The whole life Carbon Costs of Dwellings

One of the challenges noted in the Routemap to Carbon Negative related to heat and buildings is: *Clarity on whole-life carbon costs of dwellings, especially on replacing heating technology outside of natural cycles, and how this information should inform the roll-out of replacement 'low carbon' technologies.* This initial piece of research aims to provide some clarity on the impact of whole life carbon emissions, where they come from and how this relates to low carbon technologies.

Introduction and key terms:

Whole life carbon emissions are often split into **'operational'** and **'embodied'** emissions:

- **Whole life carbon emissions** – a building's lifetime is considered to be 60 years, but may be shorter or longer (POSTbrief, 2021). During this time a building generates emissions which are categorised as whole life carbon emissions, and can be split into operational and embodied emissions.
- **Operational emissions** – these are the emissions 'associated with the energy required to run a building' (POSTbrief, 2021). This might include energy used for lighting, power, water, ventilation, air con, heating etc.
- **Embodied emissions** – these are the emissions 'associated with all the non-operational aspects of a building' (POSTbrief, 2021). This might include how a building is built, maintained and what happens at the end of its life. These are sometimes referred to as hidden emissions.

Most decarbonisation of buildings focuses on reducing operational emissions by reducing energy use or swapping energy to renewable resources with heat pumps, insulation, PV solar panels etc. Currently, there are 'no statutory requirements to measure or reduce the embodied carbon emissions of buildings in the UK' (POSTbrief, 2021), but stakeholders believe that embodied emissions are crucial for achieving net zero. This is especially important because operational emissions are believed to account for a higher percentage of a building's emissions, but this can vary significantly. A building that has low energy demands may have been made using carbon-intensive materials like glass and steel (RICS), which may outweigh the operational emissions reductions. One example of this is warehouses, which have low operational energy requirements, and therefore 75% of the whole life carbon is associated with embodied carbon emissions (POSTbrief, 2021). Crucially, operational emissions can be reduced and improved and occur over a long period of time (or however long the building exists for), whereas embodied emissions cannot be changed and 'occur in high volumes over short spaces of time' (RICS). Therefore, the recommended approach is to account for both types of emissions.

What are the embodied emissions of buildings in the UK?

At the moment, 'there is no agreed single figure for the whole life carbon emissions from buildings in the UK' (POSTbrief, 2021). This is partially because there is a lot of variation in buildings and around 30-40% of emissions are associated with materials and products imported from overseas. However, there are some useful estimates.

Figure	Organisation	Description
8%	UK Green Building Council	The UK Green Building Council 'estimated that the emissions associated with the construction, operation, and maintenance of buildings and infrastructure made up 8% of the UK's total annual emissions in 2018' (POSTbrief, 2021), which does include some

		embodied emissions, and that operational carbon emissions made up 20% of annual emissions.
13%	Climate Change Committee (CCC)	The CCC 'reported that the operational carbon emissions of all buildings made up 18% of the UK's total emissions in 2019. It also reported that 13% of UK emissions in 2019 were from the manufacturing and construction sectors, some of which are associated with the embodied carbon emissions of buildings.'

These embodied emissions occur during the 4 stages of the building's lifecycle:

- **Product stage**
    - This includes raw materials being used in construction, raw materials being processed, and processing and manufacturing construction products. This is where the majority of embodied emissions occur.
- **Construction stage**
    - This may include transporting materials and products to a building site, the construction process and disposal of site waste.
- **In-use stage**
    - This includes everything needed to maintain, repair, replace and refurbish the building. Operational emissions also occur at this stage.
- **End-of-life stage**
    - This includes what happens to the building when it is no longer used, such as demolition, transporting materials to be recycled and processing waste.

Materials

One of the main areas of embodied emissions is in what materials we use and where they come from. The most widely used materials are 'concrete, timber, steel, and masonry' (POSTbrief, 2021) as well as plastic and metal for certain things. The impacts of some of these materials are below.

