CIE-MAP

Centre for Industrial Energy, Materials and Products

Research Councils UK Energy For a Low Carbon Future

Embodied carbon in construction: a CIEMAP perspective

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University of Leeds

CIEMAP

Our mission

» ***Working closely with government and industry, CIEMAP conducts research to identify all the opportunities along the product supply chain that ultimately deliver a reduction in industrial energy use***

» One of 6 RCUK funded centres focussing on end use energy demand in the UK

» Interdisciplinary team from the universities of Leeds, Bath, Cardiff and Nottingham Trent, plus contributions from the Green Alliance

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UNIVERSITY OF BATH

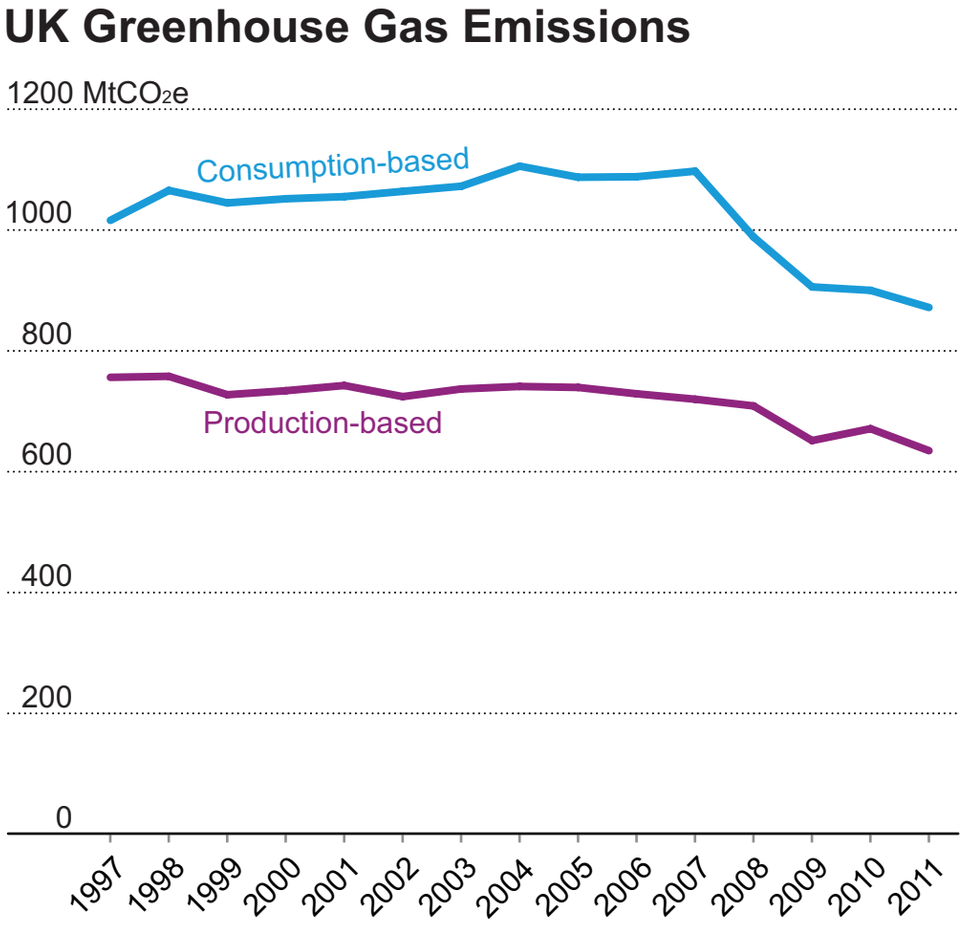
CIEMAP

Our work

» Policy relevant research to understand the relationship between environmental pressures, the economy and society

» Develop quantitative approaches to understand how energy and emissions interact with production and consumption systems

» Develop scenarios to understand underlying drivers and policy responses to minimise environmental pressures



