LETI opinion piece

Real Time Carbon Accounting - The Missing Dimension

Executive Summary

A majority of organisation and building level carbon reports currently calculate annual Greenhouse Gas (GHG) emissions using fixed average factors. However, the factors for our energy grid vary greatly over each day and across the whole year, responding to energy demand, weather, and energy costs.

Two organisations using the same amount of electricity may have significantly different GHG emissions, but this is currently not recognised when reporting using industry standard calculation methods. Organisations using techniques to shift their energy demand to times when the electrical grid is lower carbon and powered by renewable energy, cannot measure their impact because current methods for calculation do not currently recognise it. This is a key barrier to wider adoption of demand management methods within homes and businesses.

Currently, when considering investments in energy storage such as batteries or thermal storage, building level whole life carbon calculations show a predicted net increase in GHG emissions. This is because the benefit of using stored energy powered by lower carbon sources is not acknowledged, but the embodied carbon emissions of installing such technologies are being accounted for "up-front". As there is consensus[1] on the role that Demand Side Response (DSR) measures can play to decarbonise the UK grid by cost effectively incorporating intermittent renewable energy generation, it is essential that a more accurate representation of the carbon benefits is made.

This Opinion Piece proposes a change to make it mandatory for organisations to report GHG emissions using an hourly emissions factor method and for buildings to be designed acknowledging the variability in electrical emission factors. The variation in the electrical grid emission factor is available in real time at ten-minute intervals, energy meters capture data every half-hour and building energy modelling software already simulate performance on a sub-hourly basis, thus GHG reporting methods and an hourly approach within building design are prime to be developed.

Corporate reporting standards allow for real-time emission factors to be used, but until the methodology is developed further, its benefits cannot be realised industry wide. The English Building Regulations are due to be revised soon with the Future Buildings/Homes Standard and there is still a chance to ensure that the variations in carbon intensity of the electrical grid are incorporated.

A UK National Infrastructure Commission report estimates the benefits of energy storage & demand flexibility could save consumers £8bn a year by 2030 and is non-negotiable for the UK Government Clean Power 2030 target. If we are to be successful in meeting our legally binding Net Zero targets, then we need to recognise reality and upgrade the method in which we design, operate and account for emissions occurring in real-time.

1.0 Introduction

To deliver its legally-required commitment to net zero carbon by 2050, the UK must meet its energy demand from low carbon and renewable sources. This requires switching energy consumers to use electricity and upgrading national grid infrastructure to connect the increasing supply of wind and solar energy. Most of these sources are intermittent, resulting in significant swings in the carbon intensity of electricity sourced from the grid, as other sources such as gas-fired power stations compensate for the difference when "the sun isn't shining and the wind isn't blowing". Consequently, **the greenhouse gas emission intensity of grid electricity varies widely**; i.e. 2024 saw an average of 125 gCO_2/kWh, peaking at 303 gCO_2/kWh and a low of 14 gCO_2/kWh.

To increase the amount of renewable energy we use and reduce carbon intensive fossil fuel sources, we must develop the capability to store excess renewable energy and reduce demand when the generation is limited.

Analysis of the 2019 and 2021 hourly grid carbon emissions in Figures 1 illustrates the change in grid carbon intensity on both daily and seasonal basis. The hourly variation in intensity is also notable whereby **carbon intensity is often lower at night and during the early hours of the morning**, and the daily peak carbon intensity can be double the daily average.

The carbon intensity of electricity sourced from the grid also varies significantly depending on locations of energy demand and generation, low carbon or otherwise. The National Energy System Operator (NESO) Carbon Intensity API website[12] provides past, present, and limited projected carbon intensity estimates taking into account such temporal and regional variations within the UK.

Despite these well documented variations, there is **currently no standardised method that can help organisations and building designers make carbon-wise decisions around these variations** by adopting demand reduction and management measures.

The GHG Protocol does allow the use of real time emission factors, but there is little incentive for organisations to make the extra effort to use them and with no established methodology for doing so, it risks undermining credibility. Furthermore, the benefits of improving the resolution of GHG emissions reporting will not be realised without an equivalent methodology developed for building designers to appraise solutions for real time emissions reduction when in-use. Furthermore, the benefits of improving the resolution of GHG emissions reporting will not be realised without an equivalent methodology developed for building designers to appraise solutions for real time emissions reduction when in-use.

