flexing but using real-time carbon signals and associated carbon flexing needs to be better recognised and valued to accelerate the scaling up.

3.3 The Barriers to Scaling Carbon Flexing

Matching demand to supply using carbon flexing isn't happening today because our accounting, carbon markets and pricing are not geared to allow users' marginal decisions to add up to big changes. The effects of these barriers are real: the UK is over 60% of its way to 2030 targets for renewable energy deployment, but just 2% of the way on heat pump and electric vehicle adoption targets, according to the UK government's own figures.[23]

To kick-start the hidden carbon economy, there are three main challenges that can be addressed today even in advance of overcoming longer term market dynamics to unleash a carbon-free energy system.

1 Limitations of Carbon Accounting Standards

Standards that account for carbon today are limited by annualised figures used in Scope 2 reporting and lack of clarity on calculating the benefits of avoided carbon. If we want to achieve decarbonisation, we must measure carbon saved and avoided, not only energy kWh saved.

[20] https://www.cpuc.ca.gov/sgip/

[21] Proposed Decision of Commissioner Rechtschaffen (2019) Decision approving greenhouse gas emission reduction requirements for the self generation incentive program storage budget COM/CR6/mph.

[22] https://www.gstatic.com/gumdrop/sustainability/24/7-carbon-free-energy-methodologies-metrics.pdf

[23] https://www.bloomberg.com/graphics/2021-opinion-rising-energy-costs-of-boris-johnson-uk-net-zero-plan/

Scope 2

Carbon reporting should promote the shift to purchasing electrified transport and heating solutions that are then used for the demand side flexibility we need to reach net zero targets. Unfortunately, this is not the case today.

First, companies setting net zero or carbon reduction targets use The GHG Corporate Protocol with its suite of guidance and reporting standards. These are used to report their 'footprints' as Scopes 1, 2 and 3. Energy that is purchased is Scope 2. The GHG protocol allows dual reporting for Scope 2 - either 'location based' – meaning accounting for the actual grid mix at a given place and time - or 'market based' meaning the electricity is backed by a renewable certification. Using the location-based methods, half-hourly or hourly carbon intensity could be used rather than the annual average carbon intensity figures that are most common today.

But most companies or local authorities that want to 'green' their electricity can report using the market-based method, where green tariffs or contracts with renewable suppliers effectively bring the consumer's energy consumption carbon emissions to zero. This was fine when there was limited demand for green energy. But today, that is changing. Thousands of companies are using green tariffs and according to Cornwall insight, 65% of consumers in the UK are on green tariffs.[24]

> A recent report commissioned by the Climate Change Committee demonstrates how the current electricity market system in the UK, including the REGO (Renewables Energy Guarantees of Origin) and the Contracts for Difference subsidies, have created a situation whereby the individual renewable procurement decisions might have no impact on decarbonisation of the grid - instead, this will depend on the design of the green tariff or whether or Power Purchase Agreements specifically structured to create new renewable generation.[25]

While a household or public or corporate entity may be reporting 100% renewable energy, the percentage of electricity generated from solar and wind power is anywhere between 0%-50%, depending on the hour of the season or day. For a reporting entity, this means the true 'location based' carbon factor can be ignored if a renewable supply contract is in place to cover the actual total annual electricity usage, even if that supply contract has no material impact on system wide emissions or carbon intensity of the actual power supplied. The purchasing of renewable electricity (certificates or tariffs backed by them) by individual households, companies, public entities, local authorities, and cities is another example of how well-meaning micro actions might result in no new impact on the grid yet GHG accounting attributes significant impact to the reporting entity.

[24] https://www.energylivenews.com/2021/06/15/two-thirds-of-uk-homes-signed-up-to-green-energy-suppliers/

[25] https://www.theccc.org.uk/publication/corporate-procurement-of-renewable-energy-implications-and-considerations/

It would not be possible for all UK customers to be 100% green in their procurement, but the green tariff scheme allows customers to account this way. While that may be good for their own image, it is not certain that the purchase of these tariffs increases the amount of renewable energy or leads to the avoided carbon that is being accounted for. The government has since responded by announcing a review of the green tariff system to address this issue.[26]

Green tariffs are attractive for their simplicity, they have made it possible for organisations to choose not to invest in demand side actions and instead pay for a green tariff. This makes it more complex to justify financing these new on-site purchases on a 'carbon' basis.

But to have certainty of the elimination of carbon from their power supply, a city, state, or company must either go fully off-grid, which is an insurmountable challenge at a certain scale (clearly uneconomic at national scale) or need to wait until their national energy system is 100% renewable before they can truly declare their power fossil-free. With the new announcement of a net zero grid by 2035[27] the UK is signalling the intention to make carbon-free energy more available to all UK consumers, but the role of the demand side becoming a flexible partner to renewable variable energy is even more urgent to ensure this target can be achieved in the most cost-effective way.

Green tariffs are attractive for their simplicity, but they have made it possible for organisations to choose not to invest in demand side actions and instead pay for a green tariff

26 https://www.gov.uk/government/news/government-to-tighten-rules-to-stop-greenwashing-of-electricity-tariffs

27 https://www.current-news.co.uk/news/net-zero-electricity-grid-by-2035-target-announced-to-strengthen-britains-energy-security

Reporting motivates action for a world before variable renewable energy existed at scale

45% of FTSE100[28] companies have set net zero targets, and it is likely that all of these will have committed to procuring renewable energy either through a green tariff or a Power Purchase Agreement. Entities reporting via the GHG Corporate Protocol can demonstrate year-on-year energy savings and convert those directly to year-on-year carbon savings using annual carbon intensity figures – even if the actions had little to no carbon impact because of the carbon intensity at the time the action was taken.