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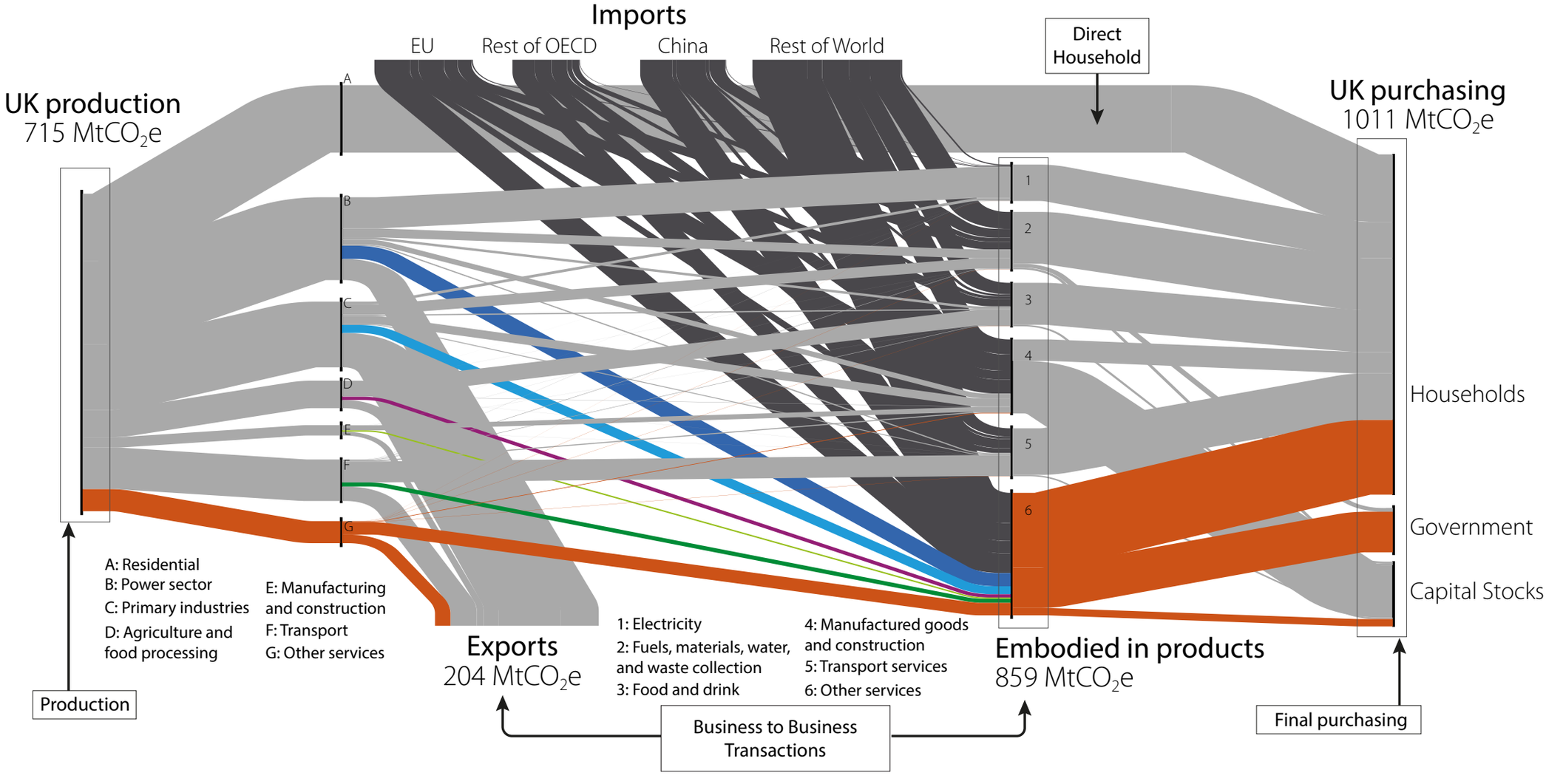
Our approach

» Combining economy wide and sector specific analyses along supply chains



CIEMAP

Our methods

» Mix of techniques required to analyse complex systems

Quantitative

» Multi Region Input Output (MRIO)

» Life Cycle Assessment (LCA):
process based, IO and hybrids

» Material Flow Accounting (MFA)

