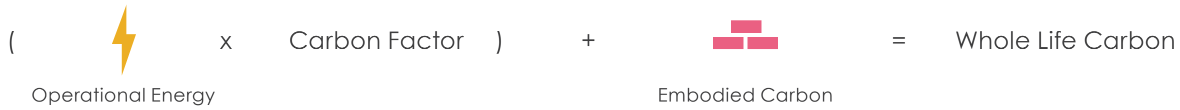
LETI Opinion Piece

Operational Carbon in Whole Life Carbon Assessments

Executive Summary

Reducing operational energy and embodied carbon are key to the reduction of the environmental impact of the built environment. As industry becomes more familiar with embodied and whole life carbon assessments, operational energy is more regularly converted to operational carbon within a whole life carbon approach. This analysis is increasingly used for scrutinising and evaluating design options, as well as quantifying the total impact of buildings.



This LETI Opinion Piece proposes a methodology for the conversion of operational energy into operational carbon, for the purpose of making design decisions. This methodology has been developed by a LETI workstream and aims to provide a basis for further analysis and discussion, through which this conclusion can be further refined.

Operational and embodied carbon emissions are interrelated, as well as varying in both numerical value and certainty over time. Central to these complexities are uncertainties around the decarbonisation of the UK electricity grid, alongside the interdependence of the amount of energy used by buildings and the ability of the UK grid to decarbonise.

The methodology proposed in this LETI Opinion Piece to convert operational energy operational carbon is a 'split carbon factor' method. In this method, a decarbonised carbon factor is applied to the electricity consumption that is below a LETI Energy Use Intensity (EUI) target, and a non decarbonised carbon factor is applied to electricity above a LETI EUI target.

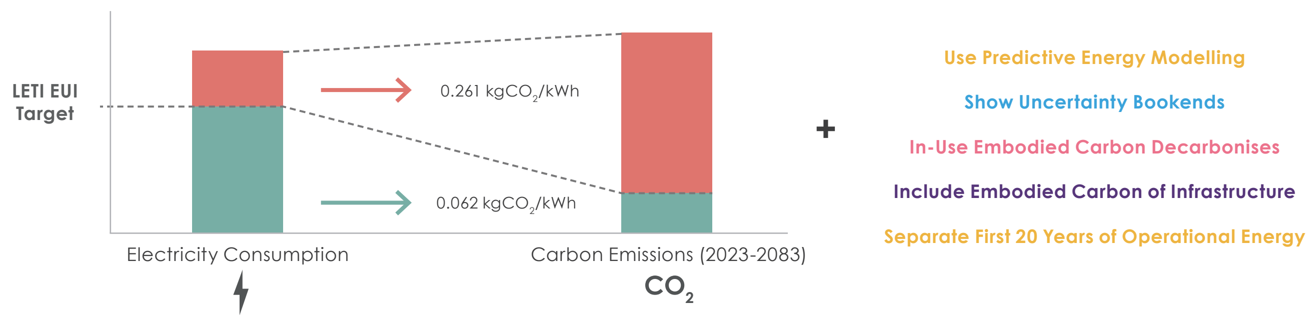


Figure 1 - Split carbon factor conversion methodology for electricity consumption

Every building must play its part and support the grid to decarbonise in an equitable way and this methodology accounts for buildings not benefiting from a decarbonised grid beyond their fair share. Further considerations include expressing uncertainty, the decarbonisation of future in-use embodied carbon emissions and inclusion of infrastructure embodied carbon which are illustrated on the dashboard below.

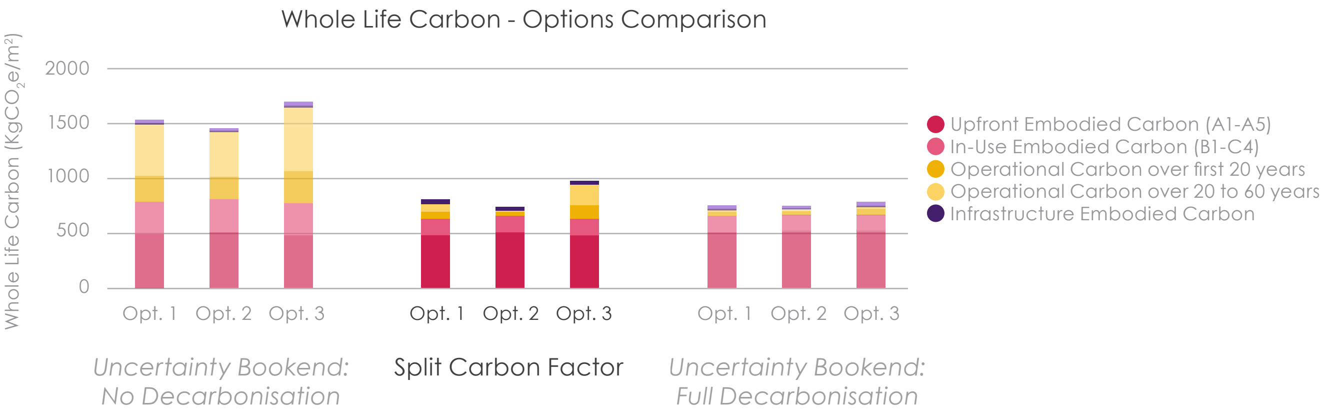


Figure 2 - Illustrative output 'dashboard' for proposed methodology. comparing three options (Opt.1, 2 and 3)

The above figure illustrates the proposed methodology reporting dashboard. Fundamental to the approach is the inclusion of two "uncertainty bookends", one showing scenario with no decarbonisation of the UK grid and the other a scenario with a fully decarbonised UK grid. Operational carbon in the next 20 years is indicated separately as this value has greater certainty than emissions over years 20 to 60 of a buildings' lifecycle. The dashboard also includes an allowance for the embodied carbon impact of the electricity grid within the whole life carbon calculations.

Operational Carbon Tool

LETI are developing a tool to carry out this analysis, which will be available through leti.uk/opinionpieces

This paper was put together by a LETI working group of about 50 built environment professionals. The group split into 5 sub working groups to explore the various methodologies which are further described in the Appendix to this study.

Explanatory notes

'***EUI***' - Energy Use Intensity (EUI, kWh/m².yr): the energy use per m² that is required by a building over a year, included regulated (i.e. domestic hot water, space heating and cooling, lighting, and ventilation) and unregulated loads (e.g. lifts, IT). It is a measure of the building's performance and therefore includes all energy supplied to the building, whether from the grid or on-site systems.

'***Carbon***' is used in this paper as a generic term to represent all GHG emissions, set out in BS EN 15978 as Global Warming Potential (kg CO_2 equivalent). GHG emissions also include methane and many refrigerants which are hugely impactful as multipliers of atmospheric warming.

'***Operational energy***' is all energy used by an asset in-use over its life cycle, which includes regulated and unregulated uses.

'***Operational carbon***' is the GHG emissions arising from energy used by an asset in-use over its life cycle.

The points raised in this piece often hold in general but may vary in differing specific contexts. The nuances underlying the impacts of many design decisions means they should, wherever possible, be supported by the calculation of carbon and WLC metrics.

It should be noted that the quantity of onsite renewables that should be installed can not be tested by the methodologies that are explored in this paper.

1.0 Introduction

1.1 Whole life carbon

'Whole life carbon' emissions are the sum total of all asset related GHG emissions and removals, both operational and embodied, over the life cycle of an asset, including its disposal (Modules: A1-A5; B1-B7 (plus B8 and B9 for Infrastructure only); C1-C4). Overall whole life carbon asset performance includes separately reporting the potential benefit from future energy recovery, reuse, and recycling (Module D).

SIGNPOST *leti.uk/carbondefinitions*

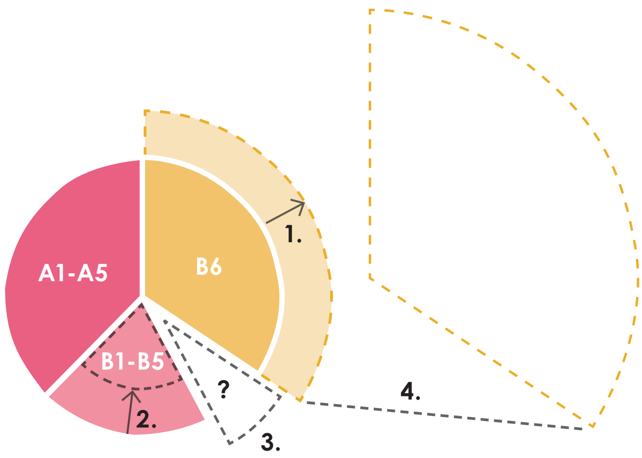
1.2 How to carry out a whole life carbon assessment

A Whole Life Carbon Assessment is an estimation of the whole life carbon associated with a building. This typically includes carrying out a Lifecycle Embodied Carbon assessment, and an assessment that predicts the energy consumption of the building (for example CIBSE TM54 or a PHPP assessment).

1.3 Outlining the problem

Part of the purpose of carrying out an embodied carbon assessment is to look at design options available that reduce the embodied carbon of a building. Similarly, part of the purpose of carrying out an operational energy assessment is to look at design options that reduce the operational energy of a building.

Bringing these two assessments together, so that the whole life carbon implications can be evaluated, is positive in principle, as unintended consequences of a design solution can be better understood. Yet, problems arise where there is a trade off between operational and embodied carbon. How do we value the potential for grid energy reduction in the future, relative to embodied carbon which we emit now?



1. **Compliance modelling underestimates energy consumption**
2. **Future decarbonisation of embodied carbon not included**
3. **Embodied carbon of energy infrastructure not included**
4. **Normally an average grid carbon factors is applied to the predicted energy consumption, that represents the average carbon emissions associated with electricity generation over the next 60 years. The RICS PS requires a decarbonised result to be presented as well, but both results are not often shown in assessments**

Figure 2 - Challenges in combining embodied and operational carbon within a whole life carbon approach

There are many related factors relevant to both the construction of the building and what a relevant carbon factor for the electricity grid would be over the next 60 years.

As we move to a lower carbon grid, we will need to construct more renewable energy, which in itself requires embodied carbon to build. Lowering the combined peak demand on the grid and increasing the ability to shift peak loads will need fewer renewables and energy storage infrastructure to be built. Thus the ability for the grid to decarbonise over the next 60 years partly depends on the energy consumption of existing buildings and new buildings that are constructed.

In addition, with a future fully decarbonised grid that is powered by renewables, (solar, wind, tidal, wave) the energy supply is inherently intermittent. The amount of electricity is governed by how much the sun is shining, whether it is windy etc. This means our future grid will need to have more storage capacity in order to deal with the peaks and troughs. However, storage is expensive (both financially and in terms of embodied carbon) and the greater the peaks and troughs, the more storage will be needed. Thus if a building is flexible in when it needs electricity, it helps the grid decarbonise. These themes are explored in more details in this paper.

Complexities and interrelationships with bringing together operational energy and embodied carbon:

→ Decarbonisation: Typically no decarbonisation is applied to embodied carbon. Installing a window in year 0 and year 30 has the same embodied carbon in a WLC assessment, even though it is much more likely that the embodied carbon relating to the window installed in 30 years time will be much lower, as fossil fuels are replaced and energy supplies and materials decarbonise. This is particularly problematic if the benefit of a design feature with additional embodied carbon reduces operational energy, but only the operational energy is subject to decarbonisation and the whole life embodied carbon is not.
→ Embodied carbon of energy infrastructure: is not usually taken into account.
→ Demand response and flexibility: carbon benefits of implementation at scale cannot be quantified, unless the embodied carbon footprint can be compared against the operational carbon benefit, which requires calculations using dynamic carbon factors with high temporal resolution.
→ Renewable procurement: how the electricity is procured will affect the carbon factors associated with the electricity consumption.

The different reasons for carrying out Whole Life Carbon Assessments

There are various reasons for carrying out a WLC assessment, and depending on the driving factors behind the assessment, it may be relevant to use a different method for converting operational energy to operational carbon. Reasons for carrying out a WLC assessment:

→ Making design decisions- i.e. understanding trade offs between operational energy and embodied carbon (Concept stage / Detailed design stage)
→ Comparing the whole life carbon of different projects, or a project against a benchmark (Concept stage/ Detailed design stage)
→ Predicting the whole life carbon of an asset, in order to understand the likely carbon offsetting costs in the future (Concept stage / Detailed design stage)
→ Embodied carbon assessment updated based on as built values (Practical completion)
→ Use stage: annual reporting based on metered energy consumption and embodied carbon relating to annual repair, maintenance and replacement. (Use stage)

This paper seeks to understand the most appropriate method for converting operational energy to operational carbon for the purpose of making design decisions - i.e. understanding trade offs between operational energy and embodied carbon – as noted above.