Avoided Emissions ("Scope 4")

How could the carbon impact of the purchase of a battery, heat pump or EV be assessed? When making an assessment of projects undertaken to reduce footprints, companies or local authorities should use a different standard, either the Project Guidance or Policy and Action Guidance. This is not the same as a 'footprinting' exercise. Instead, these allow for comparative assessment of the effects of taking different actions and the wider impact they have in avoiding emissions outside the reporting entity's boundary. However, these haven't commonly been used to assess all the comparative impacts - both positive and negative - of a product or purchase,[29] partly because of lack of data, and therefore they rely more on their footprint reporting.

Because of the accounting complexity, most of the corporate commitments and declarations (such as the RE100, Science Based Targets, the WorldGBC Net Zero Carbon Buildings Commitment) would in their current forms fail to reward use of carbon signals and carbon flexing, and instead incentivise and reward the familiar efficiency and green power supply purchasing options. By focusing on the market-based method of accounting for Scope 2 reductions, rather than the location-based method, potentially less impactful action is being recognised and rewarded.

Hidden carbon value is being missed, making carbon flexing an essential transition tool.

[28] https://eco-act.com/resource/the-10th-annual-sustainability-reporting-performance-of-the-ftse-100/
[29] https://www.wri.org/research/estimating-and-reporting-comparative-emissions-impacts-products

Footprints, handprints, slices and pies – and a missing Scope

There are a growing number of analogies and terms which attempt to explain the limitations of carbon footprint accounting. Carbon ‘footprints’ are now a household term. But the consequences of purchasing products or manufacturing better products is a separate assessment to footprinting exercises.

The accounting for these two questions has to be done separately and are never added together. In answering the first question, it would be possible to find a way to put ‘my share’ onto another reporting entity, for instance, by selling a building that is no longer needed for the organisation, reducing the carbon footprint. However, that building still exists and continues to be used by another organisation. The total burden of emissions has not been impacted.

Footprint (inventory accounting) methods ask - What is my ‘share of the burden’ of total emissions?

Consequential methods ask - Does my action avoid emissions and impact the total burden?

In answering the second question, different analysis is used to understand either the unintended consequences of actions or the benefit they provide to reducing the overall emissions emitted. Another way of looking at it is looking at a nation’s footprint emissions as a pie – and assessing whether an action is impacting its own slice of pie or whether an action is impacting the whole pie are different methods. These latter actions change the ‘pie’ but require a different approach to accounting for the reporting entity’s ‘slice of the pie. ‘Handprints’ have also been used to denote the ‘positive’ impacts that an organisation has through its products and services that are not to be confused with its own footprint. ‘Net Positive’ commitments also encourage out-of-boundary value.

Furthermore, there have been proposals floated about introducing a new Scope – Scope 4 – to address avoided emissions within a wider system and whether the reporting entity’s actions are aligned with global 1.5-degree targets. None of these have landed in the mainstream – yet – but the concepts and questions they are trying to convey are incredibly important.

2 Carbon markets are limited in coverage

The value to decarbonisation isn't in the one building owner changing their system, but in the aggregated value of many buildings operating in coordination over time to match signals locally or nationally. This is harder to finance than a large, centralised gas plant and therefore may need new approaches if we want to encourage these decentralised approaches.

Acting to avoid carbon in day-to-day decisions is not incentivised market wide. The carbon markets as they are structured today do not solve this, for a couple of reasons. First, they have limited coverage. Existing carbon markets target big polluters, not the entire economy. Only about 50% of the highest emitters (power and industrial sector are covered by the EU Emissions Trading Scheme (ETS). These polluters buy Allowances (emissions allowances which equal 1 tonne / carbon) when they generate over their allocation, but they effectively pay a penalty on their revenues rather than stop generating as a result.

50%

Existing carbon markets target big polluters, not the entire economy. Only about 50% of the highest emitters (power and industrial sector) are covered by the EU Emissions Trading Scheme

The user would not be able to use their own demand to outcompete the generators today. Many companies from 'incumbents' to start-ups are vying to be the providers of the aggregated value of these buildings and assets but continue to struggle to be paid for the value they provide as an alternative to fossil fuel power plants. In fact, the demand response that has participated until today has largely been diesel, which is, again, too small to be penalised by carbon markets.

Finally, carbon pricing is not sufficient for this kind of deep decarbonisation. Emissions decreased 3.8% due to the EU ETS between 2008-2016[30] - yet the carbon flexing potential of just one Carbon Flex use case showed that the potential annually is double this. In fact, in the battery Carbon Flex use case, battery payback could be halved if a carbon price was over £400/tonne, but currently prices are nowhere near this.

The barriers to electrification and carbon flexing – and greater flexibility – are significant but with the right actions from across the market and policy landscape, carbon flexing can be used as a key transition tool to create the flexibility needed to eliminate fossil fuel plants.

[30] https://www.pnas.org/content/117/16/8804

3 Carbon and price are not sufficiently correlated to drive action

In the search for carbon flexing incentives, the Carbon Flex project modelled whether there was any correlation between price signals and carbon signals. If this were the case, price changes could prompt consumers to operate on renewables already. Machine learning analysis of price and carbon intensity datasets show this is not the case. In comparing the wholesale price paid by retail suppliers in the UK to three different carbon intensity datasets (National Grid's average carbon intensity, WattTime and Electricity Map's marginal carbon intensity both at half hourly timescales), price would predict carbon intensity only 2% - 35% of the time.

This is not necessarily surprising, but the findings do contradict some assumptions that 'lower marginal cost' solar and wind power always results in lower prices at any given hour or day. Electricity prices include several costs that are not variable depending on the fuel inputs to a power plant. The current cost of electricity to the end user only partially reflects the carbon intensity of the energy being supplied, and therefore does not necessarily incentivise a cost and carbon reduction together. These non-variable charges pay back the costs of infrastructure that are not 'marginal' based on fuel input, so would not change based on carbon intensity. These fixed costs on consumers' energy bills can outweigh forward looking signals focused on decarbonisation. The process for changing price and tariffs will take several years given that there are historic reasons for this fact.