» Exergy analysis

Qualitative

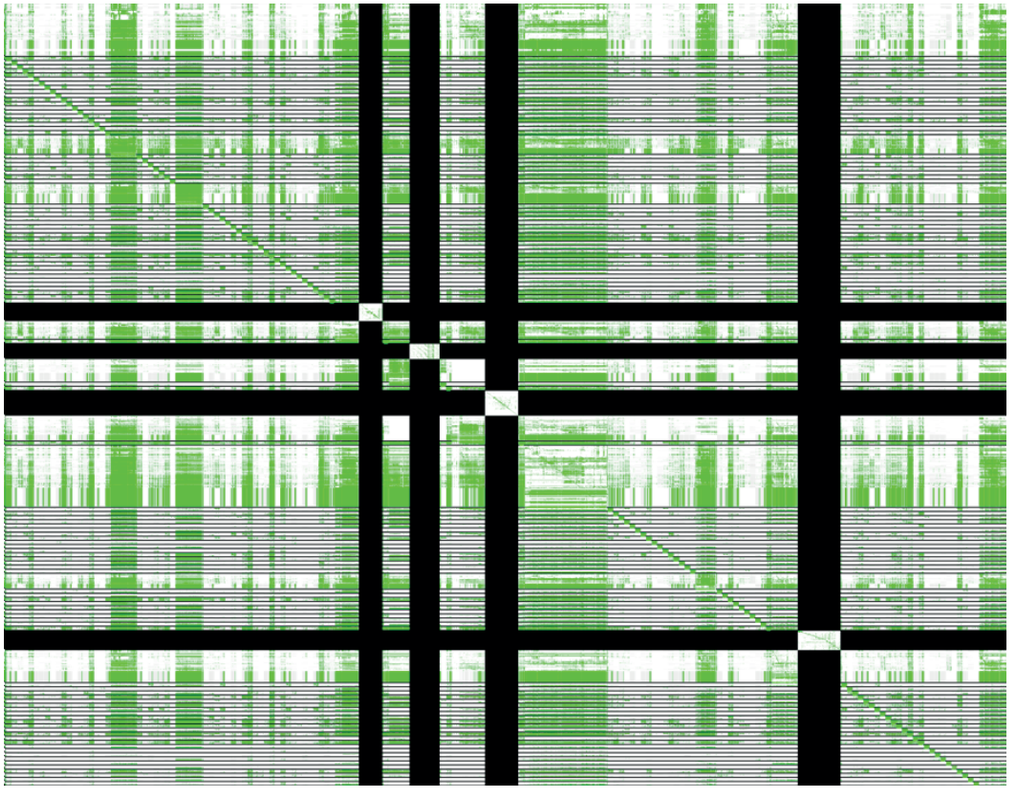
» Surveys

» Interviews

» Workshops

» Other participatory approaches

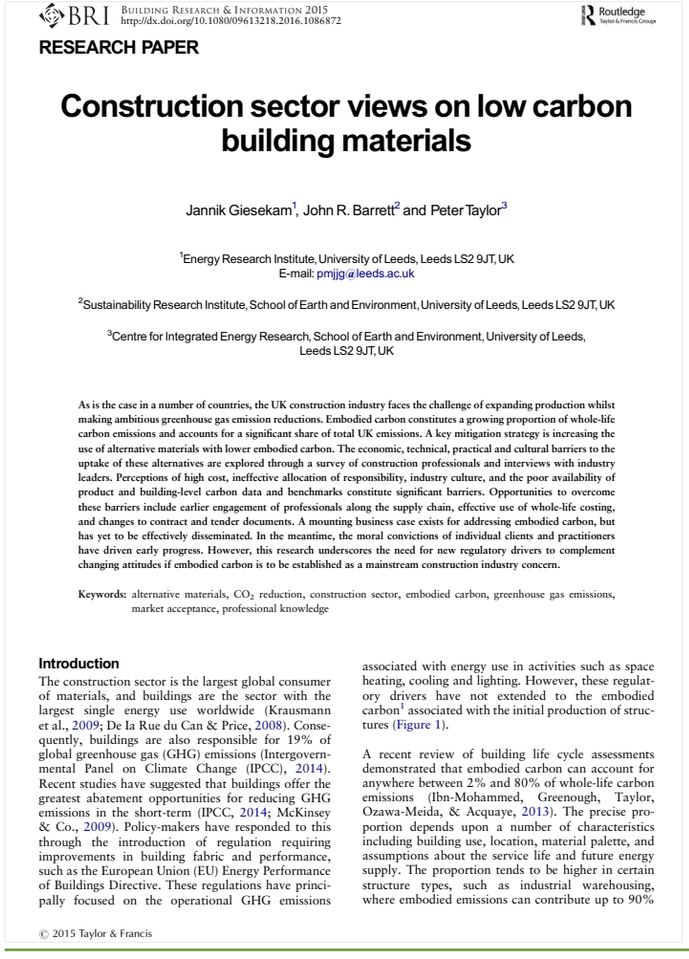
Global IO matrix (with ~112 billion entries)



CIEMAP work in construction

Two key areas

- **Assessing current and future material use and embodied carbon emissions**
- Understanding the barriers to greater material efficiency and the use of low carbon materials



BRI Building Research & Information 2015
http://dx.doi.org/10.1080/09613218.2016.1086872
Routledge Taylor & Francis Group

RESEARCH PAPER

Construction sector views on low carbon building materials

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As is the case in a number of countries, the UK construction industry faces the challenge of expanding production whilst making ambitious greenhouse gas emission reductions. Embodied carbon constitutes a growing proportion of whole-life carbon emissions and accounts for a significant share of total UK emissions. A key mitigation strategy is increasing the use of alternative materials with lower embodied carbon. The economic, technical, practical and cultural barriers to the uptake of these alternatives are explored through a survey of construction professionals and interviews with industry leaders. Perceptions of high cost, ineffective allocation of responsibility, industry culture, and the poor availability of product and building-level carbon data and benchmarks constitute significant barriers. Opportunities to overcome these barriers include earlier engagement of professionals along the supply chain, effective use of whole-life costing, and changes to contract and tender documents. A mounting business case exists for addressing embodied carbon, but has yet to be effectively disseminated. In the meantime, the moral convictions of individual clients and practitioners have driven early progress. However, this research underscores the need for new regulatory drivers to complement changing attitudes if embodied carbon is to be established as a mainstream construction industry concern.

Keywords: alternative materials, CO_2 reduction, construction sector, embodied carbon, greenhouse gas emissions, market acceptance, professional knowledge

Introduction

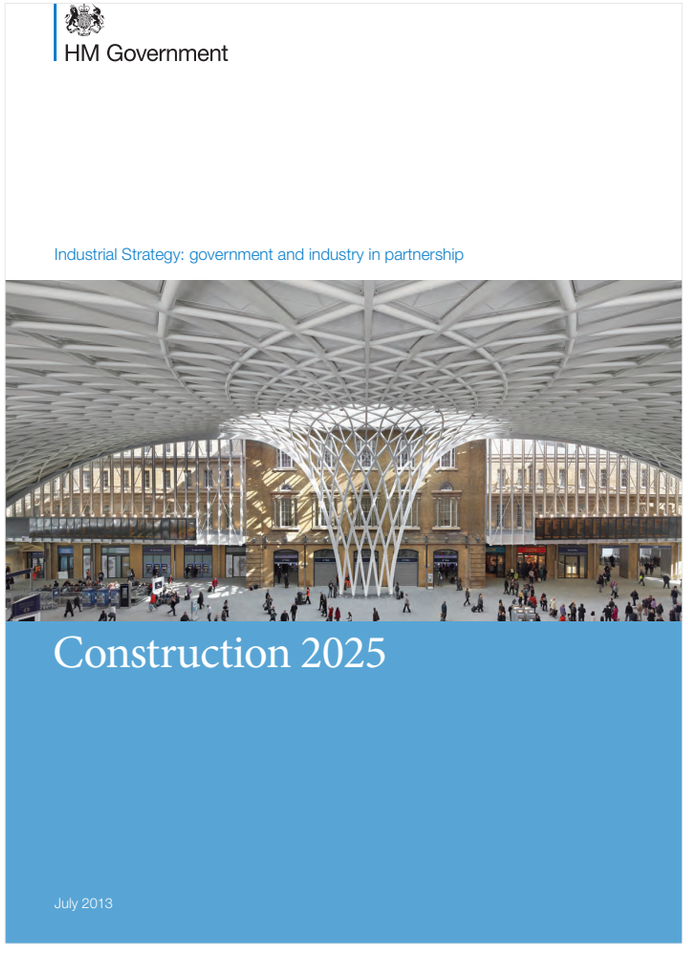
The construction sector is the largest global consumer of materials, and buildings are the sector with the largest single energy use worldwide (Krausmann et al., 2009; De Ia Rue du Can & Price, 2008). Consequently, buildings are also responsible for 19% of global greenhouse gas (GHG) emissions (Intergovernmental Panel on Climate Change (IPCC), 2014). Recent studies have suggested that buildings offer the greatest abatement opportunities for reducing GHG emissions in the short-term (IPCC, 2014; McKinsey & Co., 2009). Policy-makers have responded to this through the introduction of regulation requiring improvements in building fabric and performance, such as the European Union (EU) Energy Performance of Buildings Directive. These regulations have principally focused on the operational GHG emissions associated with energy use in activities such as space heating, cooling and lighting. However, these regulatory drivers have not extended to the embodied carbon[1] associated with the initial production of structures (Figure 1).