2.0 Proposed Methodology

2.1 Criteria for methodology selection

It is important that the carbon conversion methodology:

→ Can be easy to implement
→ Can be amended and adapted when carbon related to electricity grid projections are updated
→ Is based on a publicly available, regularly updated dataset
→ Drives the right outcomes
→ Doesn't create a perceived 'performance gap'
→ Can be applied to all building types
→ Can be applied to different case scenarios

2.2 Conclusions

As an industry we are still very much learning about the interrelationships between operational energy and embodied carbon and the uncertainties when bringing the two together in a Whole Life Carbon Assessment. We have explored these known uncertainties and interrelationships in this paper, however more are likely to emerge.

Bringing operational energy and carbon together is complex, and should only be carried out by those that fully understand the subject and its uncertainties. Operational energy and embodied carbon can be brought together in various ways, and can be easily 'gamified' such that the outcomes change depending on the methodologies used. It is important that the method produces the correct incentives as the grid decarbonises, ensuring it is fit for purpose to get us to net zero.

The methodology used to bring operational energy and embodied carbon together should be different depending on the purpose of the assessment. This paper focuses on the design stage, where decisions are being made on design options, where a design option increases either operational energy or embodied carbon and decreases the other.

Due to uncertainties of the decarbonisation pathway of the UK grid, and the relationship between the amount of energy used by buildings and the ability of the UK grid to decarbonise, this paper concludes that the central methodology that should be used to understand the trade offs between operational energy and embodied carbon is the 'split carbon factor' method. In this method a decarbonised carbon factor is applied to the electricity consumption that is below the LETI EUI target, and a non decarbonised carbon factor is applied to electricity above the LETI EUI target.

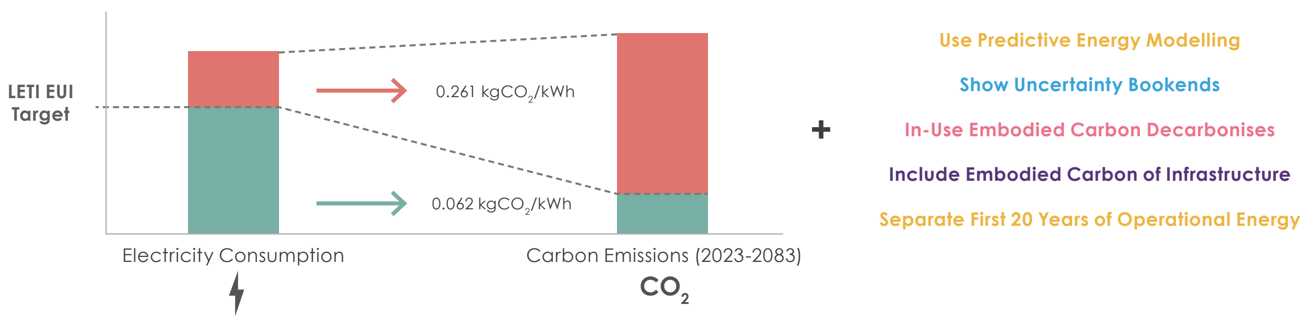


Figure 3 - Split carbon factor conversion methodology for electricity consumption

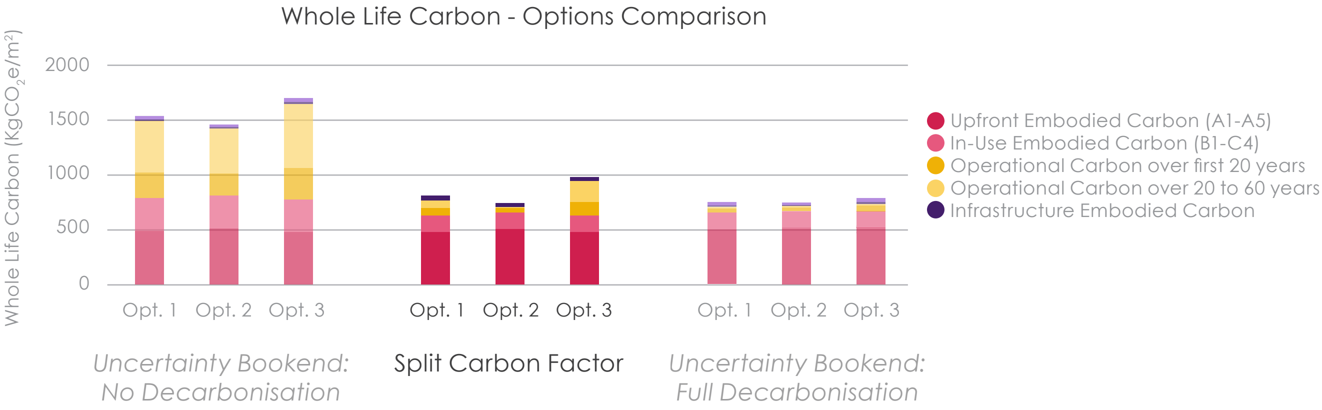


Figure 4 - Illustrative output 'dashboard' for proposed methodology. comparing three options (Opt.1, 2 and 3)

Our solution recognises that every building must play its part and support the grid to decarbonise in an equitable way, and thus buildings that use more energy than their fair share cannot use the benefit of the decarbonised grid as they don't actively support the grid to decarbonise.

The method also includes the embodied impact of the electricity grid within the whole life carbon calculations.

Fundamental to the approach is that, when whole life carbon results are presented, they must be shown in the context of 'uncertainty analysis' book ends, one showing a non decarbonised grid, and the other showing a fully decarbonised grid.

Items to note:

LETI provides EUI target for homes, offices and schools only, thus this method is only applicable to these typologies. However it is important to note that the UK Net Zero Buildings Standard, which is currently being developed, will produce Net Zero aligned EUI targets for a larger variety of building typologies.

This 'split carbon factor' methodology requires a bit of refinement. It is suggested that decarbonisation factors should be applied to module B and C embodied carbon (this could be at a flat rate, or could be used only for the embodied carbon that is below the net zero embodied carbon limit).

3.0 Next Steps

This LETI opinion piece sets out how the 'operational carbon in whole life carbon' working group believes that operational energy should be converted in operational carbon for use in whole life carbon assessments, for the purpose of making design decisions.

The next steps are to gain wider consensus on this topic, and look to establish this methodology more widely by engaging with RICS, UKGBC and others.

Actions for LETI

→ **Option B - the hourly approach**, was not explored fully in this paper, due to availability of case studies. In order for this approach to be further explored, we need to understand how to assess the benefits of thermal and battery storage and energy flexibility. This will be the subject of a separate LETI Opinion Piece.

→ LETI is developing a **guide to operational energy modelling** which will provide advice on how to carry out performance/predicted modelling, (often called TM54 or EUI modelling). This new guide will provide support on why and when this type of modelling is needed, how to carry out the required modelling and how to get maximum value for the project out of this modelling exercise.

Actions for Industry

→ Establish realistic **energy profiles for regulated and unregulated energy**. Access to current profiles of actual energy use in operation will support realistic performance energy modelling.

Help LETI develop this topic further by submitting case study information

Limited case studies were available that had assessed both operational energy and embodied carbon and looked at design options that explore trade offs between operational carbon and embodied carbon.

LETI is keen to explore this further and develop a deeper understanding of the design decisions that are taken due to trade offs in whole life carbon, and what the different methodologies that are explored in this paper incentives.

Download the data input spreadsheet here and submit to admin@leti.uk

Your comments

This is an evolving topic, and LETI are interested in your views on this paper. Please submit your comments by emailing admin@leti.uk, and to register your interest to support LETI with further work in this field.

Appendix 1: Work to Date on this Topic

LETI have been tackling the topic of Whole Life Carbon since work started on the LETI Climate Emergency Design Guide and Embodied Carbon Primer in 2019.

SIGNPOST *Climate Emergency Design Guide*

SIGNPOST *Embodied Carbon Primer*

In December 2020 LETI published an opinion piece entitled 'Whole life carbon - Separate or combined targets?' that sought to showcase the differing views of the benefits of a Whole Life Carbon target.

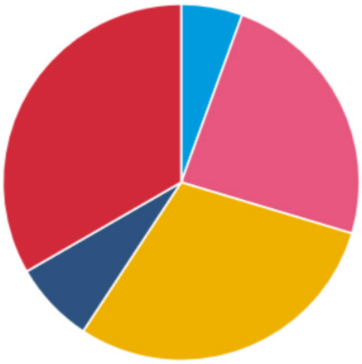
SIGNPOST *Whole Life Carbon - Separate or Combined Targets?*

As part of a consultation that LETI carried out from Nov 2020-Jan 2021, LETI asked consultees to read the 'Whole life carbon - Separate or combined targets?' opinion piece.

The survey asked the following question:
When reporting on Whole Life Carbon the operational energy consumption must be multiplied by a carbon factor to understand the carbon emissions. Section 4.2 outlines various options for carbon factors and appendix 2 shows a worked example of how the carbon factors chosen affect the Whole Life Carbon calculation.

Results are shows opposite, the conclusions was to set up a working group to look at this issues in more detail, which LETI did and this opinion piece is the outcome of this working group.

What Carbon Factors to use for operational energy when assessing Whole Life Carbon



- An average lifetime carbon factor (around 0.05 $kgCO_2$/kWh)
- I don't know / I don't have an opinion
- Other (please specify)
- SAP 10.1 carbon factors
- Stepped carbon factor that uses the average lifetime carbon factor for energy consumption within the zero carbon energy budget and a carbon factor equivalent to electricity produced by a gas turbine for any energy that exceeds the energy budget

Figure A1.1 - 'Whole life carbon - separate or combined targets?' consultation responses

Appendix 2: Workstream Process

A LETI workstream was convened to investigate this issue, the following stages were followed.

Step 1: Exploration

First the group reviewed the previous work that LETI had undertaken on this topic, see Appendix A. Next the group explored and discussed various methods of converting operational energy into carbon, these methods were grouped together as part of Step 2.

Step 2: Methodology refinement

Six sub-workstreams developed the methodologies further exploring their advantages and disadvantages and refining assumptions. The methodologies that each of the sub-workstreams developed are listed opposite.

Sub-Workstream A: Annual total approach - where, either a single factor is applied to the energy consumption (say over 60 years), that represents an average of forecast carbon factors for that time period, or annual factors from a forecast are applied to the annual energy uses projected in each year.

Sub-Workstream B: Hourly approach that rewards energy flexibility - where a different carbon factor for each hour of the year is applied, that depends on the carbon intensity of the grid and promotes peak demand reduction and demand response.

Sub-Workstream C: Split carbon factor - a carbon factor is applied to electricity consumption that meets net zero carbon energy targets, with a higher carbon factor applied to electricity consumption higher than the net zero carbon energy target.

Sub-Workstream D: Varies depending on renewable procurement - a different carbon factor that depends on if the building will use renewable energy or not.

Sub-Workstream E: Embodied carbon of energy infrastructure - an approach that includes the embodied carbon of energy infrastructure.

Sub-Workstream F: Modelling uncertainties – a group that looks at uncertainties around whole life carbon modelling and how to acknowledge this. These uncertainties are applicable to all of the above methodologies. This group proposed uncertainty bookends that illustrated scenarios for no decarbonisation of the UK grid and full decarbonisation of the UK grid.

Sub-Workstream G: Don't bring together – a group within the workstream proposed to not combine metrics and assess embodied carbon and operational energy separately.

Step 3: Voting on Methodologies to Test

Next the workstream voted on the most favourable methodologies that should be brought forward to the 'testing' phase. In the testing phase various design options were tested using a series of case studies, to understand the implications of the methodologies on how the design decision are influenced.

The following methodologies were chosen:

A: Annual approach (looking at both a decarbonised and non decarbonised scenario)

C: Split grid carbon intensity

E: Embodied carbon of energy infrastructure

It was decided that Option B - the hourly approach that rewards energy flexibility, would be refined, tested and developed in a separate study. This is due to the fact that no case studies for design iterations with an interplay between operational energy and embodied carbon were found for which an hourly energy model was available.

For further information on methodologies assessed by each of the sub-workstreams, see Appendix 2.

Step 4: Testing

One of the most important aspects of this study was to understand how the implementation of the carbon conversion methodologies might affect design decision making. Hence the methodologies chosen in step 3 where tested with a variety of case studies.

Step 5: Make recommendations on the methodology that industry should use

This paper proposes a Methodology C: Split Carbon Factor, as outlined in the Executive Summary above This preferred approach was developed through group discussion and consensus building.

More detailed explanation of this process is covered in Section 2, which explores how case studies were used to test the methodologies. Appendix 5, which presents more detail on the voting process within the workstream.

Appendix 3: Methodology Testing

3.1 Case Studies

This section presents a series of case studies, grouped into the following categories, which were collected to test the methodologies proposed by the sub-workstreams.