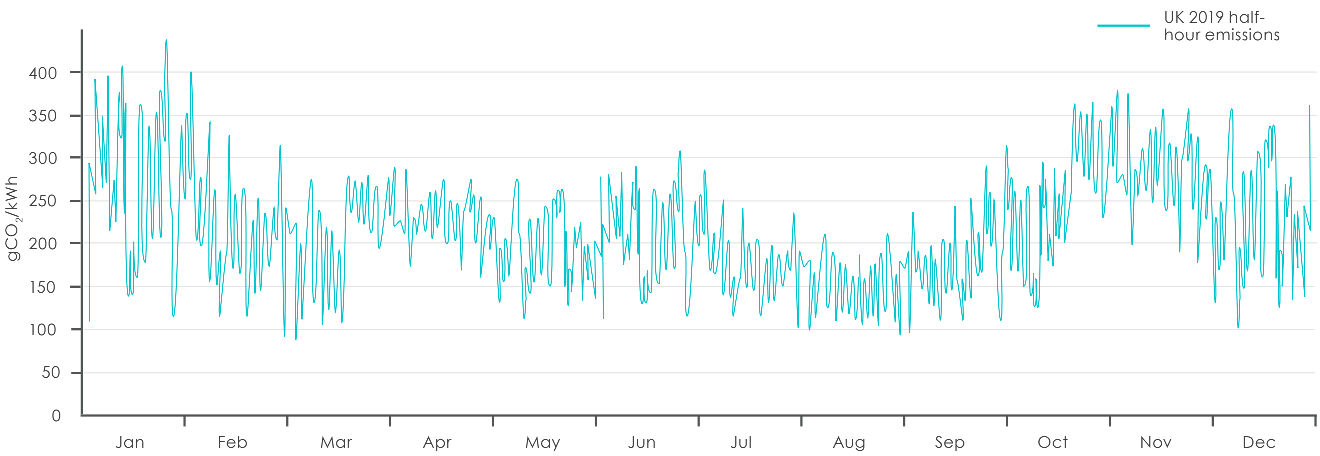

Figure 1 - Half-hourly plot of grid intensity for 2019 showing the average intensity for 3 hour periods of the day

In acknowledgement of the seasonal variations in carbon intensity, the 2021 revisions to UK Building Regulation method for assessing operational carbon emissions **(Part L) now adopt carbon factors that vary based on the month of electricity consumption** (Figure 2). This acknowledges that there is a higher contribution of renewable energy in summer and in kind, reduces the benefit of on-site PV generation. This allows engineers to optimise the PV pitch angle based on seasonal demand variations. Whilst this is a welcome step to improve the accuracy in appraising operational carbon, **it ignores the variation in carbon intensity on an hourly basis** which is essential to promote demand management strategies over shorter periods.

More positively, the Home Energy Model, slated for 2025 to update the Future Homes/Buildings Standard, point towards adoption of an hourly dynamic modelling method.

There are also precedents and emerging opportunities around implementation of these approaches suitable for commercial development. In the tech industry, 'Google Footprint'[13] uses an hourly approach to more accurately assess the carbon intensity of its cloud computing operations. The methodology and third party audit of their approach can be referenced from the product website.

Similarly, the **UK National Energy System Operator (NESO) has developed the Carbon Intensity API** to "allow developers to produce applications that will enable customers/consumers to optimise their behaviour to minimise CO_2 emissions", which can facilitate further relevant innovation in UK buildings based on high quality carbon emissions data.

With technology enabled products and services being developed to manage emissions on an hourly basis across industries, alignment of the appraisal methodology used by building designers, asset and property managers, and building users can maximise the benefit of these innovations.