A recent review of building life cycle assessments demonstrated that embodied carbon can account for anywhere between 2% and 80% of whole-life carbon emissions (Ibn-Mohammed, Greenough, Taylor, Ozawa-Meida, & Acquaye, 2013). The precise proportion depends upon a number of characteristics including building use, location, material palette, and assumptions about the service life and future energy supply. The proportion tends to be higher in certain structure types, such as industrial warehousing, where embodied emissions can contribute up to 90%

Construction 2025

Targets 50% reduction in greenhouse gas emissions

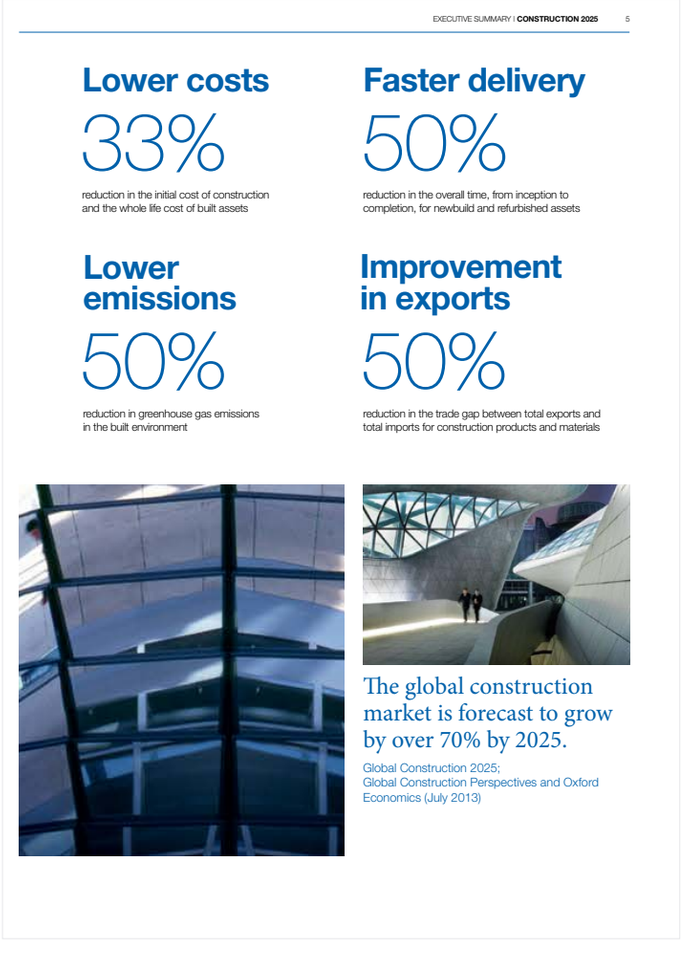
» Envisages a sustainable industry that *"leads the world in low-carbon and green construction exports"*


HM Government

Industrial Strategy: government and industry in partnership

Construction 2025

July 2013


EXECUTIVE SUMMARY I **CONSTRUCTION 2025** 5

Lower costs

33%

reduction in the initial cost of construction and the whole life cost of built assets

Faster delivery

50%

reduction in the overall time, from inception to completion, for newbuild and refurbished assets

Lower emissions

50%

reduction in greenhouse gas emissions in the built environment

Improvement in exports

50%

reduction in the trade gap between total exports and total imports for construction products and materials