Fabric – Residential

→ **Case Study 1**: Fabric and Systems
→ **Case Study 4**: Single and Double Glazed Window Options

Fabric – School

→ **Case Study 11**: Single and Double Glazed Window Options

Heating systems options

→ **Case Study 2:** Local Heat Pump and Communal System
→ **Case Study 3**: Heating System for a Terraced House
→ **Case Study 7**: Retrofit Options for a Single Dwelling
→ **Case Study 12**: Heat Pump and Ambient Loop for a Residential Scheme
→ **Case Study 13**: Plant Systems Options

Mechanical ventilation options

→ **Case Study 8a**: Retrofit Heating, Thermal Upgrade and Ventilation Options (Heat Pump)
→ **Case Study 8b**: Retrofit Heating, Thermal Upgrade and Ventilation Options (Gas Boiler replaced)
→ **Case Study 9**: New Build House Heating, Thermal Upgrade and Ventilation Options
→ **Case Study 10**: Retrofit Heating, Thermal Upgrade and Ventilation Options

Embodied Carbon Examples

→ **Case Study 5**: Structural Options Comparison and In Use Energy Comparison
→ **Case Study 6**: Structural Options Comparison

3.2 Methodologies used

The outputs reported in this paper use the following approaches to convert operational energy to carbon. The below descriptions apply to electrical energy use – a static factor for fossil fuel use is utilised for all options. Not all sub-workstreams developed an approach to best tested, as described above.

Method A - Sub-Workstream A
Total Annual Approach: the annual energy use is multiplied by a factor based on a decarbonised grid scenario.

Method C - Sub-Workstream C
Split Carbon Factor: the annual energy use is multiplied by a factor based on a decarbonised grid scenario up to the LETI Net Zero EUI, for energy use beyond this value the current annual average grid carbon factor is assumed (i.e. without decarbonisation).

Method E - Sub-Workstream E
Embodied Carbon of Energy Infrastructure: the embodied carbon of the generation infrastructure is added to the total.

Uncertainty Analysis - Sub- Workstream F
No Decarbonisation: The energy calculation does not take into account future decarbonisation of the electricity grid.

New Build – Electric Gas Turbine: As we don't have enough renewables now, all new build electricity use is reliant on a gas turbine.

Full Decarbonisation: The energy calculation takes into account future decarbonisation of the grid and a decarbonisation is assumed for material replacement in embodied carbon stage B.

3.3 What are the Case Studies trying to assess?

The case studies aim to demonstrate if and where design decisions would be impacted by the methodology chosen:

→ Which is the **lowest carbon**? Does the methodology chosen affect which option has the lowest total carbon?

→ Where is the **magnitude of change** different? Are there situations where an option would appear similar using one methodology and different using another?

Summarised in the list below are situations where the lowest carbon option or magnitude of change varies depending on the methodology chosen.

✓ Decision depends on methodology
✗ Decision unaffected by methodology

Lowest Carbon	Magnitude of Change	
		Fabric – Residential
✓	✓	Case Study 1
✗	✗	Case Study 4
		Fabric – School
✓	✗	Case Study 11
		Heating systems options
✓	✓	Case Study 3
✓	✓	Case Study 7
✗	✗	Case Study 12
✓	✗	Case Study 13
		Mechanical ventilation options
✗	✓	Case Study 8a
✗	✗	Case Study 8b
✗	✗	Case Study 9
✗	✓	Case Study 10

Figure A3.3.1 - Case studies submitted listed against whether the lowest carbon options was affected or the magnitude of change varied, depending on the methodology used

3.4 Example Case Studies

The following pages present analysis of Case Studies received, which demonstrate the design decisions described in the previous section. A full set of Case Studies tested are included in Appendix 4 of this document.

As a workstream we are looking to expand the number of Case Studies tested.

Case Study Call Out

Do you have case studies including design options that test options for both operational energy and embodied carbon? Please get in touch by emailing admin@leti.uk,

Further case studies will help us to develop this work in more detail.

3.4.1 Difference in lowest carbon option

For some of the Case Studies tested, the **lowest carbon option** varied depending on the methodology used. An example is Case Study 12, for which an extract displaying Methods A and C is shown opposite.

This Case Study looked at systems options for a new build residential scheme with variations in both embodied carbon and total energy use.

Option 1 had a lower embodied carbon value than Option 2. Using method A, Option 1 displays the lowest total carbon as the operational carbon values are similar. Using method C, Option 2 gives the lowest total carbon as the methodology calculates the operational carbon to be significantly higher for option 1, which exceeds the embodied carbon savings.

The full output of the tool is shown below, which displays the results from all methodologies tested. A full set of Case Studies is included in Appendix 4.

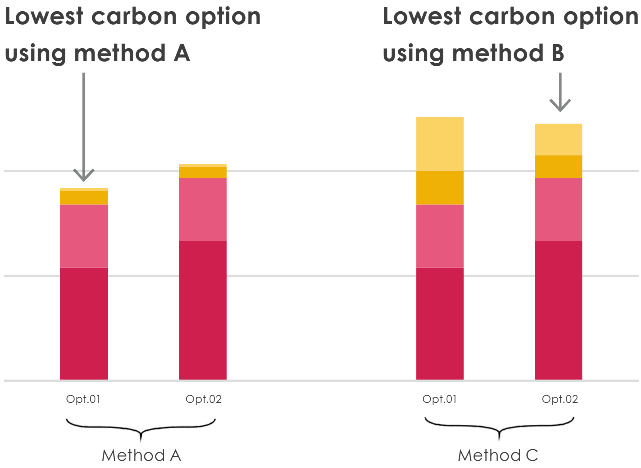


Figure A3.4.1 - Case study 12 output for Methods A and C, illustrating that the lowest carbon option varies is different for each of the two methods

Case Study 12: Systems Options

Communal heat pump and an ambient loop for new build resi

Option 1. Heat pump
Option 2. Ambient Loop

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

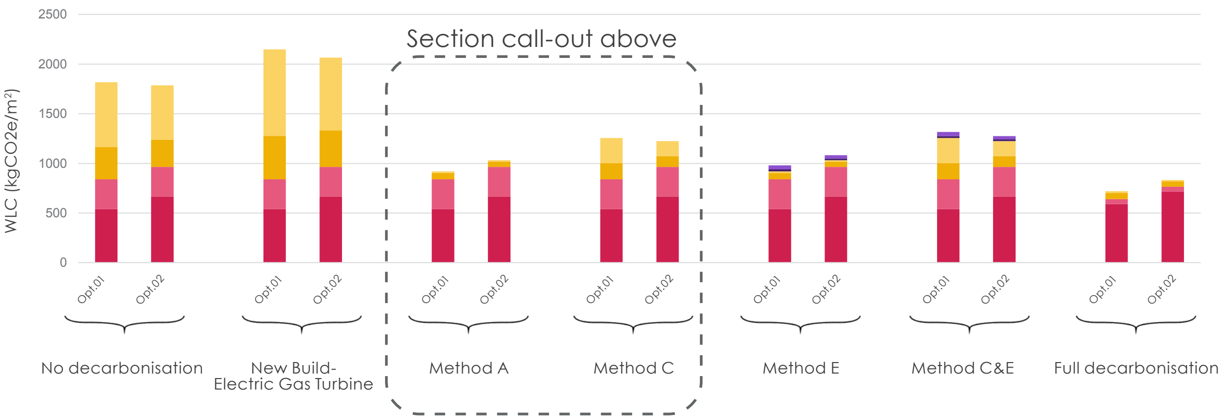


Figure A3.4.2 - Case study 12 outputs for each of the methodologies assessed

2.4.2 Difference in magnitude of change

For some of the Case Studies tested, the **magnitude of change** varied depending on the methodology used. An example is Case Study 2, for which an extract displaying Methods A and C is shown opposite.

This Case Study looked at heating systems options with variations in both embodied carbon and total energy use.

Using method A, Options 1 and 4 appear similar and the choice between them does not appear significant. Using method C, Option 1 gives the lowest total carbon as the methodology calculates the operational carbon to be significantly lower for this option, which would be significant for decision making.

The full output of the tool is shown below, which displays the results from all methodologies tested. A full set of Case Studies is included in Appendix 4.

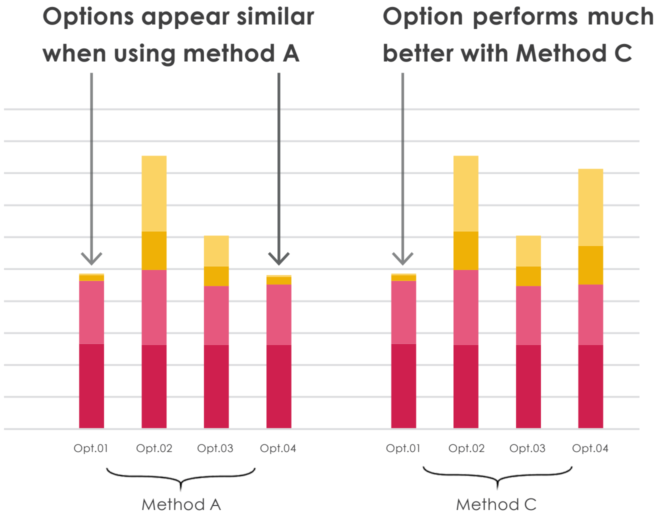


Figure A3.4.1 - Case study 12 output for Methods A and C, illustrating that the magnitude of change varies for each of the two methods

Case Study 2: Heating options appraisal

4th Generation Heat Networks and Individual Heat Pump Options

Option 1. ASHP
Option 2. Communal GB & CHP
Option 3. Communal GB
Option 4. Communal HP

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

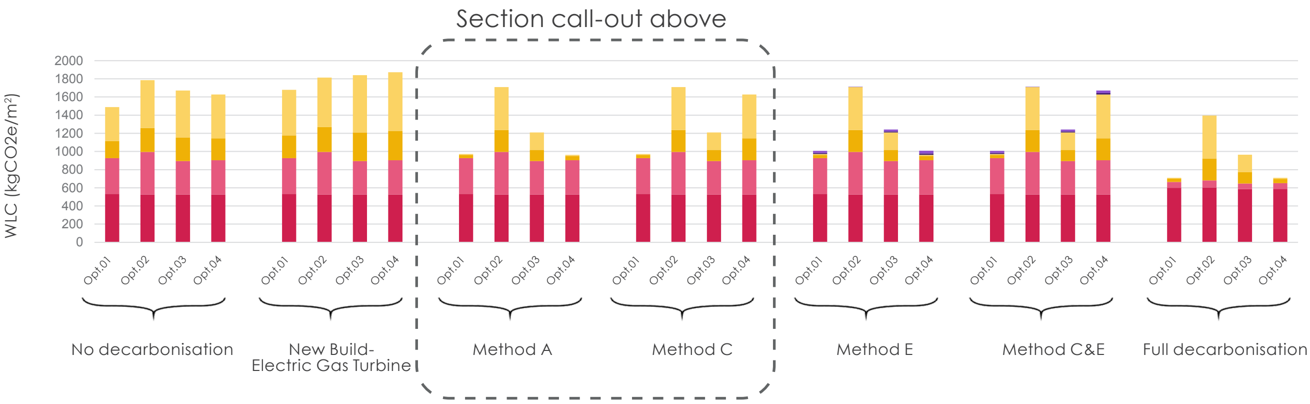


Figure A3.4.2 - Case study 12 outputs for each of the methodologies assessed

2.4.3 All options give the same conclusion

For some of the Case Studies tested, **the lowest carbon option did not vary** depending on the methodology used. An example is Case Study L, for which an extract displaying Methods A and C is shown opposite.

This Case Study looked at design iterations for a new build house. Methods A and C display similar totals and the difference between each option is similar.

Which factors varied in the Case Study generally led to outputs that varied or did not vary. The tool did not display results that varied typically where:

→ the only variable was embodied carbon
→ the only variable was operational energy
→ the iteration contained a marginal difference overall all scenarios met a low EUI target.

The full output of the tool is shown below, which displays the results from all methodologies tested. A full set of Case Studies is included in Appendix 4.