Ironically, some of these costs were designed to help fund the alternatives to high carbon infrastructure but are now effectively slowing down the ability to 'operate on' renewables after succeeding in supporting their build-out in the first place. Costs to add renewables to the electricity generation mix have been levied onto electricity price. Gas prices remain low (just when we hope to shift to electricity which has now become lower carbon on average than gas). In fact, today in the UK, despite the carbon benefits of electrifying high carbon activities such as heat and transport, electricity 'faces overlapping and confusing carbon charges,' which amount to a higher carbon price on electricity tariffs than the Zero Carbon Commission recommends for an economy-wide carbon price.[31]

This high carbon price on electricity is a non-commodity cost to the consumer, some of which can be avoided by reducing kWh consumption but cannot be reduced by shifting kWh consumption to a carbon signal. This intuitively makes sense, because the UK markets are not designed to change based only on the marginal cost of fuel, but instead to protect consumers from high costs. In a renewable energy world, where marginal costs are low but up-front costs are high, we will always need some kind of price that allows us to finance these assets.

2%-35%

The percentage of instances that wholesale price would predict carbon intensity

[31] (How carbon pricing can help Britain achieve Net Zero by 2050 report, Sept 2020)

Even if end users had some visibility on the half-hourly fluctuations in price that wholesale purchasers of electricity are exposed to (some 'dynamic' or 'agile' tariffs are emerging which would expose customers to this fluctuation) there is not a high correlation between half hourly price and carbon intensity in the UK market. The Carbon Flex project modelled the correlation between average carbon and wholesale price signals and found that price would predict average carbon intensity just 35% of the time. Unsurprisingly, there is even less of a correlation (2-12%) between marginal carbon intensity data and wholesale price.

Even if this correlation were higher, the retail price that customers pay is usually fixed and includes the wholesale price as just one component. The choices an end user is making would be less likely to reflect any marginal, hourly change in real time if they are based on price alone. This is a deliberate choice by policy makers responding to consumer desires for price certainty, but the downside of this lack of transparency is that carbon-related marginal actions are not rewarded directly in price changes.

Even if the half hourly price did fluctuate based on the fuel type, building managers do not buy electricity at the half hour, they often negotiate for one or more years at a certain price, so their 'flexing' at the half hour would be unlikely to be based on their retail prices.

kWh cost savings is no longer equivalent to decarbonisation in higher penetration renewable grids. Therefore, price does not provide enough value or incentive for end users to align their marginal choices with carbon performance.

kWh cost savings is no longer equivalent to decarbonisation in higher penetration renewable grids

4. The Actions: Jumpstarting the Hidden Carbon Economy

We need to be able to electrify and decarbonise our grids as rapidly as possible. Everything we connect to those grids needs to be avoiding emissions, from the point of purchasing a new asset or product, and at the hourly point of operational decisions, whether that is new power plants, heat pumps or e-mobility solutions.

Currently, the carbon intensity datasets exist and are getting more robust - including data demonstrating carbon intensity at short intervals throughout the day - but any associated action based on the data is not being rewarded or valued. While the use cases show the potential, and early action from some corporate entities demonstrates that the motivation is there, users contribution to avoided carbon is not valued today.

Therefore, to root out the hidden carbon, we need urgent recognition and value of using carbon signals and carbon flexing as the first step to 'hourly match' demand and supply. This has three components.

1 Action 1: Accounting and Measuring Time and Location-based Carbon

Currently, the GHG accounting methodologies - primarily the GHG Corporate Protocol Standard - focusses entities on accounting for their direct and indirect share of emissions through Scopes 1, 2 and 3. This standard - and these scopes - do not account for 'avoided emissions' or 'additionality' of actions taken which can impact on a market system, ultimately accelerating decarbonisation. More and more entities should be using more time and location based granular data to understand the carbon impacts of actions they are undertaking. Google, for instance, has recognised the limitations of Scope 2 in being able to assess 'avoided emissions' and to support their 24/7 carbon-free target, they now have created their own metric of 'Avoided Emissions' (tCO_2) which measures the carbon emissions impact of procurement decisions. "Scope 4" proposed approaches could be another way to call out avoided emissions in reporting.

These avoided emissions approaches should use marginal carbon intensity figures wherever possible, according to guidance for assessing the consequences or effects of purchasing decisions and the UK government. These datasets need to be accurate, usable and updated in a timely manner. They should be able to change and update, as the grid itself adds more renewables, rather than to calculate after-the-fact based on deemed averages or estimates – as these do not take into account any weather or real-time changes in consumer behaviour.

A new energy transition tool toward zero carbon - carbon signals using marginal carbon intensity

According to UK Government guidance, Marginal carbon intensity should be used in assessing "the change in UK electricity sector emissions associated with policies that lead to sustained marginal changes in the consumption of electricity" in contrast to average intensity that is used to assess carbon footprints.[32]

Carbon signals are a tool for transition as we trade off between high and lower carbon energy sources, and 'marginal' carbon intensity can be used for the following decisions:

1. Comparing what times are best to use or store energy
2. Comparing where is best to site a new energy asset - either on the demand or supply side of the grid
3. Evaluating electrification (especially coal dominated energy mixes)
4. Evaluating low-emissions energy sources - Marginal emission rates should be used to evaluate the environmental impact of low-pollution electricity generation technologies such as fuel cells and biomass. These technologies are sometimes mistakenly thought to increase emissions if they emit more than the local average emissions rate. In reality, however, they reduce emissions anywhere they are a lower carbon intensity than the local marginal emissions rate.

2 Action 2: Acting on Carbon Performance

Timelier location-based carbon intensity datasets are becoming more available globally. In the UK, National Grid is already providing one free average half-hourly carbon intensity dataset, and several companies globally are creating a range of carbon intensity datasets for use by the market. Methodologies differ and evidence is growing on the efficacy of using carbon intensity for a variety of use case.[33]

These datasets are currently being used for accounting and operations, but there is no agreed carbon performance evaluation for flexibility, which is what is needed next. The value of taking a local operational action to avoid emissions and decarbonising grids will need to be evaluated in a trusted manner.