Material	Impacts
Concrete	Concrete has longevity, is fire resistant and has low maintenance requirements, as well as being energy efficient. However, cement is a key ingredient in concrete. The cement industry is responsible for 8% of annual global carbon emissions, and about 1.5% annually in the UK (POSTbrief, 2021).
Steel	Steel is used in 60% of buildings and employs 34,000 people in its production (POSTbrief, 2021). However, the chemical reaction of making steel using the blast furnace technique releases CO_2.
Timber	Timber is used in 28% of new build houses, and the CCC is recommending that this should increase to 40% by 2050 'to increase carbon storage capacity three-fold' (POSTbrief, 2021). Timber is generally less carbon intensive than steel and cement (during the harvesting, drying and sawing process). However, 60% of timber used in the UK annually is imported, mostly from Europe, and has obvious links to deforestation, and so the CCC has suggested that the UK Government develops a policy about utilising sustainable UK wood supply chains.
Masonry	When masonry is used for buildings, the main emissions come from the use of concrete and from the firing of bricks which generally uses fossil fuels.

	However, there is a concern that using other methods of construction may 'undermine the British masonry industry as well as other traditional construction skills groups' (POSTbrief, 2021).

Embodied emissions and net zero technology

As with any building materials, net zero technology also has embodied emissions. An example of how this can affect a house that is retrofitted is the zero carbon house in Birmingham.

'The house was built in 1840 and extended and renovated in 2009 with solar panels and solar thermal collectors for heating water. In 2010, the house won an award for architectural excellence from the Royal Institute of British Architects.

Embodied emissions in the original building materials have been in the atmosphere since 1840. The house was retrofitted with materials that required low amounts of energy to make, such as unfired clay blocks, bricks from demolished buildings, recycled newspaper insulation, lime plaster with ground recycled glass, rammed earth floors and reclaimed 200-year old timber from the floor of a silk factory.

Even then, the embodied emissions after the retrofit amounted to more than 40 tonnes of CO_2. The renewable energy systems, including solar panels that generate electricity and solar thermal collectors that heat water, reduce the house's total emissions year on year, but our calculations showed that **the house will only reach net zero in 2030.'**

The Conversation, 2021

Image: gallery – zero carbon house (zerocarbonhousebirmingham.org.uk)

Below is a summary of the embodied carbon impacts of some methods used in retrofitting to achieve net zero.

Net Zero Item	Impacts
Solar panels	Solar panels require resources to make, and so they also have an embodied carbon impact. More than 50% of this impact comes from the panels themselves, but aspects such as mounting systems, ballast, inverters and optimisers also contribute to the impact (ELEMENTA, 2022). Design decisions such as the roof type, and pitch and orientation of the panels can also affect the whole life performance of solar panels, so this should be considered during installation (ELEMENTA, 2022). However, the embodied carbon impact of solar panels is gradually decreasing, and the thought process is that 'we need to 'invest' embodied carbon into installing renewable energy infrastructure'

	(ELEMENTA, 2022) to decarbonise and to drive renewable energy production into the UK, which will in turn reduce those embodied emissions further as more production is done in the UK.
Heat Pumps	Heat pumps actually have higher embodied carbon when they're made than gas boilers do because they have more complex parts. Most of these emissions come from the metals and refrigerant gas used, but if these elements are recycled then this should mitigate the environmental cost (The Renewable Energy Hub, 2022). However, there is not that much research about embodied carbon and heat pumps. What there is still suggests that the operational carbon that is saved by using a heat pump outweighs the embodied carbon impacts.
Insulation	Insulation can be made from lots of different materials, all of which have slightly different embodied carbon emissions. For example, cork has less embodied carbon than expanded polyurethane, and cork can sequester more carbon during its use (Bull). Foams in particular are often made with hydrofluorocarbon (HFC) agents or blowing agents that end up in the atmosphere (Emerson, 2020). However, natural insulation materials are often more expensive, and different types of materials may be required under certain circumstances, such as limited space, or if a rigid material is required.
Biomass Boilers	Biomass boilers are generally made from a lot of different materials, some of which were covered above. In one example, steel, copper, cast iron, glass wool, nylon, glass fibre, refractory material and wood packaging were all key materials (Longo et al. 2015). The same study concluded that the impacts of the boiler could be reduced by reducing the energy consumption during manufacturing, but they emphasise that no renewable energy technology can 'be considered fully ''clean'' (Longo et al. 2015). However, more research needs to be done/located to fully understand biomass boiler embodied emissions.
Airtightness	There is very little research on the embodied carbon of activities and materials that make things airtight. However, using information that we already have about materials, we can look at what methods we use to achieve airtightness in our homes. This includes looking at all the places in buildings where air can escape, such as joins of the walls, floor and rook, windows and doors, pipes and cables, and open fires or chimneys. Methods to address this include using caulking, weather stripping, having double or triple glazing, replacing exterior doors and reinsulating homes. All of these will have embodied carbon impacts, especially as many of these methods require materials like plastic, metal and foam, which have been discussed above.