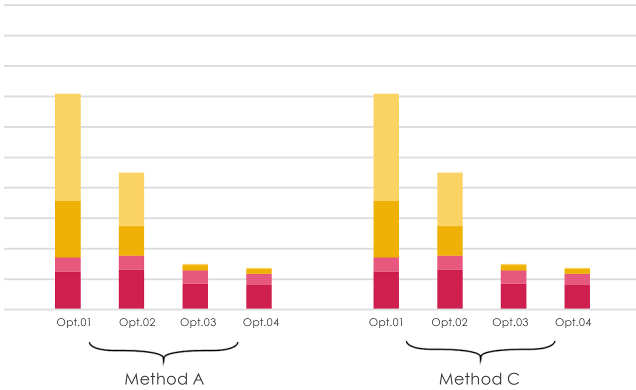


Figure A3.4.1 - Case study 9 output for Methods A and C, illustrating that the lowest carbon option does not vary for each of the two methods

Case Study 9:
Ventilation, Materials and Systems Options

Exploration of options for a new build semi-detached house

Option 1. Business as usual
Option 2. Fabric and Window Upgrades
Option 3. MVHR and Material EC Reductions
Option 4. Option 3 + better MVHR and detailing

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

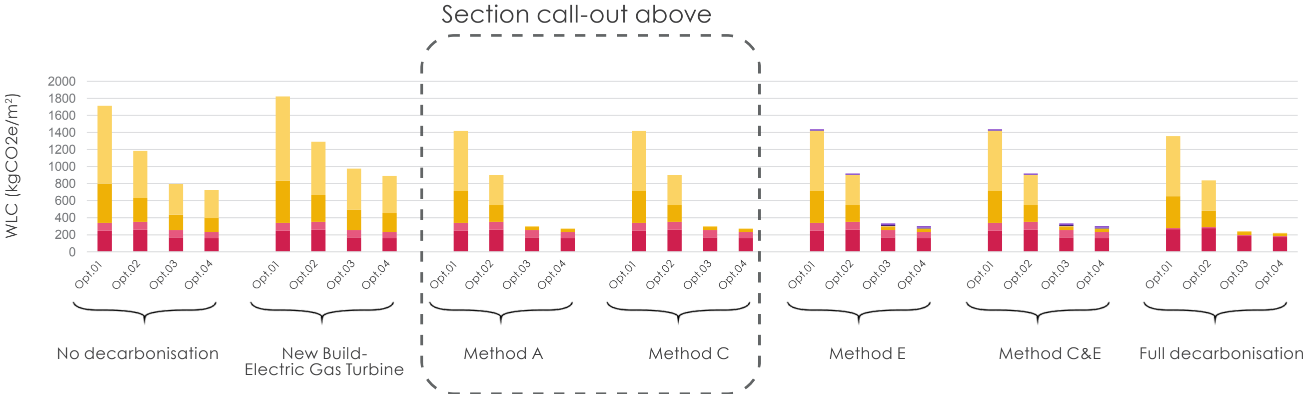


Figure A3.4.2 - Case study 9 outputs for each of the methodologies assessed

Appendix 4: Methodologies Assessed

Various Methods were assessed as part of this study, described in more detail in this section.

A: An annual total approach

Where, either a single factor is applied to the energy consumption (say over 60 years), that represents an average of forecast carbon factors for that time period, or annual factors from a forecast are applied to the annual energy uses projected in each year.

B: An hourly approach

This approach rewards energy flexibility - where a different carbon factors for each hour of the year is applied, that depends on the carbon intensity of the grid and promotes peak demand reduction and demand response.

C: A split grid carbon intensity

A carbon factor is applied to electricity consumption that meet net zero carbon energy targets, with a higher carbon factor that is applied to electricity consumption higher than the net zero carbon energy target.

D: Renewable procurement

A different carbon factors that depends on whether the building will use renewable energy or not.

E: Embodied carbon of energy infrastructure

An approach that includes the embodied carbon of energy infrastructure

F: Modelling uncertainties

A group that looks at uncertainties around whole life carbon modelling and how to acknowledge this.

G: Don't bring operational energy and embodied carbon together

This section describes the opinion that you should not bring operational energy and embodied carbon together when making design decisions.

H: Other ideas considered

This section describes other ideas that were discussed within the workstream.

Appendix 4.1: Option A Annual Approach

Annual Approach

This option takes an annual average approach to estimating operational energy carbon factors utilising published forward forecasts of electricity grid decarbonisation.

An annual average based on past point in time, (e.g. using SAP9/2012 or SAP10.1) should not be used as it is likely to significantly overestimate operational carbon emissions (by a factor of around 40 fold), as the electricity grid decarbonises.

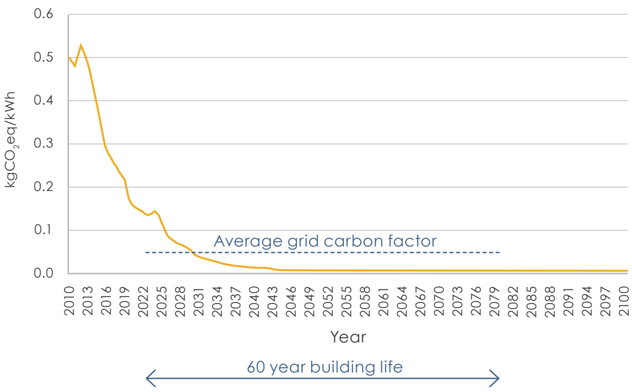


Figure A4.1 - An Annual Approach

Sub-Workstream Proposal

In the UK there are two main sources of data on future projections, the Treasury published Green Book projections and the National Grid ESO Future Energy Scenarios (FES). Both sets of projections show a significantly decarbonising electricity grid but make different assumptions, particularly in the short term.

Forward forecasts should be used and where there are various scenarios, a conservative scenario (e.g. National Grid FES "falling short" (used to be called "steady progression") should be used.

Beyond the end of published forecasts, Carbon factors should flat line and negative figures should be zero'd.

Given the current uncertainty of savings, it is currently believed that carbon capture and storage benefits should not be taken into account. For example, Bio Energy Carbon Capture and Storage (BECCS) solutions contribute to a negative emissions factor (e.g. FES 2021), these should be removed from the overall mix as any negative emissions contributions would go to offsetting other hard-to-abate sectors and the benefit should therefore not be claimed by the built environment sector.

Appendix 4.1: Option A Annual Approach

Benefits of this Approach

→ It is a simple approach and is quick to carry out and explain.
→ Only the annual energy consumption is required, and this is multiplied by a single factor per year (or a single averaged factor for the next 60 or 100 years).

Potential Disadvantages

→ No matter how much energy the building is using, the same carbon factor is applied. Lowering the combined peak demand on the grid and increasing the ability to shift peak loads will need fewer renewables and storage to be built and allow the grid to decarbonise faster and more cost effectively. This method does not incentives lowering the peak demand on the gird.
→ This method does not further incentivise low energy use intensity buildings.
→ Embodied carbon of energy infrastructure is not included.

Appendix 4.2: Option B Hourly Approach

Hourly Approach

The proposal is for an hourly approach to calculating CO2 emissions of operational energy consumption of buildings, that more accurately reflects the carbon content of the electricity consumed at different times. This is crucial for reporting greenhouse gas emissions performance as it recognises the benefits of demand side response and energy storage as mechanisms to reduce emissions today. It encourages investors and developers to deploy batteries and time-switching of demand in new development and existing buildings. These mechanisms are necessary in a zero-carbon energy system predominantly powered by wind, nuclear and solar power. If successfully implemented, this will reduce the transition infrastructure costs, reduce CO_2 emissions faster, be more accurate, and reduce energy bills.

Having an hourly CO_2 emission factor with an hourly energy consumption profile to establish whole life operational carbon, developers and asset managers would be encouraged to install energy storage and utilise demand side technologies to reduce GHG emissions and support the ever-greater integration of intermittent renewable energy as the grid decarbonises.

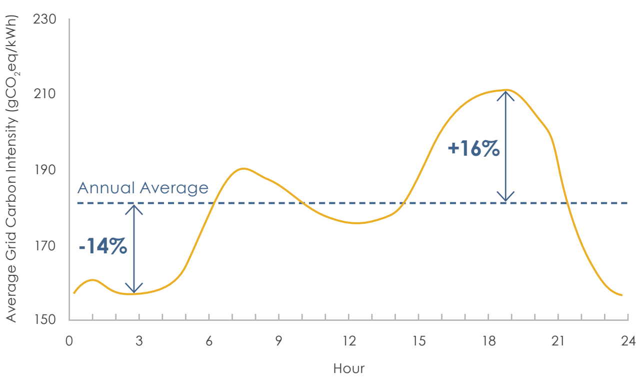


Figure A4.2 - An hourly approach

Sub-Workstream Proposal

To meet electricity demand, the electrical grid requires a mix of generating assets which changes dynamically to ensure the system is balanced. Each of these assets release a different amount of CO2 per kWh of electricity generated. Renewable forms of generation such as wind and solar emit a negligible amount of CO2, whereas fossil fuel based generation such as coal and gas inherently emit CO2 and other greenhouse gases in the power generation process.

This results in a dynamic carbon intensity that fluctuates throughout the day and throughout the year. Analysis of the 2021 carbon emissions intensity on an hourly basis reveals significant variations in grid carbon intensity even during the course of a single day. This is a function of the forecasts of daily demand for electricity and the available energy source to meet this demand.

The revised National Calculation Methodology which underpins the UK Building Regulations Part L 2021 came in effect in June 2022 to change the annual average carbon factor to a monthly resolution. This is an acknowledgement that there is significant seasonal variation in the carbon content of electricity. Whilst this is a welcome and necessary step to improve accuracy in appraising the carbon impact of buildings, further variation in carbon content is also present on an hourly basis. However, development of the monthly profiles in SAP 10.2 is required to reflect variations based on current energy generation mix.

In the half-hourly plot of UK carbon intensity in 2019 (Figure A2.2), daily peak intensity can be double the daily average. A seasonal variation in intensity can also be observed whereby lower carbon emissions are seen during the summer months.

Appendix 4.2: Option B Hourly Approach

Understanding this resolution of carbon intensity offers the opportunity to design and manage buildings that shift demand to periods of low carbon intensity.

Carbon accounting/calculation methodologies which use annual averages currently do not reward such approaches. Perversely, they show energy storage technologies increasing emissions, because of the losses in storage. Within whole life carbon assessment, storage and demand response systems also have associated embodied carbon emissions, however existing guidance and calculation methods do not account for the emissions benefit of demand side management.

This issue becomes more important as we increasingly electrify heating and transport and increase the percentage of energy that comes from intermittent renewable energy sources. It is imperative that we recognise the benefit of energy storage and demand reduction/increases from the system.

Further information on the benefits and drivers for an hourly resolution of carbon emission factors can be found in a WSP report titled: The big net zero challenge: real-time CO_2 emissions and demand side response within section 4.0 of the LETI Climate Emergency Design Guide.

SIGNPOST *Climate Emergency Design Guide*

Benefits of this Approach

Understanding this resolution of carbon intensity offers the opportunity to design and manage buildings that shift demand to periods of low carbon intensity.

This method also enables closer alignment of the design estimates with the real carbon emissions in operation.

Potential Disadvantages

Projecting Emission Factors

To forecast over a whole lifetime would require projection of the grid, hourly, as it decarbonises. One answer would be to continue to use the same shape of emissions and just reduce them in line with projections. The exact mix and ratio of sources in the future is uncertain, however, and therefore a method of estimating it would be required. The National Grid ESO have been contacted to understand the potential of forecasting future emissions within their hourly carbon emission model.

Regional Factors

Another issue to consider is if regional factors are of relevance, with the different mix of generation in different areas varying the carbon factor generated. E.g. increased wind generation in Scotland consistently yields lower emissions factors than in Wales.

Appendix 4.3: Option C Split carbon Factor

Split Carbon Factor

Method C looks to use a split grid carbon intensity factor depending on whether or not the project meets the LETI EUI and other net zero grid features. This sub-workstream explored the following:

1. **An approach that rewards buildings that are aligned with meeting the energy budgets required to meet our climate targets.**
2. **Looking to the future of a zero carbon grid: we need to be designing buildings that work with a fully decarbonised grid. WLC may not be a suitable means to achieve this.**

The methods explored looked at solutions that have built upon the principles of these ideas, looking for solutions that:

→ Treat portions of the operational energy consumption differently, depending on whether the Operational Energy use is in line with the LETI EUI targets.

→ Treat buildings differently depending on how they will react to and enable the Net Zero grid transformation.

The solution proposed for method C aims to recognise that buildings must adapt in order for the grid to decarbonise. This solution is built upon verified third party data, with any interpretation or calculation being transparent and logical.

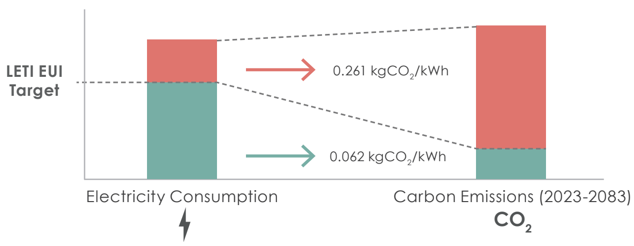


Figure A4.3 - A split carbon factor

Sub-Workstream Proposal

Depending on the project's EUI, the project is able to use a decarbonised factor:

→ The project is able to use a decarbonised carbon conversion factor for the portion of Operational Energy up to the LETI EUI target*.