32 (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1002869/2.Background_Documentation_for_guidnace_on_valuation_of_energy_use.pdf)

33 https://www.energyunlocked.org/s/LitReview_OnMarginalCarbonIntensity.pdf

Just as efficiency is often difficult to calculate based on the counterfactual of 'what would have happened otherwise' the actions at the scale of a few hours of 'turning up' demand to respond to a carbon signal' or 'turning down' to avoid the highest emissions times requires new approaches given that GHG protocols generally assume only annual carbon intensity data are available. During the accounting of a potential new purchase, a counterfactual scenario can be developed to compare to today's actual building operations. But once that device is installed, the heat pump, battery or vehicle will need to verify its flexibility compared to a baseline.

Alternatively, lessons can be taken from how flexibility is evaluated in some energy markets today. Batteries or demand response can be paid based on 'availability' and then paid again if it indeed it is used in response to the energy market signal provided.

For instance, when procuring 'flexibility' from market entities, UK Power Networks (the network that serves London) runs an auction and assesses the lowest cost options to provide payments for both availability of flexible capacity and responsiveness during the procurement window. What this looks like in practice is that a technology provider with a few hundred homes in London operating solar + battery systems could offer 100 kW of flexibility from 4-9 pm during winter evenings, and UKPN would pay that technology provider for the option to have that capacity available. When UK Power Networks predict there may be increased demand on a particular day, they would notify the technology provider and then if the homes did avoid using electricity from 4-9pm that evening, the technology provider would be again paid for that service of 'turning down' the demand of those homes.

UKPN pays for energy flexibility, not the carbon value of that flexibility (if diesel is cheaper than batteries, it will be procured first). The Self Generation Incentive Programme (SGIP) in California is triggering and rewarding battery charging and discharging based on a co-optimised price and carbon signal already. Over time the greater transparency of carbon intensity enables the improved assessment of price and carbon correlation, which would in turn support aligning energy system needs and consumer decisions. Different evaluation standards for performance could be developed based on the specific programme or region / government.

Based on learning from these policies and commercial arrangements, there is an existing body of expertise along with companies ready to implement the carbon signals that are fit for policy and programme outcomes. A 'metered energy savings protocol'[34] currently being tested in the UK could also provide some useful basis to start the discussion on how to evaluate the energy shifted and the carbon value of those actions.

[34] https://www.greenfinanceinstitute.co.uk/wp-content/uploads/2021/02/Towards-a-protocol-for-metered-energy-savings-in-UK-buildings.pdf

3 Action 3: Attributing Value

Along with co-optimising energy and carbon flexibility as in the California example, there are many hours of the day when flexibility for grid capacity or balancing is not required, and buildings, electric cars, heat pumps or batteries could be used to maximise carbon avoidance.

Even if cities do not have the control over energy markets as California does, where direct energy flexibility benefits can be rewarded, there is immediate scope for cities or other companies to utilise more hours of every day to avoid carbon. Local authorities and businesses can today state their ambition to fully operate on clean energy 24 hours a day 7 days a week. This goes beyond today's 100% renewable commitments to ensuring that the power of the consumer / user of energy is decarbonising the grid around them. Already, the UN is aiming to bring together a coalition of governments and companies that can sign up to the principles of 24/7 carbon-free energy[35] and is working on how to support them in setting 'compacts' to deliver those commitments.

Hourly guarantees of origin

Another way to value the use of renewable energy on the hour could be through guaranteeing the generation of renewable energy at the hour time stamp, rather than current Guarantees of Origin which are often annual or sometimes monthly. Hundreds of companies including Google and Microsoft have expressed interest in advancing 'hourly energy certificates' working with not-for-profit Energy Tag.[36] Further, Google is piloting its own approach called 'T-EACs' (Time Based Energy Attribute Certificates)[37] at their own energy centres. These approaches would make it possible for energy suppliers to buy certificates of origin each hour, rather than monthly or annually, which should increase demand for the hourly matching of demand to those greener hours, though there is debate about how this might play out in practice (there could be balancing decisions taken by the grid operator which would be out of view of the decision-maker operating only based on a single power plant's production). Industry will need to consider what this could mean for market-based scope 2 accounting.

35 https://gocarbonfree247.com/

36 https://www.energytag.org/wp-content/uploads/2021/05/EnergyTag-and-granular-energy-certificates.pdf

37 https://cloud.google.com/blog/topics/sustainability/t-eacs-offer-new-approach-to-certifying-clean-energy

Further, many local authorities already have procurement rules that require carbon reporting, and carbon prices built into planning laws, which are likely using annual carbon accounting today but easily could require more timely reporting where datasets on hourly or half-hourly carbon intensity are available.

Wherever the rewards and incentives come from, the industry in the UK has demonstrated it already has the capability to respond to signals coming from the market, DNOs or National Grid, and if carbon were valued, many companies could, at no cost, switch their automation and control algorithms to manage devices (such as 'smart charging' electric vehicles) to respond to carbon signals. Equally, the datasets that more accurately reflect carbon intensity of electricity exist, and there is huge interest from data scientists and companies to improve these datasets if the market were there. Policy can support the shift to financing rewarding for the capability already in all of the smart devices being adopted.

With these actions implemented at scale, the initial actions of piloting local authorities, states and corporations will trigger a wider 'domino effect' where small actions beget the potential to aggregate the small actions, and these, scaled up, bring about full system-wide change needed – full decarbonisation of the grids, without fossil fuel power plants as backup.

5. The Domino Effect

5.1 From cities, corporate portfolios, ESG, to policy

Once more and more entities undertake the three actions needed – greater use of carbon signal data, modelling of system-wide impacts, and a change in accounting –carbon 'signals' could be incentivised and accounted for based on their system impacts, and a chain of events across can be triggered.