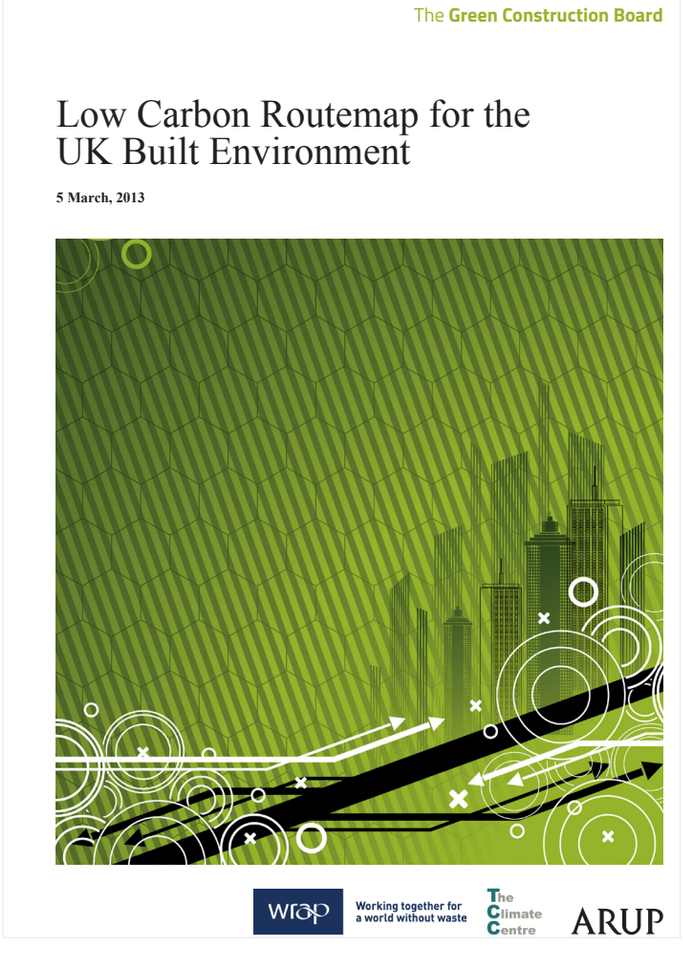
The global construction market is forecast to grow by over 70% by 2025.

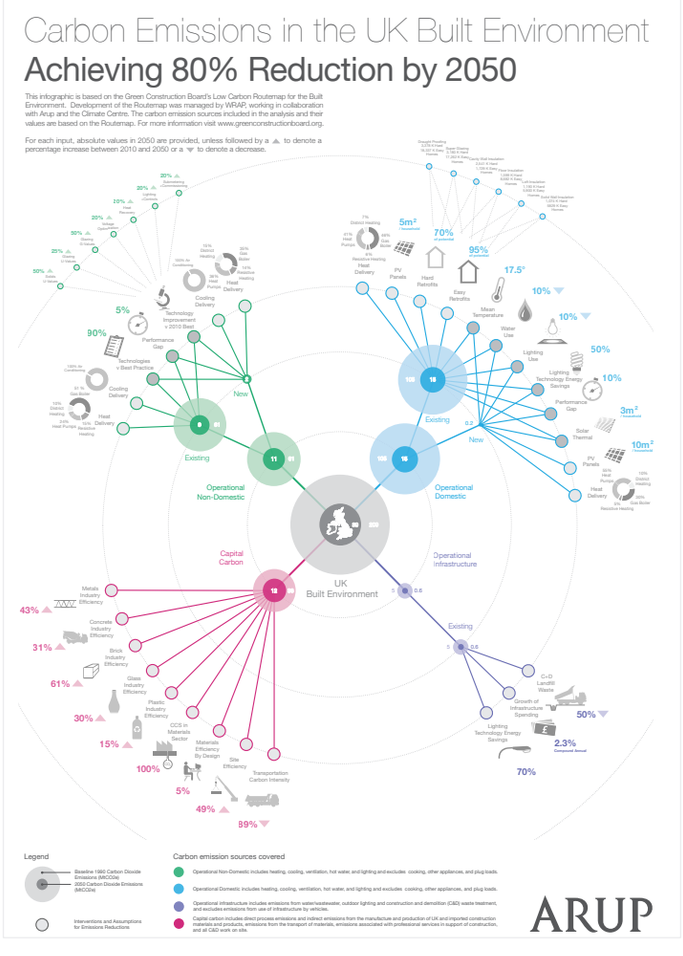
Global Construction 2025; Global Construction Perspectives and Oxford Economics (July 2013)

Low Carbon Routemap

Set trajectory for 80% reduction by 2050

» Emphasised that *"capital carbon must start to be addressed in tandem with operational carbon"*