→ The remaining Operational Energy use above the relevant LETI EUI target is converted using the most recent carbon intensity factor from DUKES "table 5.14" (e.g. for projects designed between August 2022 and July 2023, projects should use 262g/kWh for the share above the LETI EUI target).

*for Offices LETI suggest that a DEC B40 or a NABERS 6 star rating is equivalent to a the LETI EUI.

LETI Energy Use Intensity (EUI) Targets

In 2020 LETI published EUI targets. These targets represent the energy consumption that all buildings of that sector need to achieve in order for our climate targets to be met. A 'top-down' study of estimated future UK renewable energy generation is cross referenced with a 'bottom-up' analysis of best practice design strategies for each building type. Whilst the 'bottom-up' approach focuses on 'the art of the possible', the 'top-down' modelling looks beyond the building boundary to what is likely to occur on a national scale — it effectively establishes a 'budget' for our energy demand based on renewable energy that will be available in 2030 and 2050.

For more information see LETI Climate Emergency Design guide

Appendix 4.3: Option C Split carbon Factor

Benefits of this Approach

→ Reduced performance gap across decarbonised figures over the life of the project as the forecast is effectively 'weighted' based on the likelihood that the decarbonisation forecast is achieved: if every building exceeded the EUIs significantly, the grid wouldn't decarbonise as fast as the decarbonisation forecasts suggest.

→ By applying the decarbonised factor up to the LETI EUI threshold (a bit like income tax) the calculation is smooth for projects that might be over the threshold but very close. There's no potential cliff effect at the LETI EUI, which makes reporting easier to understand and more robust

→ The method is transparent: government's own factors are used without interpretation.

→ Avoids over-optimism of the benefits of forecasted grid decarbonisation, which may lead to design choices that don't support decarbonisation of the wider grid system.

→ The calculation is simple.

→ Agile: responds to the Government's annual carbon reporting factors.

Potential Disadvantages

→ Projects that don't hit the LETI EUIs are still rewarded up to the LETI EUI limit.

→ Currently there are only EUI limits for residential, offices and schools. So this method is only relevant for these typologies. Although it is important to note that in UK Net Zero Carbon Buildings Standard is developing EUI limits for other typologies that are in line with meeting a maximum 1.5 degree temperature rise.

→ Doesn't look more broadly than EUI targets. The workstream considered ways to reward other initiatives like active demand response but concluded that at this stage it became too complex trying to map the level of active demand response in each of the decarbonisation pathways to building-specific initiatives. This is being looked into further in method B.

→ Assumes that the grid won't re-carbonise.

Appendix 4.4: Option D Renewable Procurement

Renewable Procurement

In whole life carbon calculations, consultants typically assume that there are no carbon emissions associated with on-site renewable energy usage e.g. photovoltaic (PV) panels, and then use the decarbonised grid values for all electricity that is used from the grid, regardless of whether it is renewably procured or not (Option A).

This sub-workstream explored assigning different carbon factors depending on the source of the energy procured that is not client owned and generated on-site. Different carbon factors were applied to different energy sources, including on-site Power Purchase Agreements (PPA), off-site PPAs, green tariffs and non-renewable energy sources.

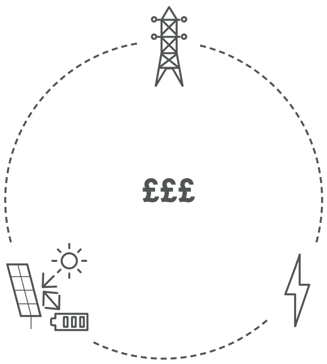


Figure A4.4 - Renewable procurement

Sub-Workstream Proposal

The carbon factor used for on-site client owned renewable energy is 0 kg/kWh. Beyond on-site client owned renewable energy, any renewable energy procured from Power Purchase Agreements (PPA) or green tariffs were also assigned 0 kg/kWh. However, any non-renewable energy sources were assigned 198 g/kWh (the residual fuel mix overall average carbon dioxide emissions, taken from "Fuel mix disclosure data table, August 2022" [15]). It is important to note the definition used for renewable procured electricity is electricity that meets the guidance set out in the UKGBC Renewable Energy Procurement and Carbon Offsetting Guidance for Net Zero Carbon Buildings.

As renewable energy has already been factored in, and to prevent double counting, for any non-renewable procured energy the overall average carbon dioxide emissions in the residual fuel mix has been used in the proposed carbon calculation. The residual fuel mix was deemed appropriate as it is used for the instances when electricity suppliers cannot evidence the source of the energy, e.g. via Renewable Energy Guarantees of Origin (REGO) certificates, for fuel mix disclosure as per The Office of Gas and Electricity Markets (Ofgem) guidelines. For comparison, in 2021/22 the residual fuel mix consisted of 2.7 % renewable energy, compared to the UK fuel mix value of 38.7 %. [15]

Appendix 4.4: Option D Renewable Procurement

Benefits of this Approach

→ For the sub-workstream D proposal, a building will only receive benefits if it uses renewable energy. This proposal would increase demand for procured renewable energy such as via PPAs. The increased demand for renewable energy would increase competition between energy suppliers and drive them to increase investment into renewables.

→ The sub-workstream D proposal empowers clients for whom capital expenditure (CapEx) in renewable energy would only be financially feasible in the long term, and enables them to reduce their carbon emissions reporting instantly by utilising renewably procured energy e.g. via PPAs. Renewably procured energy can enable clients to utilise and support renewable energy suppliers without the CapEx of onsite renewables.

Potential Disadvantages

→ For many clients, the significant CapEx required to own on-site renewable energy may not be conducive to their objectives which may include driving down CapEx. There is also significant operational expenditure (OpEx) involved in maintaining on-site renewable energy sources e.g. cleaning and replacing PV panels.

→ The sub-workstream D proposal does not particularly incentivise low-energy buildings or reducing operational energy. Reducing the energy needs of a building will only reduce the total carbon emissions in line with the carbon value of the energy supply.

→ This reporting method may encourage large scale clients to choose PPAs over investing in on-site renewables, where they otherwise may be better placed to invest in on-site client owned renewables compared to smaller scale clients. This may impact overall investment into renewable energy sources and their and availability.

Conclusion

This proposal encourages clients to utilise renewably procured energy e.g. via PPAs, where the typical use of decarbonised grid values does not. However, if the carbon associated with the operational energy of on-site renewables is considered equal to that of renewably procured energy e.g. via PPAs, then there is reduced incentive to include on-site renewables in building designs that would increase CapEx. If this proposal were to be considered for case study testing, any potential disadvantages should be considered.

This approach is relevant to carbon accounting that is completed on an annual basis (the previous 12 months) for assessing the annual carbon emissions of a building that is in operation (Whole Life Carbon Assessment Reason 5 in section 1.3)

It was determined that for this paper this proposal would not be brought forward to the case study testing, as this paper is focusing on methods to be used for making design decisions at the design stage rather than annual carbon accounting.

Appendix 4.5: Option E Embodied carbon of energy infrastructure

Infrastructure Emissions

Most whole life carbon calculations do not include the embodied carbon of energy infrastructure. The embodied carbon of energy infrastructure refers to:

Electricity:

→ **Generation**: The embodied carbon associated with the infrastructure of the power station where the electricity is generated as well as the infrastructure needed to extract and distribute the fuel used to create the electricity. For renewable energy this includes the embodied carbon of creating solar PV panels and wind turbines.

→ **Distribution**: The embodied carbon associated with electricity distribution network, (i.e. the pylons, transformers, cables etc.) as well as the storage facilities, for example pumped storage such as hydro dams.

Gas:

→ **Generation**: The embodied carbon associated with the infrastructure required to extract the natural gas from the sea (offshore) or the land as well as the processing plant used to clean raw natural gas.

→ **Distribution**: The embodied carbon associated with the gas pipelines and infrastructure required for storage.

It is important to note that the softwares Ecoinvent and Gabbi do include embodied carbon of infrastructure. Ecoinvent includes the embodied carbon of generation for renewable sources of electricity, with an option to include for other sources of energy, as well as the embodied carbon associated with electricity distribution. Gabi includes the embodied carbon of renewable energy generation.

Embodied carbon impact of energy generation

The graph below shows the lifecycle carbon emission of various energy supply technologies. For coal and gas the embodied carbon of energy generation is insignificant compared to the direct emissions. Interestingly the embodied carbon of renewables such as biomass, solar and wind has higher embodied carbon than coal or gas (although lower lifecycle carbon).

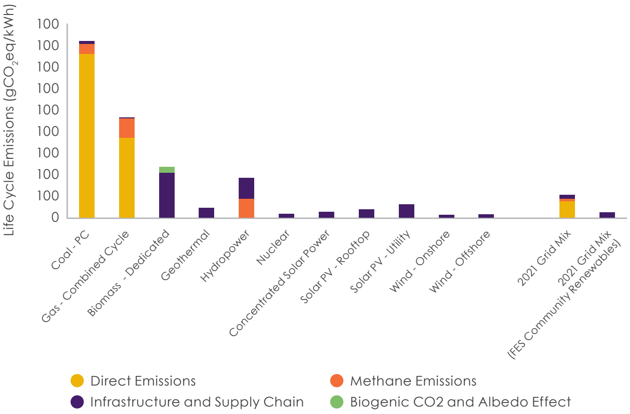


Figure A4.5.1 - Lifecycle Emissions of Electricity Supply

As the UK Electricity grid decarbonises the embodied carbon will become more significant. For 2021 grid emissions, 18% of the lifecycle emissions are associated with embodied carbon (19gCO2e/kWh). By 2050 these emissions are predicted to be 96% of emissions associated with the electricity grid (26gCO2e/kWh).

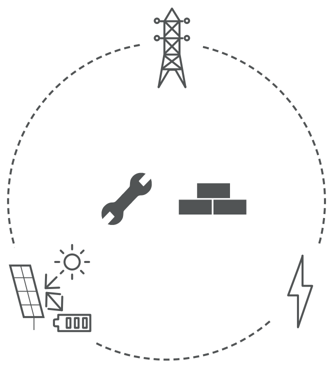


Figure A4.5.2 - Embodied carbon of energy infrastructure

Appendix 4.5: Option E Embodied carbon of energy infrastructure

Embodied carbon impact of energy distribution?

No data was found on the embodied carbon impact of energy distribution. If you are aware of this data, then please contact LETI at admin@leti.uk.

Calculating the embodied carbon of energy generation

The Intergovernmental Panel on Climate Change (IPCC) reports have information on the embodied carbon of various types of energy supply technology. There is also a Nature Energy paper 'Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling' that has some data on embodied carbon of energy supply technology.

The embodied carbon impact is related to both the kW of electricity that the building requires and when it is required, so ideally the embodied carbon of energy infrastructure should relate to this. Due to the fact that the embodied carbon data is per kWh, and that the estimated kWh of energy use is simpler to calculate, it is suggested that embodied carbon of energy infrastructure is assigned based on the kWh of energy use, as part of module B6.

Benefits of this Approach

→ The impact of whole life carbon emissions related to energy use is more fully understood and accounted for.

→ The carbon emissions associated with energy consumption (B6) increases, and includes a fuller picture of carbon emissions.

Potential Disadvantages

→ Available data presents a range of values which could lead to different conclusions.

→ If boundaries are not clearly defined, this approach risks double counting of GHG emissions.

Next Steps

Based on the mass of materials in energy distribution, and the high carbon intensity of these materials, it is assumed that the embodied carbon related to energy distribution is significant. This should be understood and then included in the calculation.

Appendix 4.6: Option F Modelling Uncertainties

Modelling Uncertainties

The uncertainty sub-workstream looked at how to understand uncertainty with Whole life carbon assessments, and thus how best to interpret results.

The key questions at design stage is 'is it beneficial, in WLC terms to do X to deliver Y?'. For example, if more insulation is added, the embodied carbon will increase and the operational carbon will decrease, but which solution has the lowest whole life carbon? Examples of uncertainties are listed below:

Operational carbon:

- → Occupancy and usage profiles
- → Heating and cooling set-points
- → Unregulated loads usage
- → Performance gap
- → Grid decarbonisation
- → Climate variability
- → Replacement of building services equipment over the life of the project may have significant impact on the operational energy performance

Embodied carbon:

- → Generic vs. specific data
- → Quantities different at design stage to what was constructed
- → Product specific embodied carbon is not available for all product, so often similar product/ proxy data is used. Thus the actual embodied carbon coefficient for the products are different.
- → Different products are procured at construction stage than specified, leading to different embodied carbon
- → For scenarios where embodied carbon is decarbonised, the supply chain decarbonisation is uncertain

Both operational carbon and embodied carbon:

- → Building maintenance, replacement rates of components and materials
- → Change of use during building's lifespan
- → Earlier than planned end-of-life

Recommendations

At design stage acknowledge uncertainties and 'stress test' the model. This is commonly already carried out with energy modelling, but less so with embodied carbon analysis. Various operational energy performance modelling approaches already advocate for this. CIBSE TM54 through high, medium and low scenario testing. NABERs requires off-axis scenario testing.