Table 2: Summary of Carbon Flexing Actions

1 Accounting	2 Acting on Carbon	3 Attributing Value
Granular time and energy system or location-specific carbon intensity used in business case development and accounting. *Example:* *Feasibility study for the carbon flexing value of a new battery or building management system.*	Use carbon signals to trigger carbon operations of buildings and fleets and develop common evaluation protocols and standards. *Example:* *Google's voluntary initiative to operate data centres to match to hourly carbon intensity and evaluate performance based on carbon.*	Local policies, programmes and procurement rules can incentivise the actions based on carbon. *Example:* *California's Self Generation Incentive Programme that provides incentives for batteries responding to carbon signals.*

Today, voluntary action should increase amongst local authorities, building owners and more corporations beyond Google and Microsoft, with the main motivation and benefit being carbon. As part of this action, carbon accounting methods may be developed independently – as Google has done – even if they are not recognised officially. Once more entities are using carbon flexing in operations - like Google's 24/7 Carbon Free approach - then a voluntary market can emerge, which would see better integration of carbon flexing requirements into voluntary programmes, like corporate commitments - such as Science Based Targets and the RE100; and the Energy Tag initiative that is setting out to narrow the timescales of guarantees of origin to one hour. Once these have achieved a critical mass of voluntary action, then price as well as carbon signals would be embedded into business models. And finally, policy would follow.

London could be the first city to adopt this approach and exploratory discussions are underway to use its Local Energy Accelerator revenue support fund to assess the impact that local matching of a heat pump, existing assets time of use or battery would have on both scope 2 emissions and avoided emissions. Once installed, these assets could feasibly be counted toward the programme's carbon performance. Soon, Greater London Authority or the boroughs within London could draw on either offset funds or efficiency and decentralised energy funds to reward for the flexible capacity that creates avoided emissions value. Equally, national governments could reward local areas for their contributions to national systems. If an incentive is not possible, policies could begin to require this simply based on the need to meet legislated carbon budgets and targets.

Ultimately, voluntary initiatives and reporting by corporates and cities will allow them to start the journey and learn by doing. This early voluntary and commercial activity paves the way for new industry standards and verified learning that can inform policy change for wider adoption. whereby the voluntary initiatives' learning for how to measure and account for carbon flexibility can be translated into market design and price or tariff changes, through to regulatory and policy actions that allow more competition, or create skills and growth for new, lower carbon technologies. The potential of carbon flexing through creating this domino effect of action ultimately accelerates the decarbonisation of the grid and avoids building unnecessary, high embodied carbon and expensive 'always on' power infrastructure, which is not needed if we optimise the growing mass of distributed energy infrastructure.

More entities using these methods begin to trigger the scale required for distributed actions to create aggregate impact. The data can be used to invest in portfolios of distributed energy resources that create options for using other forms of flexibility in future at other timescales. Demand-side flexibility is then able to deliver on the promise of avoided infrastructure, such as the 90 GW avoided gas plants, the 10 GW avoided nuclear, and 50 GW avoided wind power in a net zero scenario modelled in Great Britain.

This chain reaction will bring about significant benefits, including:

- Spreading the value of decarbonisation more equitably to every building or household, every participant who currently is not valued for how their actions trigger upstream decarbonisation.
- Spreading value geographically - because each local area can create the diversity of demand that is required for flexibility, and be rewarded for it, the investment in flexibility goes not just to large scale power plant developers but to each actor that has a flexible asset like a heat pump or electric vehicle.
- Reducing costs to customers of the electricity system if the full potential of flexibility is realised.
- Creating jobs from retrofit, data services and low carbon technology deployment.
- Building technical capabilities and growing industry of digital energy and smart, flexible, local energy system value chains.

There is a tremendous opportunity in changing energy policy, pricing and markets that is underpinned by today's digital capabilities to more accurately assess local authorities' – and any other consumer's – time and location-based actions to system outcomes.

5.2 Recommendations

To achieve the vision of allowing consumers to electrify and match their demand to carbon-free energy, supporting the transition towards an efficient and fully decarbonised grid, concerted, and coordinated action from a range of key actors are needed. These recommendations for national governments, third sector, and standards organisations will spur the shift required to make it possible to intelligently use buildings and cities to decarbonise energy.

1 Recommendation 1 - Carbon accounting needs to recognise the impact of carbon flexing

GHG Protocol for Scope 2 corporate accounting should require that granular average carbon accounting be used if possible. A new "Scope 4" using marginal carbon granular and timely datasets would help bring clarity to the 'avoided emissions' benefits of using local actions to decarbonise the system around them.

Investor initiatives, climate commitments and GHG Protocol initiatives can support by requiring entities to show additionality in their Scope 2 reporting – as per the UKGBC guidance. ESG reporting, such as GRESB for real estate portfolios, should require location-based Scope 2 accounting alongside market-based accounting. RE100 and WorldGBC Net Zero Buildings Commitment/UKGBC Net Zero building standard should move to require operating on renewables rather than recognising green procurement only. Science Based Targets should begin consulting on updating their requirements to value avoided carbon. New net zero standards should consider carbon flexing as in scope.

Governments should move toward requiring mandatory carbon reporting (as the UK has done, though this is mandatory for only larger companies today), and the value of carbon flexing should be in scope.

2 Recommendation 2 - Create open and fair access to carbon flexing

Carbon data to trigger and measure performance should be open and accessible, or the building blocks of that data made available. National Governments can ensure that system operators publish marginal and accurate carbon intensity data to support decision makers or require transparency of underlying data to allow third parties to create these trusted datasets. Unleashing data allows the operations of many more grid-connected buildings and assets or appliances to be managed for system-wide benefits.

Appliance standards can support 'Internet of Things' integration of hardware and software to be used for optimisation of devices in future.

Learning from competition in the IT industry, energy regulators should ensure that data platforms - such as those created by utilities around smart meters - are fair to consumers and accessible to all market participants.