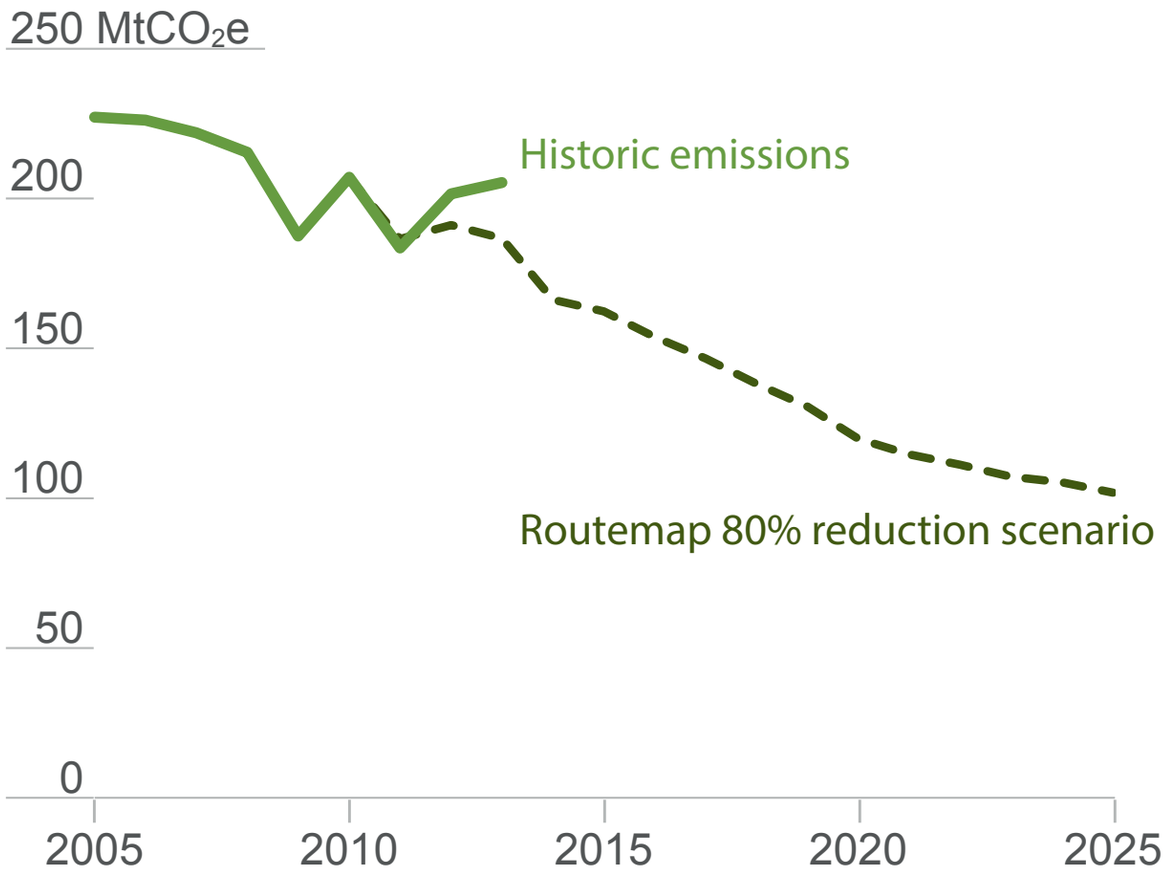


Low Carbon Routemap update

Progress report produced in December 2015

» Capital carbon emissions have increased since original Routemap report

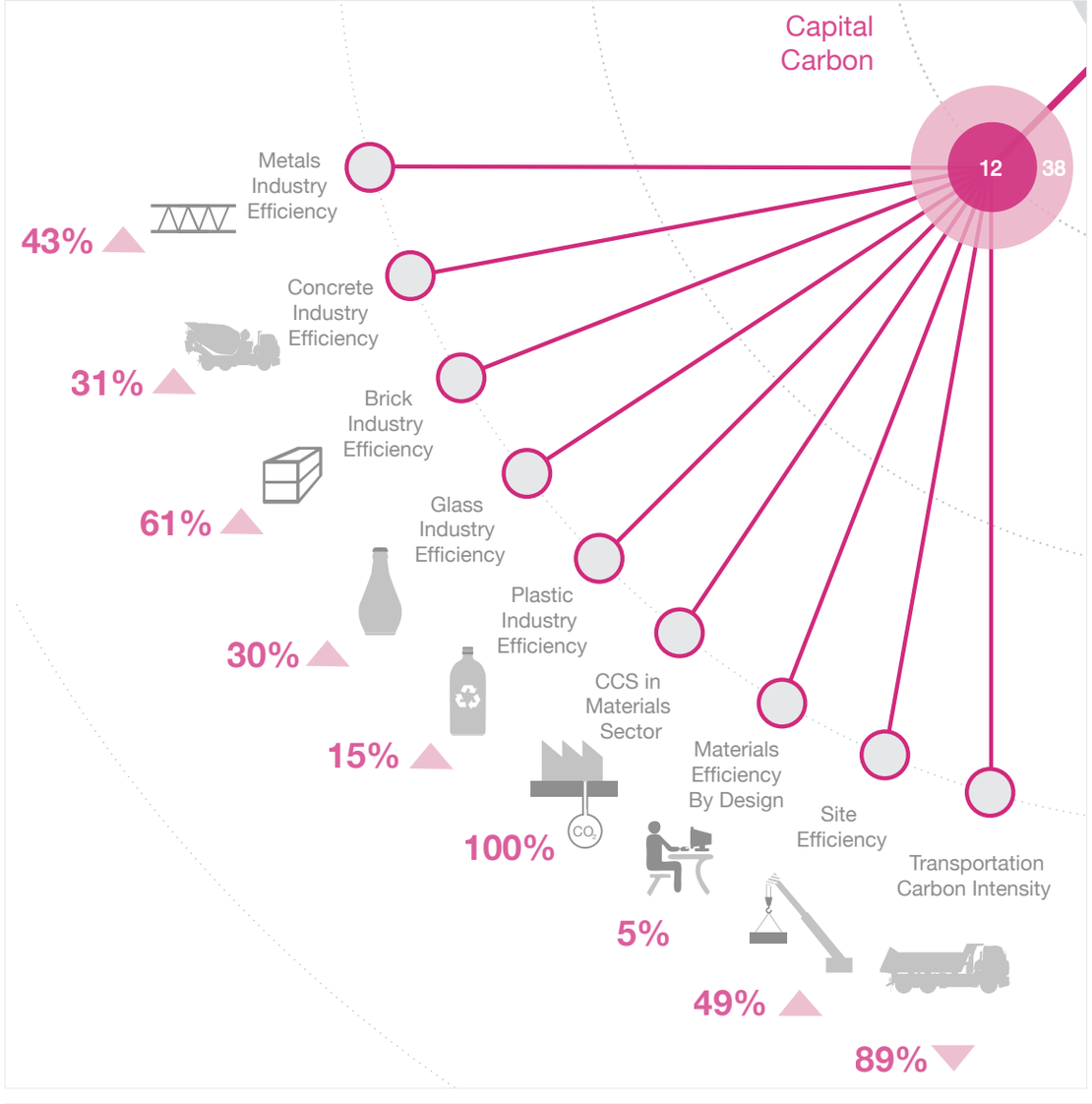
» Progress to 2013 suggests we are not on trend to meet 2025 ambitions