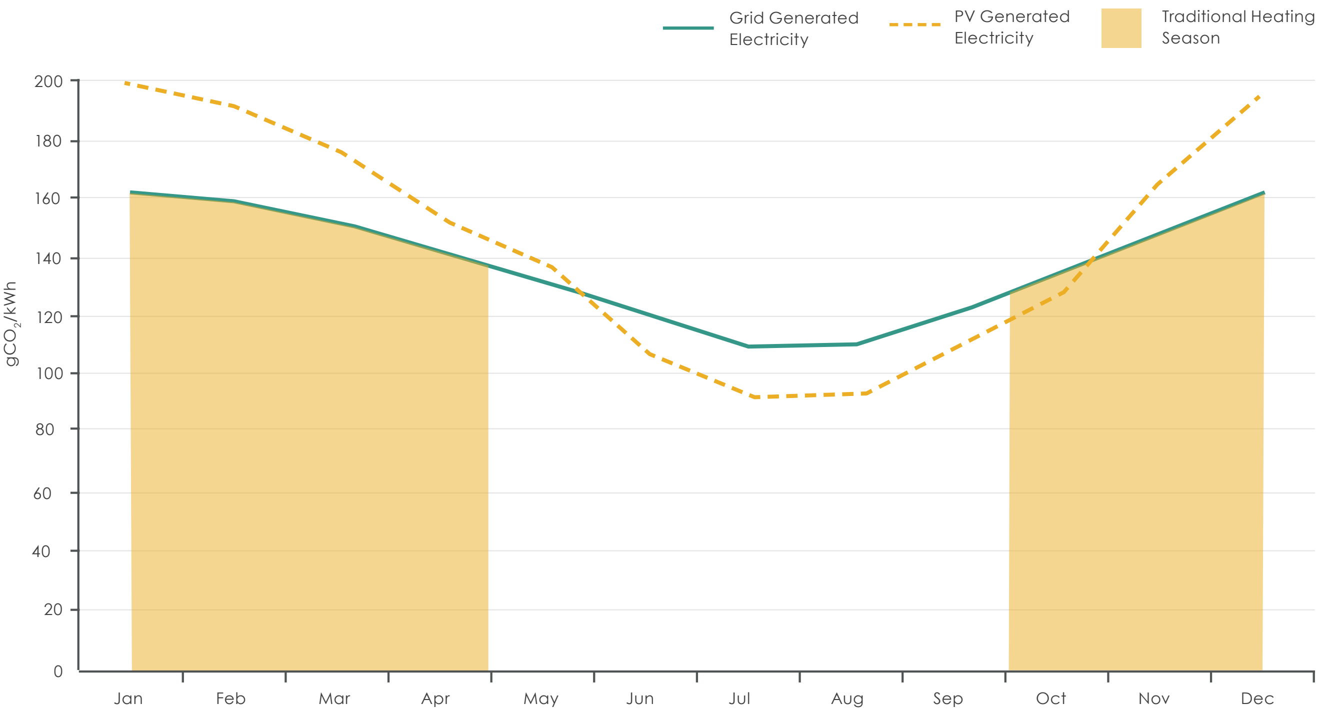

Figure 2 - Monthly electricity carbon emission factors and PV generated electricity carbon factors adopted in NCM 2021 and SAP 10.2

2.0 Benefits of an hourly approach

5 reasons for challenging current practice

1 Representing real emissions more accurately

The carbon intensity of electricity in a grid that increasingly relies on intermittent low-carbon energy sources varies significantly at the hourly and seasonal scales. Therefore **accurate representation of carbon emissions necessitates hourly calculations**. In corporate reporting and other uses, this is rarely utilised, despite recommendations to do by leading authorities in emissions reporting guidance (GHG Protocol 2001: Accuracy, SECR 2019 - Reporting Renewable Energy)[14]. The results in the case study highlight a potential increase in reported emissions when using hourly emission factors vs an annual average approach.

2 Encouraging Energy storage and demand management

Hourly accounting of operational carbon emissions recognises **the benefits of demand side response and energy storage** as mechanisms to reduce emissions today. This in turn enables investors and developers to deploy energy storage and energy sharing solutions such as batteries and time-switching of demand.

These measures are becoming increasingly attractive because the cost of generation is typically higher at times of high carbon intensity, due to expensive fossil fuel use. Variable price tariffs are emerging to transfer the change in price to consumers for them to make informed decisions on their use, further encouraging demand shifting from times of high carbon intensity towards low-carbon and cheaper renewable supply.

By pairing hourly greenhouse gas emission factors with hourly energy consumption profiles, designers, developers and organisations can establish lifecycle operational carbon more accurately. Understanding grid carbon intensity at an hourly resolution offers them the opportunity to **design and manage energy uses to shift demand to periods of low carbon intensity**. A WSP report illustrated in Figure 3 visualises the benefit of demand side response. Perversely within Whole Lifecycle Carbon Assessments, storage and demand response systems also appear unfavourably due to the associated embodied carbon emissions. Industry guidance for Whole Life Carbon Assessment (WCLA) (RICS WLCA v2 2024) makes reference to the use of hourly carbon factors, however there is no requirement to use them or suggestion of an appropriate methodology.

3 Reduction in infrastructure and operating costs

If implemented at scale, demand side response mechanisms **reduce need for redundancy in generation and improve utilisation of the installed power generation equipment**, the transition infrastructure costs and associated embodied carbon emissions, and energy bills for the energy end users. A UK National Infrastructure Commission report estimates the benefits of energy storage & demand flexibility could save consumers £8bn a year by 2030. The UK National Energy System Operator recent paper on Clean Power 2030 emphasises that these techniques are crucial.

We are already seeing the National Grid routinely contracting users to turn off or turn on demand when needed to help balance the network, reducing the need for costly upgrades to manage this without the help of the users. Many energy providers now have tariffs to reward electricity use reduction at times of peak demand as this reduces both the overall greenhouse gas emissions, the need for renewable generation capacity and grid upgrades, yet it does not appear within corporate GHG reporting.

Even though network providers already recognise the value of hourly demand management, our buildings and businesses often lack the necessary infrastructure to respond. This is in large part because our current carbon accounting methods do not acknowledge the benefit of storage and demand side response. Therefore, when working on new development or investments, designers and operators do not have the right tools to evaluate and implement these measures at scale.

4 Aligning design and operational reporting methodologies

The same hourly approach proposed for adoption in design and construction stage can be easily adopted within the energy and carbon management of organisations, as energy meters report on a sub-hourly basis as standard. This data aggregated and utilised for public reporting frameworks. E.g. CRREM, SBTi, GRESB, CDP etc.

5 Minimising perverse incentives and unintended consequences

Another benefit of an hourly accounting methodology is to avoid locking in design measures, technologies, and management practices which may limit flexibility of energy users to operate in the most carbon efficient manner.

Renewable Energy

An hourly emissions accounting increases the representativeness of estimated carbon emission benefits for generating renewable energy on-site. Using the same carbon emission factor at all times in a year means that the relative benefit of renewable energy technologies can be misrepresented, especially if electricity is generated consistently at times of lower grid carbon intensity due to the grid's reliance on similar technologies.

Most notably, solar arrays optimised for summer generation yield their highest output at times when the grid carbon intensity is also typically the lowest (Figure 2). In contrast, output is significantly lower in winter months when days are shorter and the grid carbon intensity is typically higher. Therefore, treating the carbon benefit of each unit of electricity generated by solar panels equally throughout the year can overestimate their benefit, and introduce incentives towards designing solar arrays sub-optimally. The benefit of emissions displacement from on site solar energy generation should be assessed using more realistic and time dependent factors.