Reduce uncertainties through:

Short term
(i.e. within the assessment itself)
Operational Energy modelling:

- → Create bespoke, occupancy and user profiles that are agreed with the client/ building users, to represent the likely scenarios.

Embodied carbon modelling:

- → Fully understand the building to ensure all construction elements that are in the scope are included. Where not all elements are designed (for example shell & core) appropriate assumptions must be made.
- → Use product specific data where possible

Long term
(i.e. changes that need to be made within the industry)
Measure building performance after 1 year and 3 years, to validate energy model and put right any issues, i.e. mandate Building Performance Evaluation (BPE).

Appendix 4.6: Option F Modelling Uncertainties

Key Take Aways

→ When bringing together Operational Carbon and Embodied Carbon to scrutinise and understand Embodied Carbon and Operational Energy trade-offs, a key consideration is the decarbonisation of the electricity grid.

→ This sub-workstream recommends looking at various decarbonisation scenarios e.g. a decarbonised and a non decarbonised scenario when making design decisions.

→ Whole life carbon analysis is typically carried out for 60 years. There is much more certainty for the parts of the assessment that are in the first 5,10,20 years than the last 40 years.

→ In the case study testing, the bar charts show the first 20 years of operational and embodied carbon separately to the last 40 years.

→ Verification of net-zero / WLC claims can only be completed / verified once the building is in-use and its performance is proven. There needs to be recognition of this in any modelling of operational emissions in relation to WLC.

Appendix 4.7: Option G
The case for separate metrics

Don't bring operational energy and embodied carbon together

This section makes the case for not bringing operational energy and embodied carbon together.

Converting energy to carbon in future scenarios is subject to risk/uncertainty. There is no industry consensus on how this is calculated, even if there was consensus this is likely to change continuously over the next ten years. We cannot predict exactly how the carbon intensity of the grid will vary hour to hour, year to year over the next 60 years. In contrast, a 1kW heat source used for 1 hour, will use 1kWh now and in 2050. Operational efficiency should thus be tracked in energy, not carbon, and not mixed with embodied emissions which will mostly be calculated using today's carbon factors.

We need metrics that are verifiable by measurements today.

It is better to keep them separate as there is a false equivalence between scope 3 embodied carbon incurred "today" and scopes 1 and 2 operational carbon over next 60 years - both due to scope and climate impact from residence time in atmosphere. Achieving energy efficient operation is paramount to enabling grids to decarbonise (the Paris-proof concept), otherwise we will always be running to keep still on renewables capacity and operational carbon will not drop away in future like the Green Book shows.

Appendix 4.8: Option H Other Ideas Considered

Other Ideas Considered

The notes below are a collection of other ideas considered by workstreams, or discussed at workstream meetings. This section is primarily for others that are doing work in this field, that were not part of the LETI workstream, to provide a record of ideas that could potentially be developed further.

Sub-Workstream C

An alternative idea for the carbon conversion factor for electricity above the EUI targets was to apply the peak annual hourly grid carbon factor from the previous year, available from here: https://carbonintensity.org.uk. For projects designed in 2021 that would be a carbon factor of approximately 0.371kg/kWh applied to the portion of energy above the EUI target. This would have the benefit of reflecting a grid that does re-carbonise due to increased demand, from buildings that exceed the EUI targets. Whilst this approach has a lot of merit, ultimately the decision was made to prioritise the alternative approach as only 31 days of data can be downloaded at a time, which posed a barrier to the uptake of this approach. The website is also privately hosted which means there is a risk of data becoming unavailable in future is higher than referencing the government's own data.

Looking beyond just the EUI target, we considered mapping the grid decarbonisation factor forecast to different FES scenarios depending on other features in the project design. For example, projects without active demand response would refer to the 'Steady Progression' scenario, whereas projects with demand response, onsite renewables etc., would refer to a more aggressive decarbonisation factor pathway. This idea was dismissed because of the difficulty in mapping project features to the FES scenarios with precision; ultimately it was agreed this is a very complex approach.

Within Workstream Meetings

A shorter (20yr) accounting period would be beneficial because carbon that we can save now is worth more than carbon we could save in the future.
Using a location based carbon factor: location based energy demand uses local grid renewable infrastructure. Development in geographies with high carbon grid encourages maximising on site renewables.

To address the tension between embodied carbon and operational energy performance in retrofits, an option could be to set linked building level embodied carbon and operational energy targets: the higher the embodied carbon, the more stringent the operational energy efficiency threshold. For example for offices, EC<100 kgCO2/m2 gets a 4.5 stars NABERS UK target, 100-250 kgCO2/m2 gets 5 stars, 250-400 kgCO2/m2 gets 5.5 stars and > 400 kgCO2/m2 gets 6 stars.

The analysis of WLC seems to focus on balancing the EC and EUI outcome for a project, drawing the system boundary at the project level. There is a concern that it should also weigh up the cost and EC of a kWh avoided (by further energy efficiency measures, etc) against the cost and EC of an extra kWh generated (by wind, solar, nuclear, green H2 production and storage, etc). Expenditure on additional renewable supply capacity potentially may be a better use of EC and capex budgets to 2050 and beyond than a deeper refurbishment of all existing buildings.

References to embodied carbon decarbonisation and what is included in the infrastructure embodied carbon may need to be clarified (i.e. is the road going to the new solar farm included).

Appendix 5: Upstream Emissions

CIBSE LETI FAQs

This paper does not go into the details of the upstream carbon emissions that need to be included in the calculations, these will be included in the tool provided with this paper. Information on upstream emissions can be found in the CIBSE LETI FAQs.

SIGNPOST *CIBSE LETI FAQs*

Appendix 6: Case Studies

List of Case Studies by Type

This section lists the case studies numerically, starting with Case Study 1. The below list groups these case study by category, for ease of reference.

Fabric – Residential

→ **Case Study 1**: Fabric and Systems
→ **Case Study 4**: Single and Double Glazed Window Options

Fabric – School

→ **Case Study 11**: Double or Triple Glazed Window Options

Heating systems options

→ **Case Study 2:** Local Heat Pump and Communal System
→ **Case Study 3**: Heating System for a Terraced House
→ **Case Study 7**: Retrofit Options for a Single Dwelling
→ **Case Study 12**: Heat Pump and Ambient Loop for a Residential Scheme

Mechanical ventilation options

→ **Case Study 8a**: Retrofit Heating, Thermal Upgrade and Ventilation Options (Heat Pump)
→ **Case Study 8b**: Retrofit Heating, Thermal Upgrade and Ventilation Options (Gas Boiler replaced)
→ **Case Study 9**: New Build House Heating, Thermal Upgrade and Ventilation Options
→ **Case Study 10**: Retrofit Heating, Thermal Upgrade and Ventilation Options
→ **Case Study 13**: Plant Systems Options

Embodied Carbon Examples

→ **Case Study 5**: Structural Options Comparison and In Use Energy Comparison
→ **Case Study 6**: Structural Options Comparison

Case Study 1:
Fabric and systems

Fabric and systems options for a new build residential scheme

Option 1. Business as Usual Fabric and Heat Pump
Option 2. Ultra Low Energy and Heat Pump
Option 3. Ultra Low Energy and Direct Electric

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

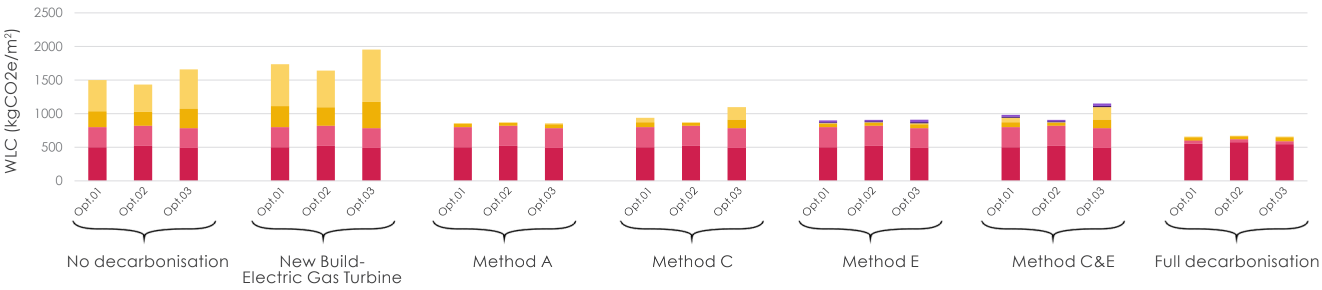


Figure A6.1 - Case study 1 outputs for each of the methodologies assessed

Case Study 2:
Heating options appraisal

4th Generation Heat Networks and Individual Heat Pump Options

Option 1. ASHP
Option 2. Communal GB & CHP
Option 3. Communal GB
Option 4. Communal HP

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

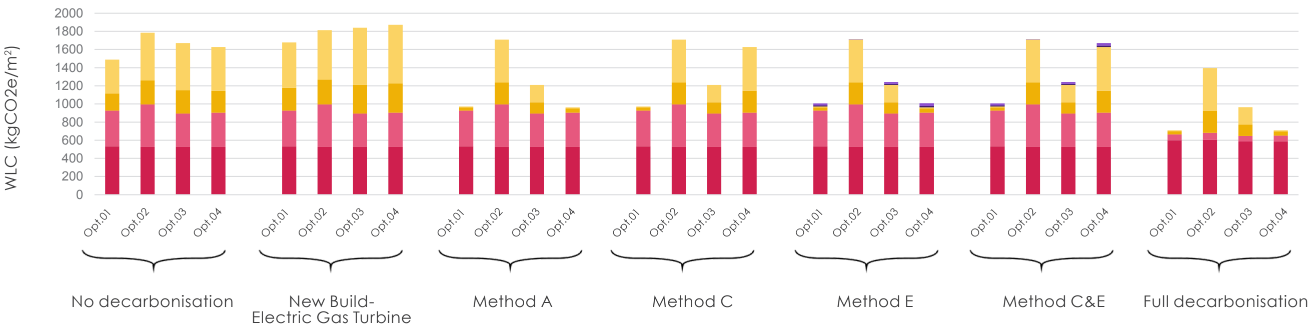


Figure 6.2 - Case study 2 outputs for each of the methodologies assessed

Case Study 3:
Heating Systems Options

Fabric and systems options for a new build terraced house

Option 1. Gas Boiler
Option 2. Direct Electric
Option 3. Air Source Heat Pump

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

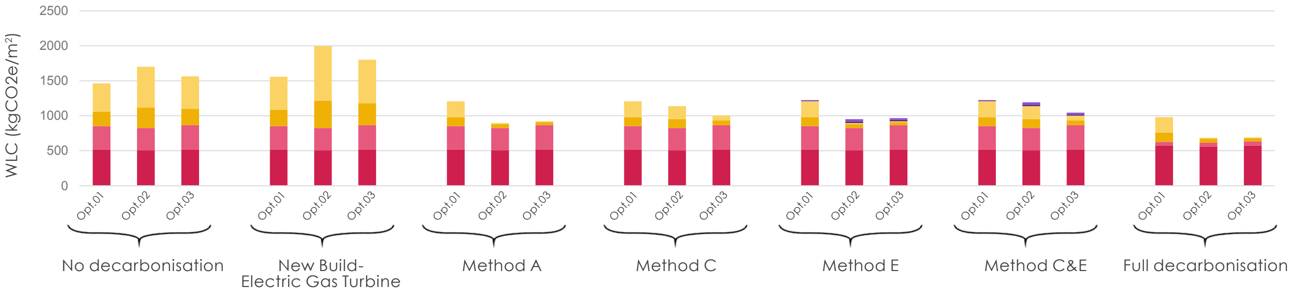


Figure A6.3 - Case study 3 outputs for each of the methodologies assessed

Case Study 4:
Glazing Options (compliance energy modelling only)

Double and triple glazed window options (hypothetical scheme)

Option 1. DG - Glasgow
Option 2. TG - Glasgow
Option 3. DG - London
Option 4. TG - London

