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The greenhouse gas emissions and mitigation options for materials used in UK construction

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ABSTRACT

The UK construction industry faces the daunting task of replacing and extending a significant proportion of UK infrastructure, meeting a growing housing shortage and retrofitting millions of homes whilst achieving greenhouse gas (GHG) emission reductions compatible with the UK's legally binding target of an 80% reduction by 2050. This paper presents a detailed time series of embodied GHG emissions from the construction sector for 1997–2011. This data is used to demonstrate that strategies which focus solely on improving operational performance of buildings and the production efficiencies of domestic material producers will be insufficient to meet sector emission reduction targets. Reductions in the order of 80% will require a substantial decline in the use of materials with carbon-intensive supply chains. A variety of alternative materials, technologies and practices are available and the common barriers to their use are presented based upon an extensive literature survey. Key gaps in qualitative research, data and modelling approaches are also identified. Subsequent discussion highlights the lack of client and regulatory drivers for uptake of alternatives and the ineffective allocation of responsibility for emissions reduction within the industry. Only by addressing and overcoming all these challenges in combination can the construction sector achieve drastic emissions reduction.

1. Introduction

The evidence of climate change is now "unequivocal" [1] and the anticipated increases in the frequency of extreme weather events, threats to water and food security and the massive loss of biodiversity represent a fundamental risk to the health and livelihoods of a large portion of the global population. The extensive and growing evidence base suggests that it is "extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century" [2], principally through the extraction and burning of fossil fuels alongside changes to land use. Humans have already significantly altered three quarters of the world's terrestrial habitats and continue to extract 60 billion tonnes of raw materials each year [3,4]. The construction sector is the largest user of these materials [4]. Buildings are the sector with the largest single energy use worldwide and are responsible for approximately a third of global carbon emissions [5,6].

In the UK, the volume of carbon dioxide emissions that the construction sector influences is significant, accounting for an estimated 47% of total UK CO_2 emissions [7]. In a typical year, the UK construction industry requires over 420 million tonnes of material resources, energy equivalent to just under 8 million tonnes of oil, and is responsible for over 90% of non-energy mineral extraction [8,9]. The construction sector is also the largest generator of waste, at over 100 million tonnes per year in 2008 [10]. Furthermore, every year the construction industry uses 6500 ha of land and is responsible for a third of all industry-related pollution incidents [11]. In addition to direct environmental impacts from its activities, the sector also has a critical role to play in enabling the supply of clean energy and facilitating sustainable practices in other areas of the economy. The impending transition to a low carbon economy represents a sizeable package of works for the construction industry. Indeed, the influential 2010 UK Innovation and Growth Team (IGT) report concluded that "over the next 40 years, the transition to low carbon can almost be read as a business plan for construction" [12].

The UK is facing a sizeable housing shortfall, the imminent replacement of the majority of its electricity generating plant, and intends to increase public investment in many pieces of large-scale infrastructure (such as high speed rail and highway networks) [13].

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In addition, the sector faces the challenging task of retrofitting millions of 'non-decent' domestic properties that are responsible for high levels of fuel poverty and operational greenhouse gas (GHG) emissions [14]. The production of these new structures and the retrofit of existing stock will require a considerable volume of construction materials over the coming decades. Over this same period, to meet legally binding targets, the UK must make reductions in GHG emissions of 80% relative to 1990 levels. Reducing the emissions associated with the production of these materials and structures could play a significant role in meeting this target [15].

The carbon emissions associated with construction are typically distinguished as either *embodied* or *operational* emissions. Embodied emissions (sometimes called capital carbon) are those associated with the initial production of a structure. Typically this includes emissions from: raw material acquisition, transport, processing and manufacturing of building materials; distribution of materials to site; and energy used on-site in assembly. A comprehensive definition would also include indirect emissions associated with supporting activities such as design, project financing, legal support and other professional services. For most projects the embodied emissions are dominated by emissions associated with the extraction and processing of materials [7,16]. Meanwhile operational emissions are those associated with the operation and maintenance of a structure. This typically includes activities such as space heating, lighting, and air conditioning. Emissions associated with the deconstruction and disposal of a structure can also be considerable, though the method of estimation and documentation varies between studies.