Thermal Properties of a Building

In the last 20 years, in the EU & UK, there has been a focus on energy efficiency in processes and buildings. In buildings, the principle of addressing the thermal efficiency of the fabric has been challenged as the generation of energy has become cheaper and the embodied carbon of materials has become a greater factor, relative to a products life cycle emissions.
Using real time emission factors will allow insulation to be recognised for it's primary benefit in temperate climates. This is because the operational carbon benefit of thermal insulation in homes and other buildings will be realised in winter and in the evenings when carbon emission factors are typically higher due to additional demand and lack of contribution from solar power.

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Chapter 4 Demand Side Response

Methodology

A methodology is proposed within Appendix A below and focuses on a typical workflow which could be implemented by a Building Performance Engineer or Sustainability Consultant within the design stages of a building.

Case Study

The results of the case study analysis is presented within Appendix C, providing initial evidence and demonstration of the importance in adopting an hourly emissions accounting method.

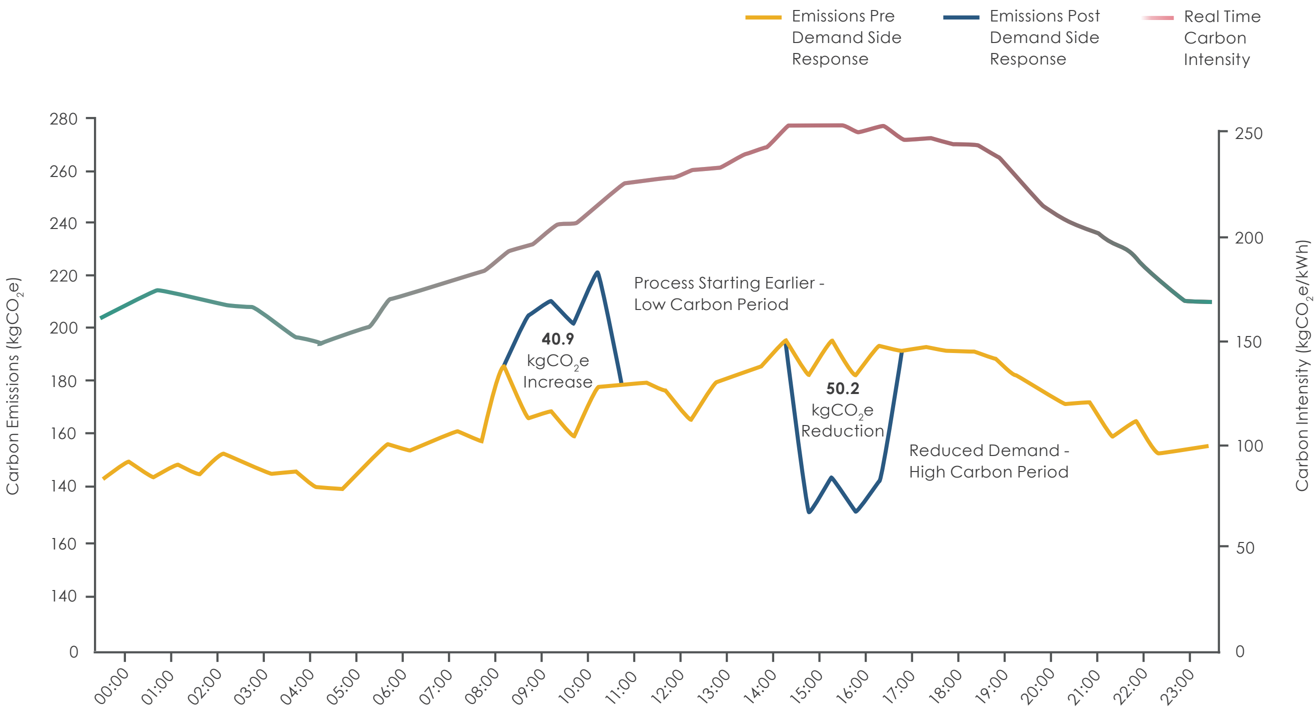

Figure 3 - Use of hot water storage tanks in dwellings can reduce operational carbon emissions in dwellings - WSP report on real-time CO_2 emissions[10]

3.0 Conclusions

The study critiques the current practice of using static, annually-averaged emission factors for Scope 2 greenhouse gas emissions in buildings, arguing that it fails to account for the actual impact of different operational patterns on emissions.

It proposes a new method that uses hourly carbon emission factors, which more accurately reflects the grid's variable carbon intensity and encourages lower energy consumption during carbon-intensive periods. This approach can better support demand management strategies, reduce infrastructure investments, and align design with operational reporting.

Case study analysis shows that the hourly emissions method increased reported emissions in multiple building types compared to an annual average method. Modelling battery storage as a demand side response measure was shown to reduce emissions.

This Opinion Piece proposes that an hourly reporting method becomes mandatory for GHG reporting. However, the estimation methodology in the design stage will require regulatory support and careful consideration, particularly for residential buildings.