Routemap 80% reduction scenario

Sets unrealistic targets for material manufacturers

» But underestimates scope for material substitution and material efficiency



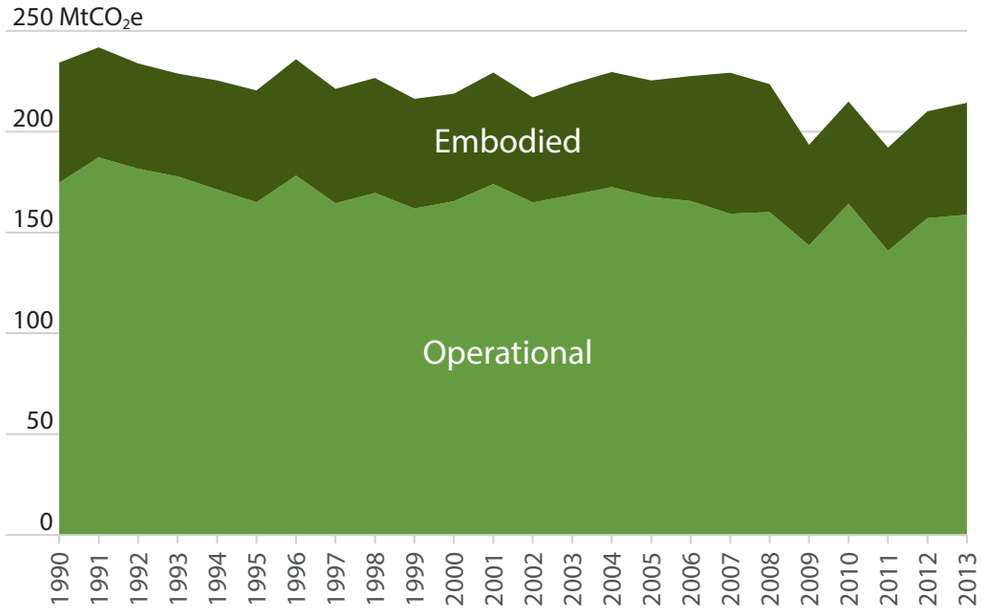
"My personal view is that the assumptions the model makes are so heroic that I don't believe anyone will believe it will happen in the timeframe"