> '**Renewable energy technologies cannot be considered fully "clean"** because they cause energy and environmental impacts during their life cycle. Thus, all components and aspects of the examined technology should be taken into account following a life-cycle approach.'
>
> *Longo et al., 2015*

This summary is not complete, and to fully understand embodied carbon in methods used for achieving net zero, there needs to be more research into current materials, products and services. It is also worth noting that because items used for reaching net zero rely on certain materials, as these are decarbonised the item itself will see a reduction in embodied emissions. For example, steel is a critical material in wind turbines, electric vehicles and the energy sector, so as the steel industry decarbonises, the embodied emissions of wind turbines, electric vehicles and the energy sector will also reduce (POSTnote, 2022).

How can we reduce embodied emissions?

There are several strategies that can be used to reduce embodied emissions, which will also reduce the amount of residual emissions that need to be reduced by carbon capture or offset later on.

- Repurposing existing buildings rather than building new ones.
    - This is often neglected because it can be expensive, so stakeholders are calling for VAT to be reduced to be in line with new builds.
- Altering the design of the building.
    - Altering the design to minimise materials could minimise operational and embodied carbon emissions – e.g. reducing material quantities and maximising efficiency, reducing waste and making buildings adaptable.
- Choosing materials with lower embodied carbon emissions.
    - Stakeholders consulted in a POSTbrief about reducing the whole life carbon impact of buildings have called for certification for construction materials so that people can include carbon impacts when they choose materials.
    - The same stakeholders could also choose materials that don't need to travel as far, or can travel more sustainably and choose locally sourced materials where possible, if these materials are available.
- Thinking about the construction process and the associated emissions.
    - This includes on-site activity and construction waste, for example materials waste from measuring errors or over ordering of materials.
    - This could also include the temporary construction of on-site facilities like offices or utilities.
- Choosing materials that require little maintenance and can be reused or recycled at the end of their life, utilising CE thinking.
    - This includes reusing the building and ensuring it is adaptable, but also utilising individual materials such as wood or steel if the building is decommissioned or otherwise unused.
    - However, adaptability may increase the upfront carbon emissions and the cost of the building, and it could be difficult to account for future needs e.g. people building offices 5 years ago could not account for Covid-19.

Whole Life Carbon Assessment:

A life cycle assessment looks at the environmental impacts of something across its lifetime. A Whole Life Carbon Assessment (WLCA) looks at the carbon emissions for each stage of a system's life, and can be used for buildings. This can identify where emissions and costs can be reduced. However, this is reliant on having the correct data on the carbon impacts of materials, processes etc., on the scope of the assessment (looking at the whole lifetime or just aspects), and accounting for carbon storage and release accurately. WLCAs are not a requirement, but they are encouraged. (POSTbrief, 2021)