Appendix A: Proposed Methodology

Non-domestic buildings

Steps to adopt hourly carbon assessment for non-domestic buildings during design

1. Develop hourly electricity demand profile through an Operational Energy estimation model aligned with CIBSE TM54 and/or NABERS UK DfP, using the most recent full year's weather file.
2. If this is not viable, use the Dynamic Simulation Model for Part L compliance and extract hourly electricity demand.
3. Using a spreadsheet, multiply each hour's electricity demand with corresponding hourly grid carbon intensity from UK Grid Carbon intensity website.
4. Sum the total hourly emissions for the entire year.
5. Multiply with the decarbonsation factors for the considered life cycle of the building being assessed (see discussion of this further below).

For non-domestic buildings in the UK, Dynamic Simulation Modelling (DSM) software is often used to calculate the energy consumption and carbon emissions required to demonstrate compliance with the Part L of the Building Regulations. To generate this output, DSM software simulates hourly energy flows in a building using a test reference weather file, and thus calculates the energy consumed to maintain a comfortable condition in the building for each hour of a typical year.

The methodology involves one additional step to the workflow, whereby instead of summing the energy consumption for the whole year and multiplying by an annual carbon emission conversion factor, there is an opportunity to **multiply the hourly energy consumption by the carbon emission intensity at the same time interval**. Consequently the time of energy consumption becomes an active variable within the calculation of annual carbon emissions. This enables building designers to embed functionality within the building to allow users to **shift their energy use towards times of low carbon intensity**.

NABERS UK (Design for Performance for commercial offices), and CIBSE TM54 (applicable more broadly), are methods that promote more detailed and building-specific estimation of energy consumption on an hourly basis. These methods are becoming increasingly popular within the commercial sector as they are required by the London Plan for major commercial development within Greater London, and encouraged by the BREEAM. They enable more robust hourly energy use estimations compared to Part L calculations, including greater potential to account for demand response measures. As a result they improve accuracy in estimating the energy consumption of a building and provide the opportunity to test relevant technology or operational procedures proposed to minimise carbon emissions in operation. We encourage adoption of such methods for the calculation of hourly or sub-hourly carbon emission rates when following our recommended approach.

Non-domestic buildings in-use

- → Extract electricity consumption from energy bureau services/metering data service provider on an hourly/sub hourly basis.
- → Extract sub-meter electricity data if this is available.
- → Using a spreadsheet, multiply each hour's electricity demand with corresponding hourly grid carbon intensity from UK Grid Carbon intensity website.
- → Sum the total hourly emissions for the entire year.
- → Explore consumption data profile & test building management strategies to minimise energy use at times of high grid carbon intensity.