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

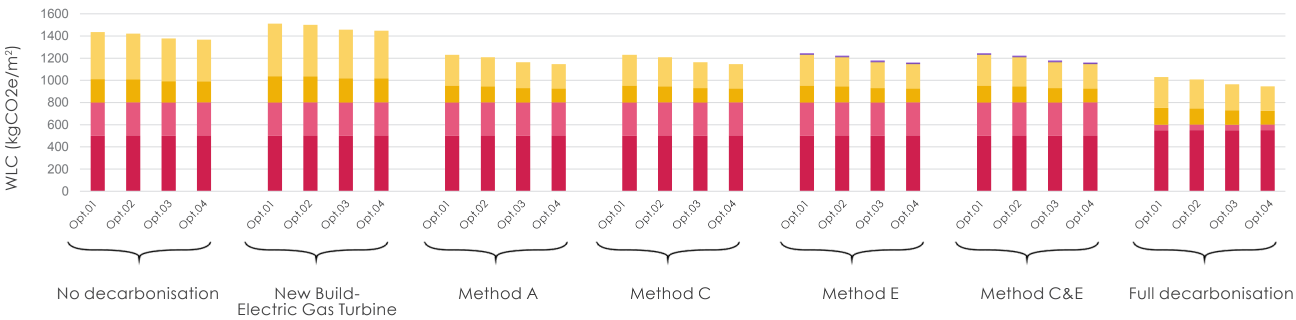


Figure 6.4 - Case study 4 outputs for each of the methodologies assessed

Case Study 5: Structural Options

Exploration of structural options for a new-build residential scheme

Option 1. CLT Frame
Option 2. LGSF

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

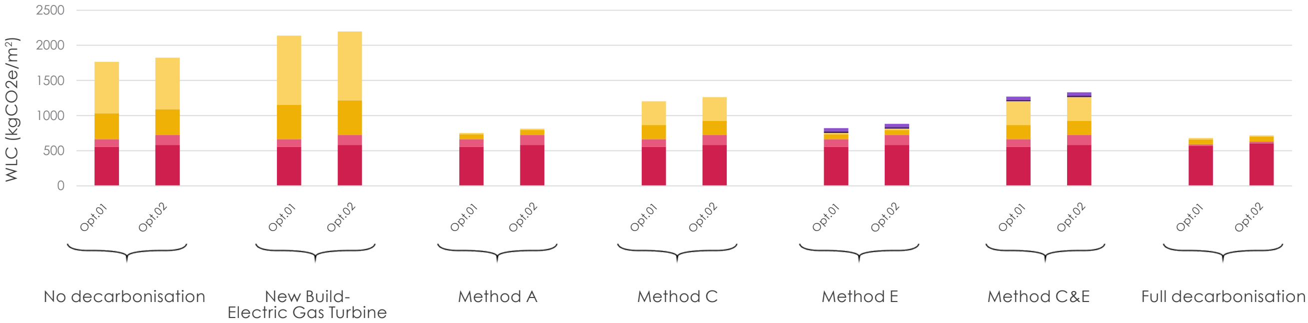


Figure A6.5 - Case study 5 outputs for each of the methodologies assessed

Case Study 6: Structural and In-Use Options

Exploration of structural options and in-use options for a school

Option 1. Stage 3 Concrete Frame
Option 2. Stage 3 CLT Frame
Option 3. As Built (Half Occupation)
Option 4: As Built (Full Occupation)

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

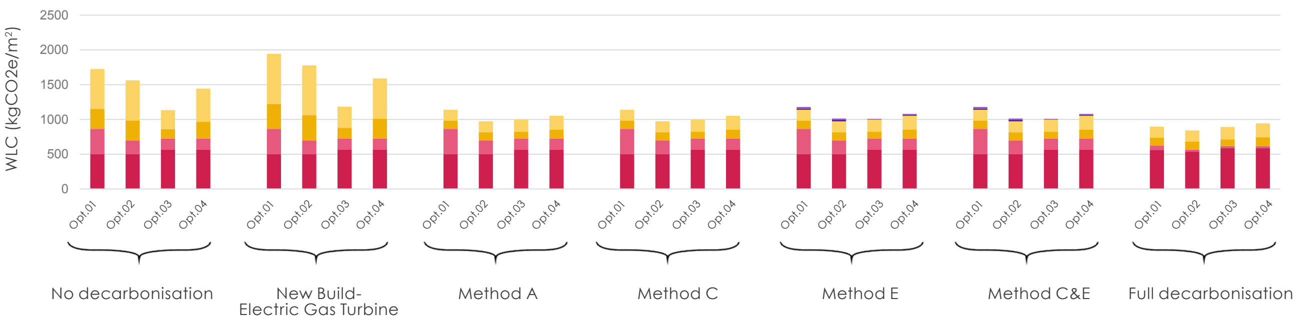


Figure 6.6 - Case study 6 outputs for each of the methodologies assessed

Case Study 7:
Heating Systems

Exploration of heating systems options for a retrofit of a single house

Option 1. ASHP and HW
Option 2.Direct Electric and HW
Option 3. BAU – Gas Boiler

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

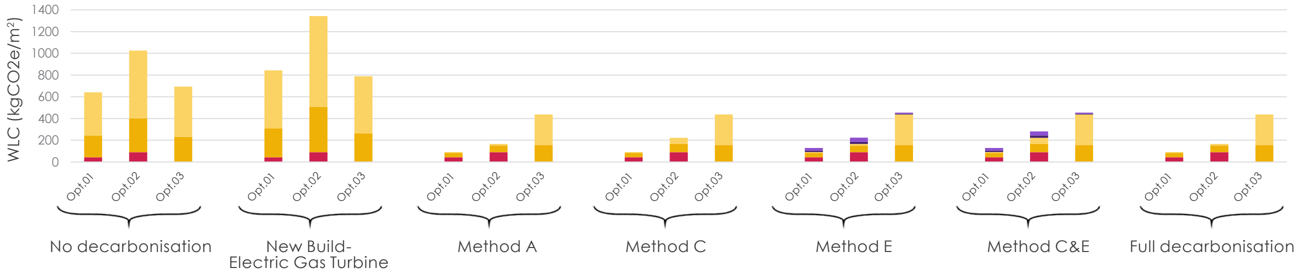


Figure A6.7 - Case study 7 outputs for each of the methodologies assessed

Case Study 8a:
Ventilation, Materials and Systems Options

Design options for a retrofit of a single house

Option 1. Existing Building
Option 2. Conventional Retrofit with Heat Pump
Option 3. Traditional Materials Retrofit with Heat Pump
Option 4. Traditional Materials Retrofit with Heat Pump + MVHR

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

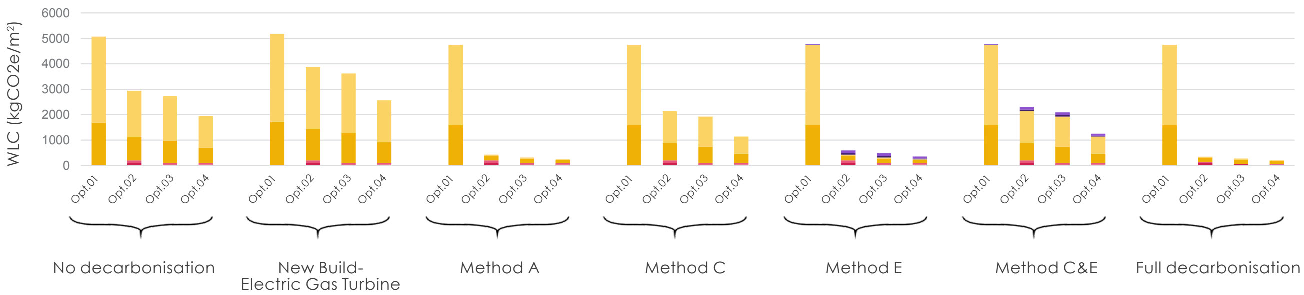


Figure 6.8a - Case study 8a outputs for each of the methodologies assessed

Case Study 8b:
Ventilation, Materials and Systems Options – Gas Boiler

Design options for a retrofit of a single house

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

Option 1. Existing Building
Option 2. Conventional Retrofit (new boiler)
Option 3. Traditional Materials Retrofit (new boiler)
Option 4. Option 3 + MVHR

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

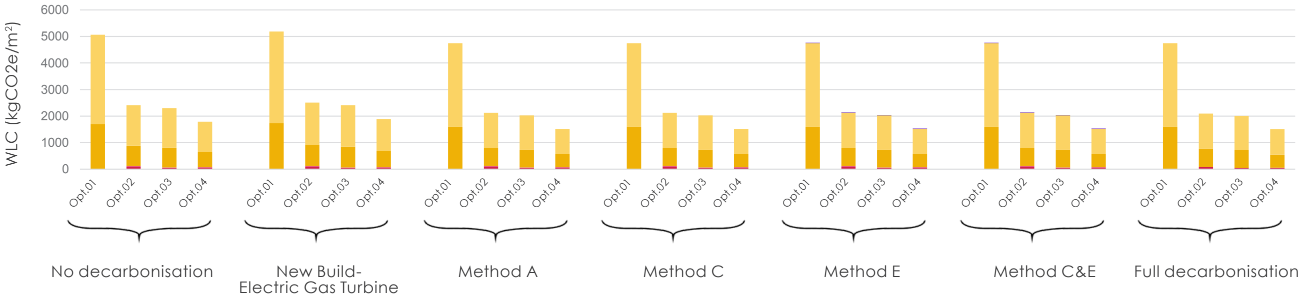


Figure A6.8b - Case study 8b outputs for each of the methodologies assessed

Case Study 9:
Ventilation, Materials and Systems Options

Exploration of options for a new build semi-detached house

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

Option 1. Business as usual
Option 2. Fabric and Window Upgrades
Option 3. MVHR and Material EC Reductions
Option 4. Option 3 + better MVHR and detailing

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

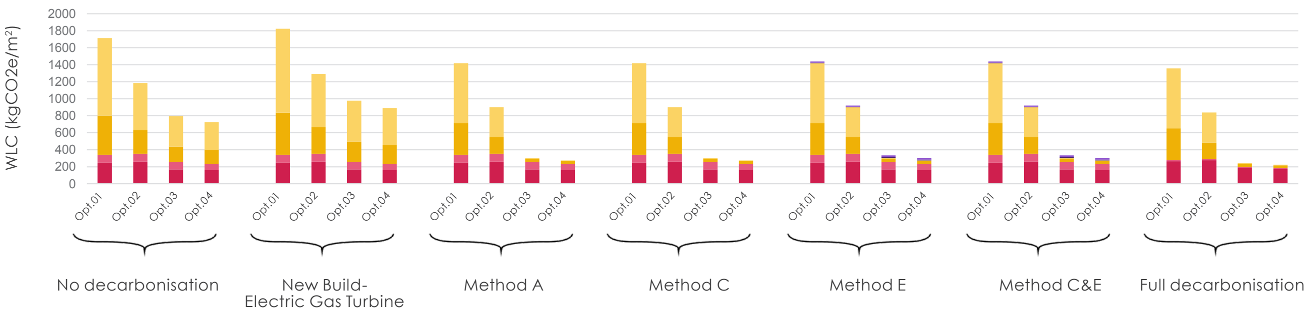


Figure 6.9 - Case study 9 outputs for each of the methodologies assessed

Case Study 10:
Ventilation, Materials and Systems Options

Design options for a new build apartment

Option 1. Business as usual
Option 2. Fabric and Window Upgrades
Option 3. MVHR and Material EC Reductions
Option 4. Option 3 + better MVHR and detailing