<u>What approaches are being taken?</u>

Approach taken	Description
Government initiatives	In the National Infrastructure Strategy the UK Government committed to making the construction sector more sustainable. However, there are no requirements to measure or reduce the embodied carbon emissions of buildings (POSTbrief, 2021). The UK Government's 2020 Construction Playbook advises contractors to look at the wider supply chain and ensure that everything is evidenced. Additionally, the Infrastructure and Projects Authority updated their Best Practice in Benchmarking Guidance to provide a method of including whole life emissions assessments in data collection and reporting by organisations (POSTbrief, 2021).
Voluntary initiatives	Campaign groups and institutions have campaigned for initiatives, guidelines and targets for carbon reduction. This includes: World Green Building Council's Whole Life Carbon Vision, the Royal Institute of British Architects 2030 Climate Challenge, the London Energy Transformation Initiative, the Architects Climate Action Network, the Institution of Structural Engineers Embodied Carbon Tracking scheme, the Construction Declares movement and guidance from the Royal Academy of Engineering's National Engineering Policy Centre. And, 'in 2020 the World Green Building Council set a target to reduce embodied carbon emissions by 40% by 2030' (POSTbrief, 2021).
Building Sector and industry initiatives	Some UK construction companies have their own targets which include design changes, manufacturing process changes and use of materials. However, some of these targets only look at operational emissions. This approach is held back because other stakeholders, like planning authorities and suppliers, need to be involved. The Construction Declares movement includes operational and embodied carbon reduction strategies, but those involved are not held to account because it is voluntary (POSTbrief, 2021). In 2021 experts and representatives from the construction industry published proposed changes to Building Regulations 2010, including whole life carbon assessments and reducing embodied carbon emissions (POSTbrief, 2021).
Local Authority Initiatives	The majority of local authority carbon reduction plans for buildings focus on operational emissions. But there are some that have looked at whole life emissions such as the Greater London Authority's London Plan, Eastleigh Borough Council's 2011-2029 Local Plan, and Bath and North East Somerset's 2011-2029 Local Plan (POSTbrief, 2021).
Other Nations	*Netherlands* – the 'Building Decree 2012' means that new buildings that are larger than $100m^2$ have whole life carbon calculations and mitigation cost estimates.

	France – all new housing projects will require whole life carbon calculations from early 2022, and there is an emphasis on the use of wood in construction. *Finland* – All new buildings from 2025 will require measurement and reporting of operational and embodied emissions, and targets will be set for different types of buildings. *California* – carbon intensity limits are set for certain construction materials. (POSTbrief, 2021)
Databases	There are several databases that provide carbon information for different construction materials and buildings, including: • The inventory of Carbon and Energy (ICE) • The Ecoinvent Database • The GaBi Software • The RICS Building Carbon Database • The Wood for Good Lifecycle Database • The SteelConstruction.Info Database • The Mineral Products Association

What are some potential positives to reducing embodied emissions?

Reducing GHG emissions and impact on climate change:

Of course, this is the main reason for looking at the whole life carbon costs of buildings. The UK Government estimate that developing greener buildings, which includes new and existing buildings, could save 71 $MtCO_2e$ of operational carbon emissions (POSTbrief, 2021), and the UK Government's Future Homes Standard aims to reduce operational carbon emissions of new homes by 75% or more by 2025. However, this does not include embodied carbon emissions, which may distort how close we are to net zero. Including embodied emissions in our carbon reductions will allow us to get the full picture of UK emissions.

Creating jobs and investment:

Building greener buildings is estimated to support 50,000 jobs in 2030 (POSTbrief, 2021). Building greener buildings is also estimated to create £11 billion of private investment during the 2020's (POSTbrief, 2021). Additionally, if contractors are selecting British made materials over those from abroad to reduce emissions, this could boost British industries and improve supply chains.

Social benefits of reusing buildings:

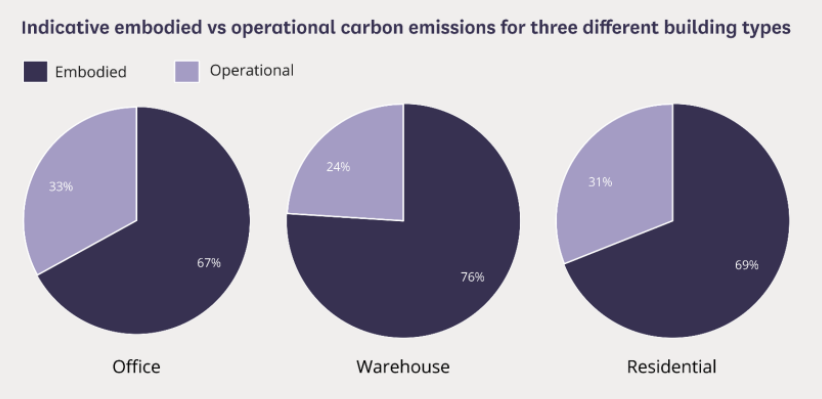
A common criticism of Local Authority approaches is that buildings fall into disuse and new houses are built instead, and this is also a common response to housing projects (i.e. in the Tadcaster development plan). Utilising buildings that already exist rather than building new ones could help to improve this dialogue as well as reduce embodied emissions and preserve some historical buildings. This is difficult though, as these buildings are often not as adaptable as newer buildings, and may cost more to update.

What are the current challenges to reducing these emissions?

Growth of construction:

Construction is estimated to increase across the world, possibly by 3.9% annually to 2030 (Designing Buildings). In the UK, the UK Government has invested in housing including a £600 billion investment in infrastructure to 2025, plans to build 300,000 new homes per year to the mid-2020's and an increase in housing investment. This is likely to increase emissions, but specifically embodied emissions, especially because embodied emissions are not usually considered as much as operational emissions.

Different buildings have different whole life carbon splits:



The proportion of embodied vs operational emissions can vary 'depending on design, energy supplier and occupants' (POSTbrief, 2021), making it difficult to measure emissions accurately. This is important to consider when looking at the different types of buildings in the UK and in our region. Some examples of different building types and their emissions splits are above (POSTbrief, 2021).

Embodied emissions are locked in:

Over 70% of current building stock in the UK will still be in use by 2050, and most of this stock has been reported to be 'amongst the most inefficient and oldest in Europe' (POSTbrief, 2021). This is because UK housing was mostly built before the 1990's. Because most of our buildings are not very efficient, this affects operational carbon emissions, but it also affects embodied emissions too, as those have already happened, and it is likely that if/when these buildings are decommissioned, demolished etc., this will create additional carbon emissions. Additionally, as operational emissions are tackled and reduced, embodied emissions will become a larger percentage of overall emissions.

Data and collaboration with multiple stakeholders:

Measuring embodied carbon relies on knowing the carbon impact of products, processes etc., which is extremely difficult to be accurate with. It also requires working closely with multiple stakeholders such as producers and installers, which requires coordination and trust. This means that much of the data available is not 100% accurate, and not as accurate as that for operational carbon.

Skills & supply chain

Stakeholders have said that there is likely to be a skills shortage, especially because the move to net zero requires 'innovation, increased efficiencies, and a mix of new skilled jobs' (POSTbrief, 2021). The Construction Industry Training Board estimated that by 2028 there will need to be 350,000 new jobs in addition to the 2.7 million who are already employed in the sector (POSTbrief, 2021). This must also include bolstering the UK supply chain to allow more access to British materials, resulting in less travel for materials and therefore fewer embodied carbon emissions. The following are themes that recommendations for filling the skills gap fell into (POSTbrief, 2021):

- Investing in net zero to support good quality green jobs in the UK.
- Building pathways into green careers.
- A just transition for workers in the high carbon economy.

Actions so far

In conversation with some businesses that work in construction, it is clear that they are considering embodied emissions, but that particularly for those in the retrofit industry, it is thought that the benefits of retrofitting outweigh the potential costs of embodied emissions. Additionally, whole life carbon is to be included as a topic for discussion in designing a retrofit strategy for York and North Yorkshire, and is identified as an area for consideration in the retrofit supply chain action plan. However, more research is needed to discover what the impact of embodied emissions is, particularly during retrofitting.

Conclusions

Overall, although there are uncertainties about embodied emissions, it is important that we consider them, especially when retrofitting buildings and commencing new builds. Ignoring these emissions may make our net zero targets inaccurate, so we should begin to gather information about embodied emissions, and use this to consider the impact of embodied carbon at different stages of construction.

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