Studies based around Life Cycle Assessment (LCA) methods have found the ratio of embodied to operational emissions varies considerably by structure type and from project to project [17]. Academic studies have most frequently found operational emissions to constitute 70–80% of life cycle emissions associated with a variety of structures [18]. Non-academic studies have also arrived at comparable estimates [12,19]. However, many of these studies have suffered from a number of crude assumptions [17]. Common simplifications include the omission of emissions from on-site activity, personnel transport, material transport and material wastage. End of life considerations, for example deconstruction and recycling or disposal of key materials, are frequently excluded. A number of studies are also predicated on the assumption that there will be no further decarbonisation of the electricity supply over the lifetime of the structure [e.g. 113] – resulting in a likely overestimation of operational emissions. For these reasons the ratio of operational to embodied emissions is often overstated.

The last decade has also seen an increased emphasis on improving building fabric to achieve better thermal performance. This has necessitated an increased use in materials, as better performing wall systems are typically thicker and more complex [20]. A study of homes built in recent years found embodied emissions now typically make up 31–42% of total life cycle emissions [21]. New regulations and increasing construction activity are expected to continue this trend towards increasing embodied emissions and reduced operational emissions [17].

These trends have led authors to conclude that "as gains in operational energy reduction are realised, embodied energy of the construction, maintenance, refurbishment and disposal cycle will become increasingly important in making further progress" [22]. Recent industry publications have also identified the need to address embodied carbon in tandem with operational carbon. For example, the authors of the Green Construction Board (GCB) Low Carbon Routemap for the Built Environment estimated that capital carbon reductions of 21% by 2022 and 39% by 2050 relative to a 2010 baseline will be needed, alongside reductions in operational emissions of 85% (for domestic properties) and 77% (for non-domestic properties), to meet sector targets [19].

Table 1
Estimates of GHG emissions attributable to the built environment.

Estimate	Innovation and Growth Team [7]	Green Construction Board [19]
Total emissions attributable to the built environment	298.4 $MtCO_2$ in 2008 Of which 51.9 $MtCO_2$ embodied	190 $MtCO_2e$ in 2010 Of which 33.6 $MtCO_2e$ embodied
Ratio of operational: embodied emissions	17:83	18:82
Breakdown of embodied emissions	Product manufacture: 45.2 $MtCO_2$ Distribution: 2.8 $MtCO_2$ Operations on-site: 2.6 $MtCO_2$ Design: 1.3 $MtCO_2$ Refurb/demolition: 1.3 $MtCO_2$	Materials extraction, manufacturing and production: 18.1 $MtCO_2e$ Distribution: 3.4 $MtCO_2e$ On-site activities: 6.7 $MtCO_2e$ Design services: 1.7 $MtCO_2e$ Other: 3.7 $MtCO_2e$
Methodology	Domestic: sum of emissions attributable to the domestic production of 'Wood and wood products', 'Paints, varnishes, printing ink, etc.', 'Rubber products', 'Plastic products', 'Glass and glass products', 'Structural clay products, cement, lime and plaster', 'Articles of concrete, stone, etc.', 'Metal products', plus 28% of the total for 'Iron and steel, non-ferrous metals, metal castings' based on figures from the Environmental Accounts. Imports: 2004 embodied emissions from imports from Sector 88: 'Construction' of the University of Leeds and CenSA two region MRIO model.[a]	The entire capital carbon allocation is extracted solely from Sector 88: 'Construction' of the two region University of Leeds and CenSA MRIO model for the period 1990–2009. This is then apportioned into 'Infrastructure', 'Non-domestic buildings', and 'Domestic buildings' based on the financial value of construction output during this period [19, pp. 22–24]

[a] See Supporting Information for a description of the model and its coverage.

This paper provides an improved estimate of the total embodied emissions associated with construction and presents a range of mitigation options that focus on reducing the use of materials with carbon-intensive supply chains. The barriers to uptake of these alternatives are presented and the subsequent discussion highlights the lack of client and regulatory drivers for their adoption. Key gaps in existing qualitative research, data and modelling approaches are also identified.

2. Quantifying the embodied emissions of the construction sector

2.1. Previous estimates and their limitations

At least two recent attempts, summarised in Table 1, have been made to estimate the emissions that fall within the influence of the UK construction sector [7,19]. Both of these concluded that operational emissions are the dominant component and thus warrant the principal attention of policy makers. However, the means by which embodied emissions are computed remains a subject of much debate [17]. Owing to the poor granularity of data currently gathered for the UK's territorial and consumption-based emissions