Non-domestic buildings - Workflow

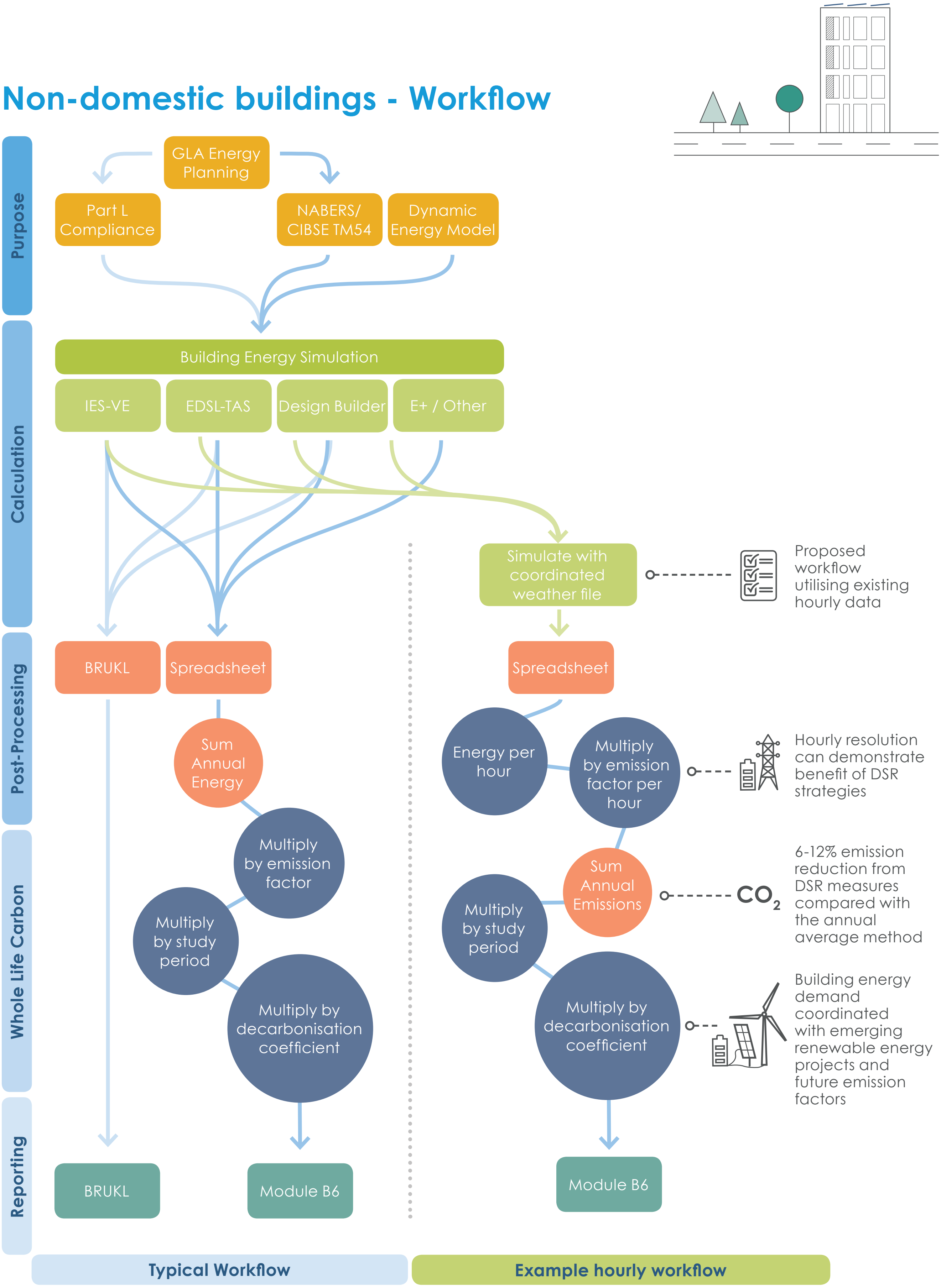

Figure 4 - Example wokflow for an hourly emissions methodology for non-domestic buildings.

Domestic buildings

Steps to adopt hourly carbon assessment for dwellings during design

1. Develop hourly electricity demand profile through an operational energy estimation model aligned with CIBSE TM54 using the most recent full year's weather file. [Future Dev. Home Energy Model]
2. If this is not viable, use outputs from SAP assessments and generate hourly demand profiles using external resources such as Elexon profile classes.
3. Using a spreadsheet [or future Home Energy Model 'wrapper'], multiply each hour's electricity demand with corresponding hourly grid carbon intensity from UK Grid Carbon intensity website
4. Sum the total hourly emissions for the entire year.
5. Multiply with the decarbonsation factors for the considered life cycle of the building being assessed (See discussion of this further below).

For compliance with the building regulations, energy performance and carbon emissions of dwellings in England and Wales are currently estimated using the Standard Assessment Procedure (SAP).

This procedure currently uses steady state calculations to estimate monthly energy consumption. Therefore, adoption of our recommended **hourly approach of carbon accounting requires additional steps to estimate hourly consumption profiles** which are temporally aligned with the corresponding hourly grid carbon emission factors, so that the two can be multiplied. This is a challenge, as hourly energy use profiles are not commonly utilised within current energy assessment methods for dwellings, and their development can be cumbersome for practitioners due to poor data availability.

Even so, we note **the increasing adoption of dynamic simulation modelling for dwellings**, in part due to the adoption of CIBSE TM59 and Part O of the Building Regulations on overheating. We therefore encourage practitioners to seize this opportunity and develop hourly or sub-hourly estimation of dwelling energy demand using a similar approach to CIBSE TM54 - although we note that the operational assumptions will often need to differ from the assumptions listed in CIBSE TM59 and bespoke profiles may need to be developed to represent the dwelling in question.

If this is not possible in practice, use of generic but building-type specific profiles from third party resources can be considered. For example, Elexon have standard hourly profiles for typical domestic energy use that can form a starting place for creating a post-SAP hourly energy demand profile. We adopted and discussed this approach as one of our case studies.

On the side of progress, such admittedly convoluted methods may be a temporary stop-gap solution. In alignment with the proposed adoption of the Future Homes Standard by 2025, The Home Energy Model / SAP11 is currently being developed by BRE. The HEM **proposes to adopt half hourly calculations**. This provides a much needed opportunity to modernise the way dwelling energy use and carbon emissions are assessed. The HEM/SAP 11 is developed in widely used open-source programming languages. However, its development is still in the early stages, with adoption tentatively by 2025/2026. Although it is likely the software will develop profiles of energy demand internally, it is yet unclear if it will use hourly emission factors, what the source of these factors and their projection will be, and how the benefits of energy storage and demand side management might be accounted for. If this opportunity is missed, a manual approach using demand profiles and externally sourced carbon intensity factors may continue to be necessary.