3 Recommendation 3 - Value carbon flexing performance to drive uptake

Policies and programmes that value avoided carbon are urgently needed. Governments at local, state, or national level can create policies that encourage the technologies and demand side solutions for electrification and operating on renewables to accelerate. These programmes can be designed to support matching demand at the timescales that are most appropriate for the use cases, for instance half-hourly was appropriate for the local authorities because the data is available at half-hourly increments, half-hourly meter data is available, and tariffs are settled half-hourly in the UK market. Governments that can support, design, and adopt carbon flexing programmes that use carbon signals to trigger actions, such as California has done, will also need to agree the performance evaluation for these actions. Programmes that already fund or evaluate based on carbon outcomes can allow avoided carbon to count toward their performance outcomes.

6. Conclusions

Acting on the above recommendations creates the confidence in, and evidence for, sustained market redesign for a near future that requires we operate off carbon and onto carbon-free energy across the economy. Government can use the targeted policies and programme learning recommended above to inform fundamental market redesign toward the end goal of a fully carbon-free energy system. Kickstarting uptake of electrification is very likely, through retrofit incentives or rebates on technologies such as heat pumps, or other tax incentives such as those on electric vehicle purchases in the UK for businesses. Further, ongoing optimisation of energy pricing, tariff design, carbon pricing, performance-based outcomes for infrastructure investors, design of balancing and ancillary services mechanisms and many other market-wide changes are necessary. The decarbonisation of energy may rely on a basket of environmental (and carbon intensity) data co-optimised with price as the necessary price changes are made over the coming decades, addressing different industry use cases from proving 'green' hydrogen production to balancing the grid. The specific recommendations for all these market use cases were out of scope of this project.

This report focused on the end users, specifically local authorities, who mainly play a role in this transition through decisions around retrofit, purchasing decentralised energy resources, electrifying their buildings and transport, and operating them, along with energy procurement that today can only be green if there is a way to assign environmental attributes to the kWh that are purchased. The recommendations were focused on how governments could support local action. Notwithstanding the current high gas prices, gas has been much cheaper to the consumer than electricity, which fundamentally dis-incentivises electrification in the UK. Over time, green tariff reviews, Power Purchase Agreement 'additionality' guidance, and other enquiries to align price more closely with future decarbonisation outcomes could make reforming current environmental attribute certification a good solution for matching demand to carbon-free energy, in which case Energy Tag and other related voluntary initiatives can allow industry to demonstrate the value and how to solve questions of scope or double counting to spur this forward. In the meantime, specific carbon intensity datasets can be used to jumpstart real programmes and projects that provide evidence for market redesign.

There is no single silver bullet to solving decarbonisation. Avoiding emissions through applying mature technologies and digital capabilities available today could boost renewable power's utilisation by matching our cities, buildings and daily purchasing and operating decisions to make electricity carbon-free every hour of every day. **A hidden carbon economy can be unlocked to eliminate fossil fuel generation, unleash the power of individual action, and redirect £ billions to solving the problems of climate change** if we act today to value the coordinated actions of many over the blunt instruments of the past.

Appendix A:
Carbon Flex Use Cases

Use Case 1:

For buildings to add solar panels to the rooftops, there are substantial carbon savings (16,801 kg) in not consuming electricity from the grid mix (which is higher carbon than the on-site solar generation.) The buildings already had installed rooftop solar so the modelling only took into consideration about a battery would impact in terms of higher self-consumption of site produced solar and what the impact of shifting discharge times overnight would do to shift the building demand away from high carbon times.

Four buildings were modelled with the following installed solar and potential new batteries:

Building solar sizes (actual)

Building 1 - *52kWp*

Building 2 - *49 kWp*

Building 3 - *21 kWp*

Building 4 - *146 kWp*

Building battery sizes (modelled)

Building 1 - *5 kW; 20 kWh*

Building 2 - *10 kW; 40 kWh*

Building 3 - *5 kW; 20 kWh*

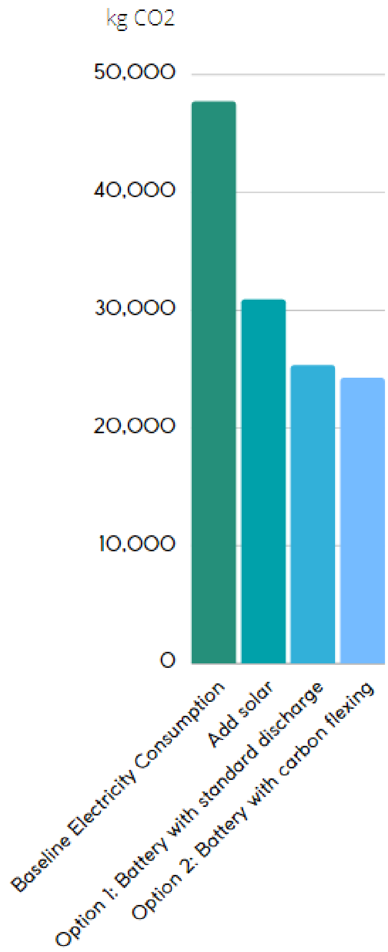
Building 4 - *15 kW; 60 kWh*

Buildings Footprint with Battery (Scope 2)

Option 1: For site level accounting, the additional value of the battery is to ensure any solar generation can be stored for later use in the building (saving 5,589 kg)

Option 2 of adding additional carbon flexing to match the battery to the cleanest times brings an additional 1,078 kg savings)

The real value to the site in this use case is switching away from the highest carbon energy, in this case grid electricity, and increasing self-consumption.