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

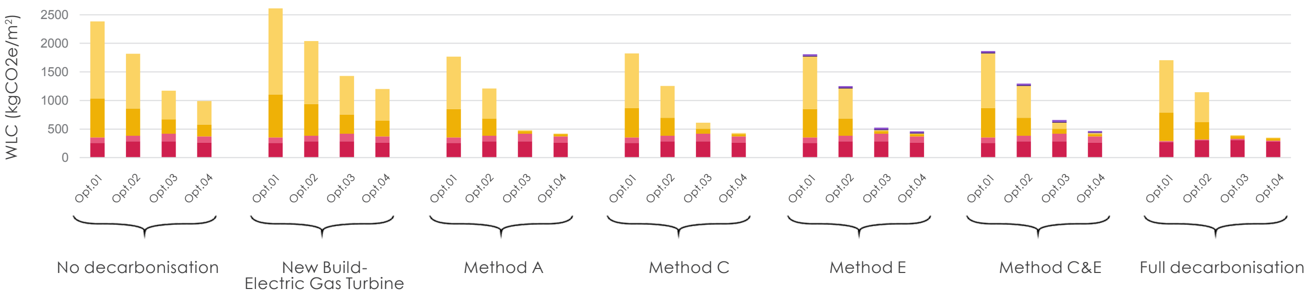


Figure A6.10 - Case study 10 outputs for each of the methodologies assessed

Case Study 11:
Double and Triple Glazed Window Options

Double and triple glazed window comparison for a new build school

Option 1. Double Glazed
Option 2. Triple Glazed

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

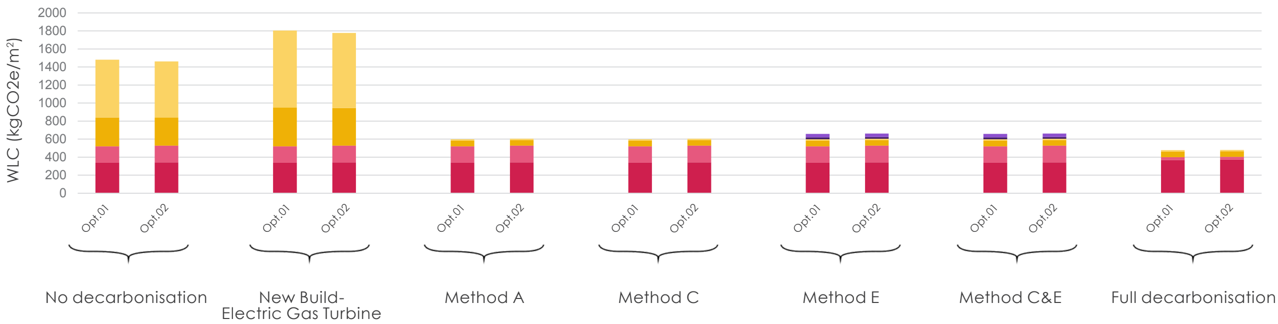


Figure 6.11 - Case study 11 outputs for each of the methodologies assessed

Case Study 12: Systems Options

Communal heat pump and an ambient loop for new build resi

Option 1. Heat pump
Option 2. Ambient Loop

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

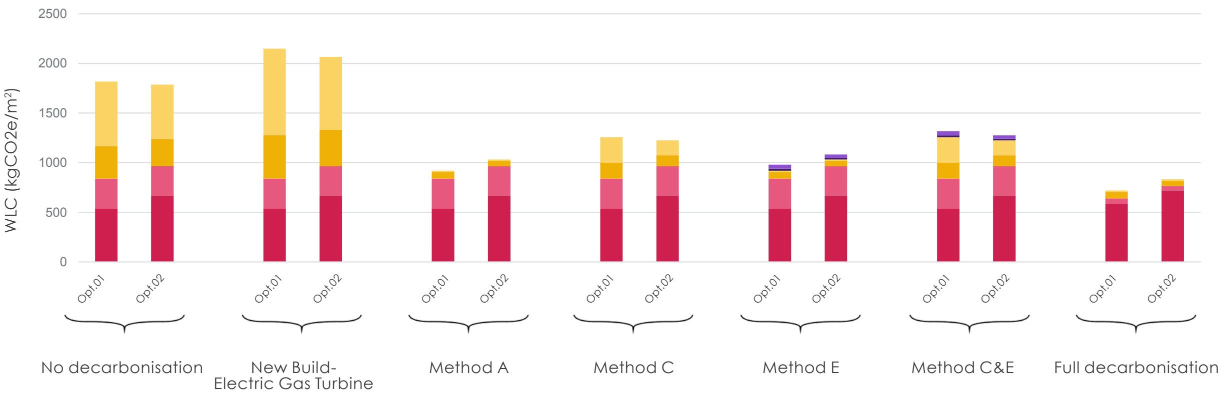


Figure A6.12 - Case study 12 outputs for each of the methodologies assessed

Case Study 13: Plant Systems Options

Systems options for a large commercial and residential scheme with retail at ground

Option 1. Centralised Plant
Option 2. On-floor Air Systems

Method A: Total Annual Approach
Method C: Split Carbon Factor
Method E: Embodied Carbon of Energy Infrastructure

- Upfront Embodied Carbon (A1-A5)
- In-Use Embodied Carbon (B1-C4)
- Operational Carbon over first 20 years
- Operational Carbon over 20 to 60 years
- Infrastructure Embodied Carbon

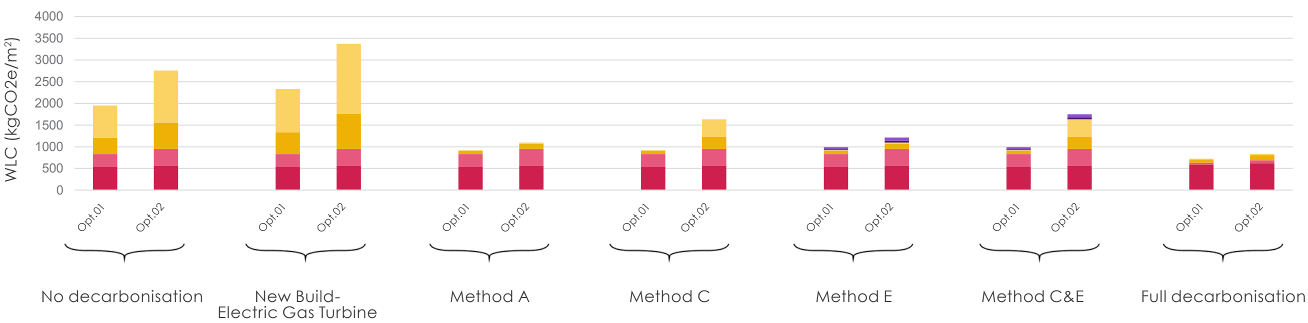


Figure 6.13 - Case study 13 outputs for each of the methodologies assessed

Appendix 7: Voting on Recommendation

Voting Outcomes

The workstream had the opportunity to put forward conclusions on the study, and then the wider workstream had the opportunity to discuss and vote on the outcome of the study. The results are shown on the graph to the right.

Approaches that were put forward:

1. Show all methods – as per the case study analysis
2. Combine Method C&E, and show with the uncertainty analysis book ends
3. Use a single approach- either A, C,E or C&E
4. Operational energy and embodied carbon should not be brought together when making design decisions

By far the greatest votes was for combining methods C&E and showing the results in the context of the uncertainty analysis book ends. When these votes are combined with those that either voted from method C,E or C&E as a single approach this represents 50% of the votes of the workstream, hence it was decided Method C&E was the recommended approach put forward in this paper.

17% of those that voted preferred the approach for showing all of the methods. 17% of those that voted preferred the approach of Method A - the annual average approach.

Which method do you think the paper should conclude is the most appropriate for WLC assessments done to inform design decisions?

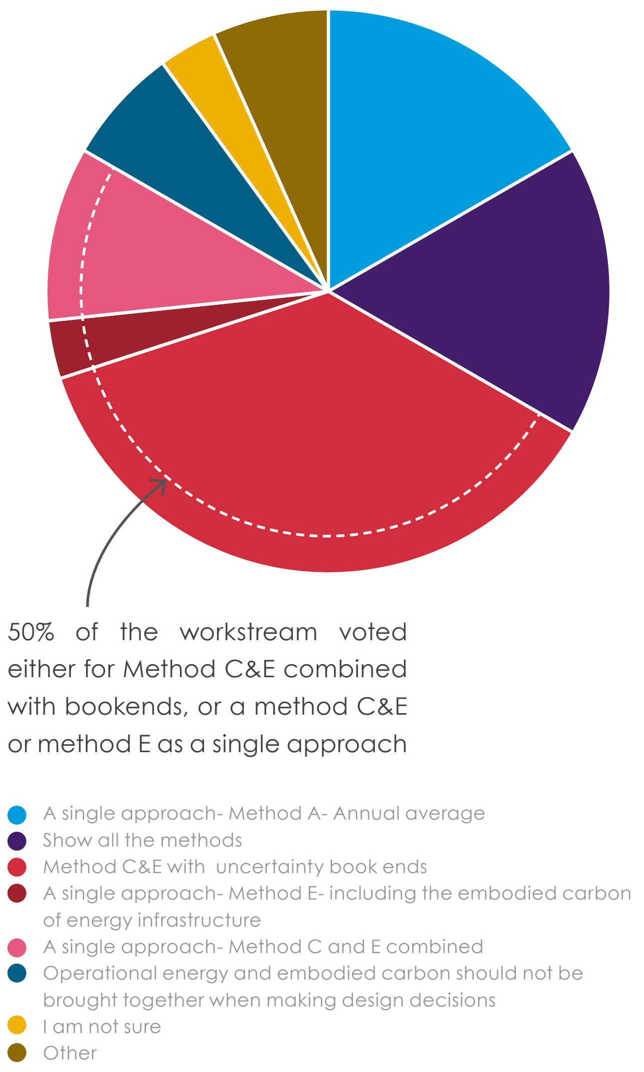


Figure 7.1 - Operational Carbon in Whole Life Carbon Assessments workstream - voting outcomes

With thanks to all who contributed to this document:

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Michela Ravaglia

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D - Jon Pairman - Red Engineering
E - Hannah Kissick - CPW
F - Kate Brown

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Antonia Khayatt - RAFT
Antonietta Canta - ARUP
Barny Evans - Turley
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Clare Murray - Levitt Bernstein
Chris Worboys - Etude
Christian Dimbleby - Architype
Dave Powis
Debbie Hobbs
Debby Ray - Knight Dragon
Ed Cremin - Etude
Elizabeth Ray - Hoare Lea
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Karina Williams - British Land
Leighton Smith - AHMM
Leonardo Poli - Introba
Louise Hamot - Introba
Louisa Bowles - Hawkins\Brown
Lucy Atlee - TfL
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Mina Hasman - Climate Framework
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Pat Hermon - BRE
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Roaa Babiker
Robert Cohen - Verco
Ryan Menezies
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Simon Wyatt - Cundall
Soki Rhee-Duverne – Historic England
Sneha Sanu - Eco Design Consultants
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Timothy Clement - Morgan Sindall
Tom Wigg - UKGBC
Wendy Bishop - Architype
Will Wild - ARUP
Xinlong Wang - Chapman bdsp

The views expressed in this document do not necessarily represent the views of the organisations to which contributors have affiliations.

Notes and references

[1] LETI EUI/New Zero EUI targets: Energy Use Intensity (EUI, kWh/m2 .yr): the energy use per m2 that is required by a building over a year, included regulated (i.e. domestic hot water, space heating and cooling, lighting, and ventilation) and unregulated loads (e.g. lifts, IT). It is a measure of the building's performance and therefore includes all energy supplied to the building, whether from the grid or on-site systems. The UK Net Zero Buildings Standard, being developed, will produce Net Zero aligned EUI targets for a large variety of building typologies

[2] Life Cycle Modules definitions set out in BS EN 15978.

Upfront embodied carbon covers modules A0-A5 and excludes the biogenic carbon sequestered in the installed products at practical completion.

Life cycle embodied carbon covers modules A1-A5, B1-B5, C1-C4.

Operational energy covers module B6.

[3] GHG - Greenhouse Gasses are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself and by clouds. This property causes the greenhouse effect. Water vapour (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4) and ozone (O3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Beside CO2, N2O and CH4, the Kyoto Protocol deals with the GHGs sulphur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). See also Carbon dioxide (CO2), Methane (CH4), Nitrous oxide (N2O) and Ozone (O3).

[4] Whole Life Carbon Assessment, methodology as defined in the RICS "Whole Life Carbon Assessmnent for the Built Environment", 1st Edition, November 2017.

[5] PHPP - the PassivHaus Planning Package is a planning tool for calculating buildings energy efficiency.

[6] CISBE TM54: methodology for evaluating operational energy performance of buildings at the design stage.

[7] SAP - Standard Assessment Procedures, is the government's method for calculating the energy performance of dwellings. These calculations are only necessary for residential properties.

[8] DUKES Table 1.14 - Estimated carbon dioxide emissions from electricity supplied [https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes].

[9] DEC - Display Energy Certificate [https://www.gov.uk/government/publications/display-energy-certificates-and-advisory-reports-for-public-buildings/a-guide-to-display-energy-certificates-and-advisory-reports-for-public-buildings],

[10] NABERS - National Australian Built Environment Rating System, administred by BRE, provides reliable, and comparable sustainability measurement for offices only at this stage and it is expected to be expanded to other sectors.

[11] UK Net Zero Carbon Buildings Standard is being developed by leading industry organisations: BBP, BRE, the Carbon Trust, CIBSE, IStructE, LETI, RIBA, RICS, and UKGBC, who have joined forces to champion this initiative.

[12] UKGBC Renewable Energy Procurement and Carbon Offsetting Guidance for Net Zero Carbon Buildings [https://www.ukgbc.org/ukgbc-work/renewable-energy-procurement-carbon-offsetting-guidance-for-net-zero-carbon-buildings/]

[13] IPPC Climate Change 2022: Mitigation of Climate Change [https://www.ipcc.ch/report/ar6/wg3/].

[14] Nature Energy - Understanding future emissions from low-carbon power systems by integration of life-cycle assessment and integrated energy modelling [https://www.nature.com/articles/s41560-017-0032-9].

[15] Department for Business, Energy & Industrial Strategy (2022) Fuel Mix Disclosure Data Table.