Domestic buildings - Workflow

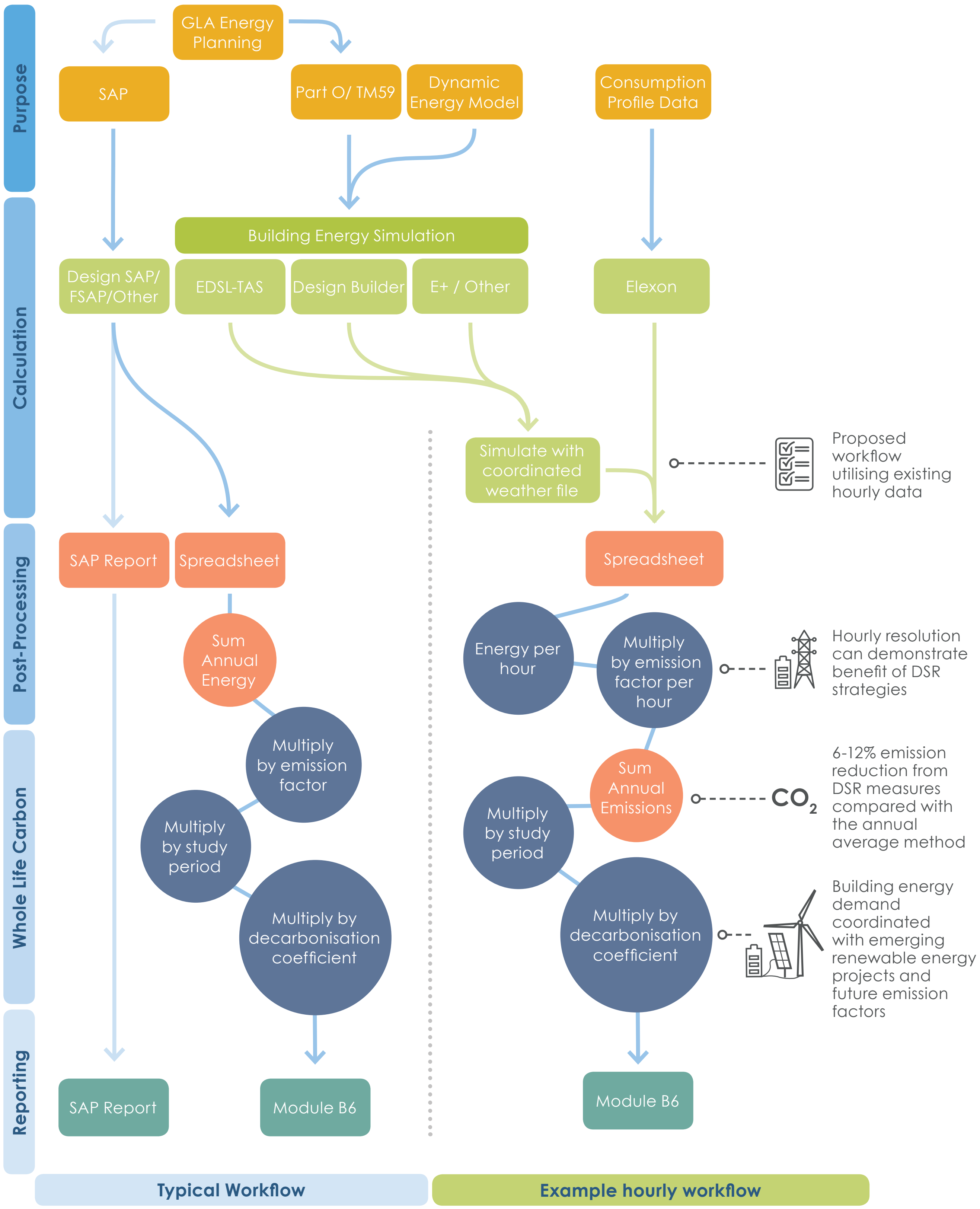

Figure 5 - Example wokflow for an hourly emissions methodology for domestic buildings.

Appendix B: Challenges and Other Issues to Resolve

Alignment of hourly simulation weather data with carbon emission rates

For the recommended hourly method to reach its full potential, the dynamic simulation model and **the hourly carbon factors should ideally be based on the same external conditions** and capture the interdependency between the two.

This is because weather and seasons can strain the grid at times where renewable capacity is limited (summer with low wind speeds or winter with low solar radiation).

A building that employs peak demand reduction/ shifting measures at times of peak demand on the grid, for example by incorporating insulation, thermal mass, storage tanks/ batteries, or load shedding approaches, should see the full benefit of adopting these design measures through reducing demand during times of high grid carbon intensity and aligning with the management objectives of the national grid.

We propose one of the two following approaches to overcome this challenge, with the latter option already achievable:

1. Generation of a representative but synthetic hourly carbon profile that aligns with the test reference year weather conditions.
2. Use a fixed year's observed data for both building energy demand simulation and carbon intensity of the grid.

Projecting emission factors

To project carbon emissions consistently over the entire building life would require projection of the grid carbon emissions hourly as it decarbonises.

Our recommended response to this challenge is to continue using the same shape of hourly building energy demand and grid carbon emissions established for one year of operation, and reduce the grid carbon intensity proportionally (i.e. in terms of percentage reduction over the previous year, and not in absolute gCO_2/kWh_e terms) in line with the appropriate decarbonisation projections.

We have contacted National Grid ESO to understand the potential of forecasting such future emissions within their current carbon emission forecasting models yet a very high degree of uncertainty remains. Based on our communications, we understand that the rate of renewable energy project implementation and the types of renewable energy sources will heavily influence the hourly carbon intensity, both nationally and within local electrical grids.

Regional carbon emission factors & reporting

Another issue to consider is the regional variation in emission factors resulting from the mix of generation connected to District Network Operators (DNO).

The UK National Grid carbon intensity website[3] offers sub-hourly **carbon factors both at national and regional levels, with significant differences between various parts of the UK**. We expect the adoption of an hourly approach using data from this resource to raise valid questions around the adoption of hourly carbon profiles for different regions.