Avoided Emissions from the Battery ("Scope 4")

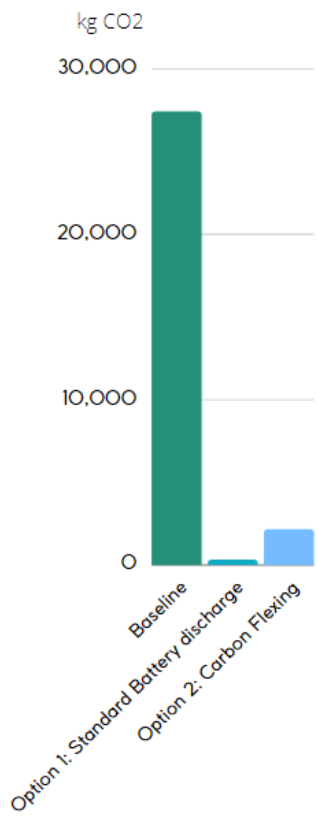
In buildings with solar panels already on the roof, to be able to compare the additional value of using a battery to flex either to use the building's own solar or avoid grid carbon, the baseline represented in the graphic is the residual carbon intensity of the grid imported electricity (27,393 kg CO2 annually).

The same options were modelled as above, just using a consequential accounting methodology to capture the avoided carbon impact.

Option 1 is to optimise further by adding batteries to improve self-consumption and discharge them to be ready to charge the next day. From the perspective of the system, this avoids very little additional carbon (282 kg CO2e)

Option 2 is to 'flex' the batteries every half hour to carbon intensity and this provides 8% additional system value measured in avoided carbon (2,132 kG Co2e)

The 8% additionality comes from 'carbon flexing' - discharging the battery at high carbon hours, thereby reducing the highest carbon intensity grid import, at no additional cost to the site after the battery is purchased.



Use Case 2: Heat Pump

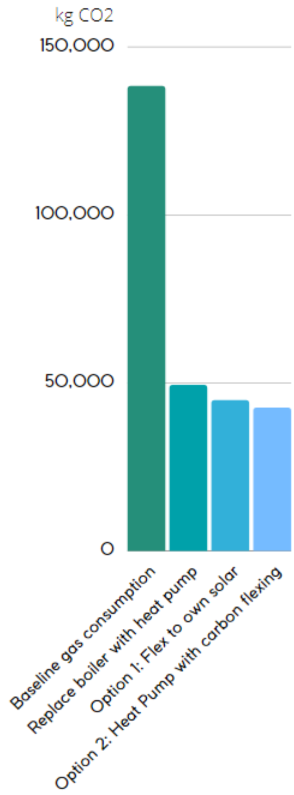
Heat Pump Footprint (Scope 2)

Replacing the gas boiler with a heat pump provides a carbon savings because the intensity of today's grid is lower than the carbon intensity of gas. The heat pump saves 64% of the heating carbon footprint just through electrifying heat. However, cost to the site is 17% higher than gas heating. These costs were modelled before gas price volatility in autumn 2021 in the UK.

Option 1: For buildings with solar panels on the rooftops, the heat pump can use on site solar generation to reduce carbon even further, for a total footprint reduction.

Option 2: If the heat pump shifts 3 hours over 2am-8am to cleaner half-hours, and a half hour over the day to limit impact on the building, the footprint reduces by 69% (5% more than the baseline).

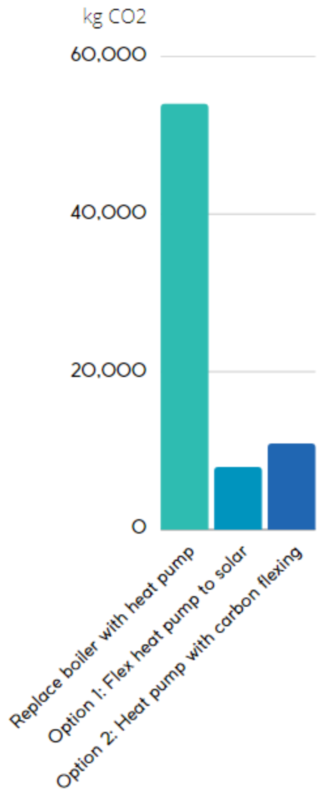
Heat pumps can be dynamically controlled to optimise comfort. Modelling half-hourly carbon intensity for this study shows relatively low impact to the site from 'carbon flexing' over 4 hours of the day. More precise dynamic heat pump management would be possible with more heat storage, along with more real time information about the fabric of the building, and occupancy. In theory then, more carbon flexing would be possible if this information were available and more buildings were managed in aggregate, or heat networks or other communal options were put in place.



Heat Pump Avoided Emissions ("Scope 4")

Buildings that add a heat pump will see their baseline gas consumption decrease significantly and therefore the carbon impact of electric heating avoids 39% carbon over the baseline. Starting with the baseline of simply adding a heat pump, the options are the same as above, just using a consequential methodology to capture the avoided carbon impact.

Option 1 is to optimise further by using the locally produced rooftop solar as much as possible. This combined self-consumption and electrification avoids 9% more system carbon than without on-site solar.



Option 2 is to 'carbon flex' the heat pumps in the early morning hours to try to pre-heat the building using the lowest carbon intensity and use one other hour of the day to flex away from high carbon intensity. This creates 13% additional avoided carbon value to the system over the heat pump alone.

In both option 1 and 2, the building operates on less carbon intensive electricity more of the time, but the heat pumps will cost the site 17% more than gas heating, which is an area that policy makers are already addressing in the UK with heat pump grants.

In the system impact analysis, adding a heat pump has significant decarbonisation impacts due to fuel switching. The heat pump could be managed dynamically to 'flex' to carbon more of the time; therefore this modelling could be considered limited or conservative. Optimisation of aggregated individual heat pumps, or communal or district heating systems provide greater scope for flexible heating to become a system-wide decarbonisation resource.

Appendix B:
Methodology Notes

It is challenging to apply a full life cycle approach including embodied emissions of the products like a battery vs a power plant to the simple actions of purchasing a heat pump or battery, and full disclosure of consequences or effects of purchases and operations are not standard practice, partly due to data availability challenges but also because companies would generally prefer to focus on the 'positive' impacts only.[1] In the use cases undertaken for Carbon Flex, the best attempt was made. For instance, when a battery is added to a building, it reduces the benefits that exporting solar to the grid provide to the rest of the system, though it also reduces the need to serve the building with electricity. These positive and negative system impacts both need to be considered.

Use Case Data

The analysis was undertaken using the following datasets:

1. Much more granular half-hourly carbon intensity data from the grid mix was used, going into depth to understand half-hourly dynamics in the buildings' operations given the operational focus of the work. Average carbon intensity datasets were used for the 'slice' (or attributional) accounting.

2. Two 'marginal' carbon intensity datasets were used in line with best practice of 'whole pie' consequential accounting. In electricity, marginal carbon intensity is used to account for actions based on the marginal impact they cause. If, for example, even a small increase in demand would result in a combined cycle gas turbine (CCGT) power station being turned up to meet that need, the marginal carbon intensity would be that of the CCGT, rather than the average of all supply carbon intensity on at that moment.

3. Embodied carbon figures were taken from literature reviews and ultimately not used in the final analysis because of the complexity of comparing this to the counterfactual (a gas fired power plant is already existing, what portion of this should be attributed to the site?) Instead, the method focused on the value of reducing or shifting energy used in operations.

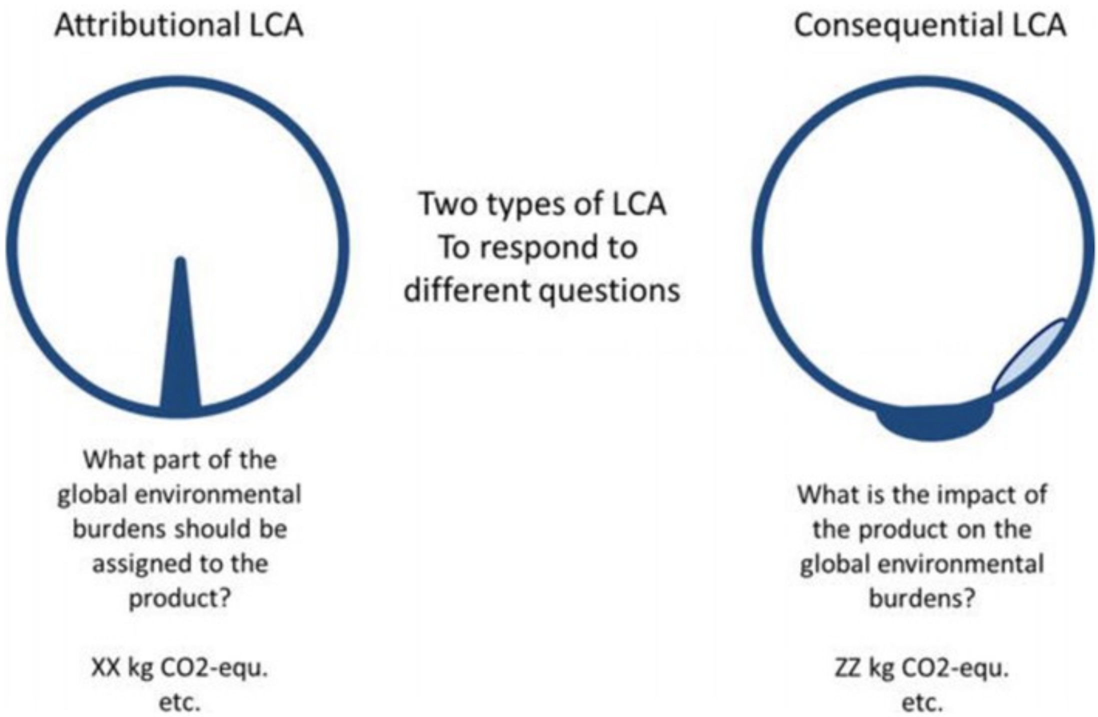
4. Half hourly energy demand and solar production data was used from four buildings for 2019 and 2020. The work focused on 2019 savings for a complete pre-Covid year of baseline data.

5. Costs and benefits were based on retail prices to the site and flexibility revenues from FFR (fast frequency response) and potential local UKPN flexibility payments.

6. Price and carbon correlations used the three different methods to assess the correlations. Machine learning was used to understand whether price would predict carbon.

1 https://ghgprotocol.org/estimating-and-reporting-avoided-emissions

Life Cycle Analysis methods



Reference: Thomas Ekvall, Extract from edited Volume 'Sustainability at the 21st Century' Feb 12th, 2020

https://www.intechopen.com/books/sustainability-assessment-at-the-21st-century/attributional-and-consequential-life-cycle-assessment

Marginal Intensity and Literature Review

GHG Protocols

GHG Protocol Guidance	When to use it	Method
Project *Assessment*	Decision-making for installations of a project, often aligned with measuring the 'offsets' that a project could receive, mainly written for project developers.	Measures effects of a project (primary and secondary). Consequential methods used and can use marginal carbon intensity if available.
Policy or Action *Assessment*	Policies and actions at a larger scale than an individual project. Lines can blur between projects and policies.	Assesses the effects of new policies and practices including incentives (this uses grid marginal carbon intensity data where possible).
GHG Goal Mitigation Guidance	To set targets and measure progress toward those targets over a baseline.	An inventory is required. However, assessing above projects or policies within this, consequential methods can be used (see above and https://ghgprotocol.org/estimating-and-reporting-avoided-emissions
GHG City Inventory Guidance	This treats grid electricity as scope 2 emissions, and can be used to understand trends over time.	Attributional methods are used to ensure city inventory is aligned with national inventory (not appropriate use for marginal carbon intensity).
GHG Corporate Standard	Corporate level emissions inventory (Scopes 1, 2 and 3)	This should be done separately from Policy or Action or Project Assessments and use attributional methods.

Using GHG methodologies today, the most applicable accounting methods to carbon flexing are below, even in advance of "Scope 4" or something like it being introduced.

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