Additionally, whilst the hourly approach aligns with the 'location based' method for accounting of Scope 2 emissions according to the Greenhouse Gas Protocol, it does move away from the current published definition which primarily refers to grid average emission factors.

A benefit of adopting this accounting approach would be that the demand side response measures adopted by building management can be rewarded in emissions reporting frameworks and potentially contribute towards meeting relevant carbon reduction commitments / Net Zero Carbon pathways.

We have not explored this subject in detail and recommend this as an area of investigation for others.

Appendix C: Case Study Analysis

To demonstrate the potential impact of our proposed method, we developed several case studies based on limited generic hourly energy use data collected and volunteered by the work-stream members. Here we document some of our methods and observations from these case studies for reference.

As our data sources were not developed and optimised for this specific purpose, our case studies do not bookend the potential benefit of the proposed method or the assessed strategies. Instead, they demonstrate the general relevance and importance of adopting our recommended method, and we share our case studies as inspiration to highlight some of its potential use cases in practice.

Overall we reviewed 13 annual hourly energy use profiles for a selection of buildings, however four key typologies are presented:

→ A best-practice all-electric two-bed flat
→ Operational electricity use data from an existing office building in Manchester
→ A best practice all–electric four-bed detached dwelling
→ An all-electric office in design, with an estimated energy use intensity of 100kWh/m²/yr

	Area	EUI	Baseline WLC A-C	Baseline Carbon Emissions		△	Demand Management Benefit		△	Battery Upfront Embodied Carbon	Carbon Payback	Simple Payback (inc. 5% annual decarb)
				Annual Average	Hourly (2019 data)		Battery Capacity	Carbon Emissions (Hourly) +Battery				
	m^2	kWh/m^2	$kgCO_2/m^2$	$kgCO_2/m^2$	$kgCO_2/m^2$	%	kWh	$kgCO_2/m^2$	%	$kgCO_2/m^2$	Years	Years
3- Bed Semi-Detached	97	48	800	10.2	10.7	5%	13.5	8.8	-17%	13.9	7.5	9.8
Elexon PC1	70	117	1200	24.4	25.1	3%	13.5	22.2	-12%	19.3	6.6	8.7
Office 55 kWh/yr	65,000	55	970	10.7	11.2	5%	6750	9.8	-12%	10.4	7.6	10.0
In use office data (Manchester)	20,000	143	1400	30.5	32.4	6%	2700	30.2	-7%	12.9	6.0	7.9

Table 1 - Summary results table of key typology analysis, testing the impact of an hourly emissions methodology.

Other observations

Impact of hourly methodology

The study explored the impact of using hourly grid carbon emission factors versus an annual average on the carbon emissions of various building types. It found that using hourly factors generally increased reported emissions by 1% to 6% due to lower energy consumption during periods of low grid carbon intensity, such as overnight. The research suggests that annual average carbon factors may misrepresent operational emissions unless carefully weighted by demand. Specifically, buildings with consistent internal energy use, like low-energy offices, showed less sensitivity to hourly factors, indicating the importance of passive design measures and supporting the adoption of hourly calculations for more accurate emission assessments.

Aligning datasets

The study assessed the sensitivity of operational carbon calculations using the hourly method to the alignment between the periods of energy use and hourly grid carbon emission data. By simulating office buildings' energy use for 2019 and 2020 [1] and comparing them with corresponding national electricity carbon intensity profiles [2], a 3% difference in annual operational carbon estimates was observed when periods were misaligned. The study recommends aligning these periods to avoid underestimating the carbon benefits of peak demand reduction measures, which are most effective during high grid demand periods. Misalignment could lead to inaccuracies, particularly in evaluating lifecycle carbon benefits of design improvements.

Demand side management

The study highlights that beyond accurately representing operational carbon emissions, the hourly calculation method also enables the evaluation of demand response measures and their carbon benefits. By testing Tesla Powerwall 2 [3] batteries with a simple control algorithm, the study observed over 15% reduction in annual operational carbon emissions for some buildings without reducing total energy use. This reduction was particularly significant for all-electric residential buildings with high energy demand during periods of high grid carbon intensity. The study also assessed the carbon payback of the batteries, finding it to be less than the 10-year warranty period in most cases, despite their high embodied carbon. We emphasize that adopting an hourly carbon calculation method is crucial for evaluating and optimizing such measures, as it prevents these solutions from being dismissed due to their embodied carbon costs.

Where there is no hourly estimate

The study points out that, unlike non-domestic buildings, there are no widely-adopted methods for estimating the annual hourly energy demand of dwellings during design, as the current Standard Assessment Procedure (SAP) uses monthly calculations without standardized inputs for typical usage patterns. Despite this, the study encourages practitioners to develop hourly dynamic models for domestic buildings, as the benefits of such an approach are evident. Where specific energy use profiles aren't feasible, generic demand profiles, like Elexon Profile Classes [4], can be used with building-specific adjustments. However, these generic profiles may not accurately represent new all-electric dwellings, and we urge practitioners to carefully scrutinize data and consider alternative datasets from regions with more prevalent heat electrification.

[1] https://power.larc.nasa.gov
[2] https://carbonintensity.org.uk
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