Paul Morrell - Chief Construction Adviser 2009-2012

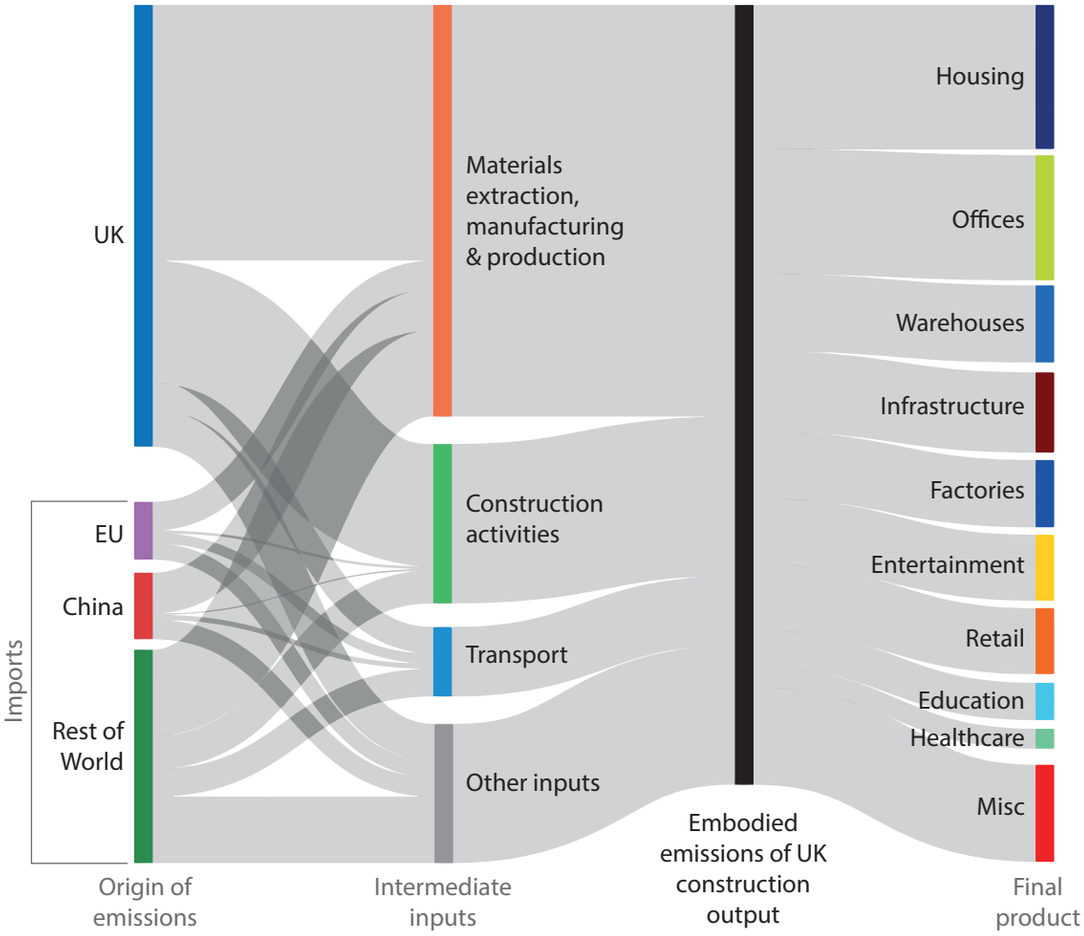
Embodied carbon in construction

Estimated carbon footprint of UK construction supply chain

» Built environment emissions 1990-2013



» Embodied emissions in 2007



Giesekam et al. (2014) The GHG emissions and mitigation options for materials used in UK construction *Energy and Buildings*

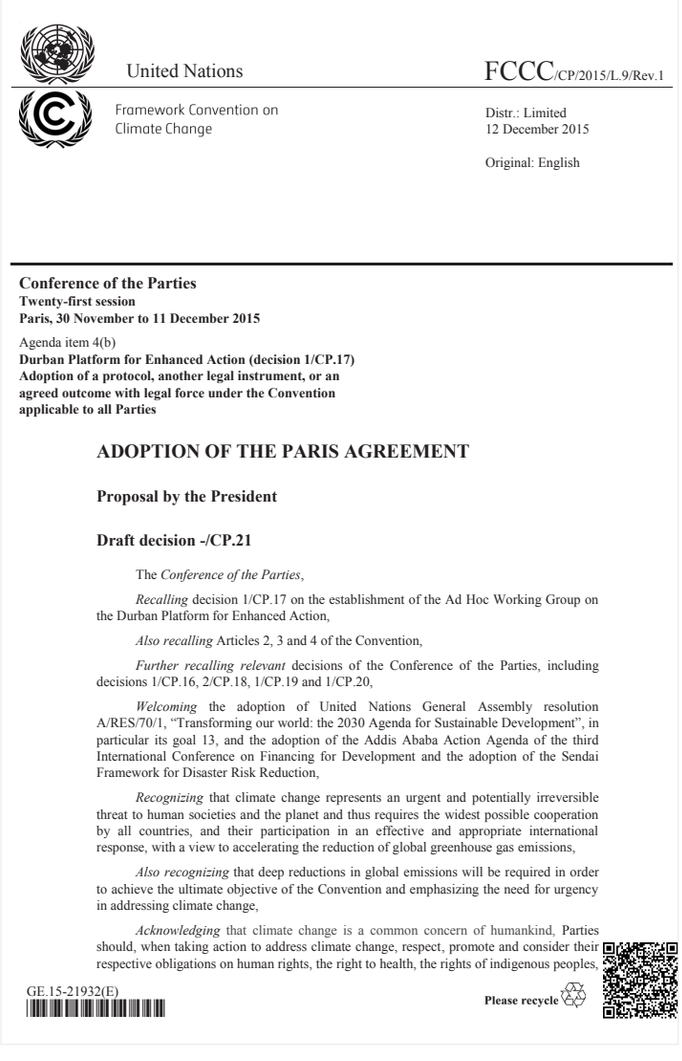
Giesekam et al. (Under review) Building on the Paris Agreement: making the case for embodied carbon intensity targets in construction

Paris Agreement on climate change

Global agreement in December 2015

» Commits to *"holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels"*

» With goal of achieving *"a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century"*



United Nations

Framework Convention on Climate Change

FCCC/CP/2015/L.9/Rev.1

Distr.: Limited
12 December 2015

Original: English

Conference of the Parties
Twenty-first session
Paris, 30 November to 11 December 2015

Agenda item 4(b)
Durban Platform for Enhanced Action (decision 1/CP.17)
Adoption of a protocol, another legal instrument, or an agreed outcome with legal force under the Convention applicable to all Parties

ADOPTION OF THE PARIS AGREEMENT

Proposal by the President

Draft decision -/CP.21

The *Conference of the Parties*,

Recalling decision 1/CP.17 on the establishment of the Ad Hoc Working Group on the Durban Platform for Enhanced Action,

Also recalling Articles 2, 3 and 4 of the Convention,

Further recalling relevant decisions of the Conference of the Parties, including decisions 1/CP.16, 2/CP.18, 1/CP.19 and 1/CP.20,

Welcoming the adoption of United Nations General Assembly resolution A/RES/70/1, "Transforming our world: the 2030 Agenda for Sustainable Development", in particular its goal 13, and the adoption of the Addis Ababa Action Agenda of the third International Conference on Financing for Development and the adoption of the Sendai Framework for Disaster Risk Reduction,

Recognizing that climate change represents an urgent and potentially irreversible threat to human societies and the planet and thus requires the widest possible cooperation by all countries, and their participation in an effective and appropriate international response, with a view to accelerating the reduction of global greenhouse gas emissions,

Also recognizing that deep reductions in global emissions will be required in order to achieve the ultimate objective of the Convention and emphasizing the need for urgency in addressing climate change,

Acknowledging that climate change is a common concern of humankind, Parties should, when taking action to address climate change, respect, promote and consider their respective obligations on human rights, the right to health, the rights of indigenous peoples,

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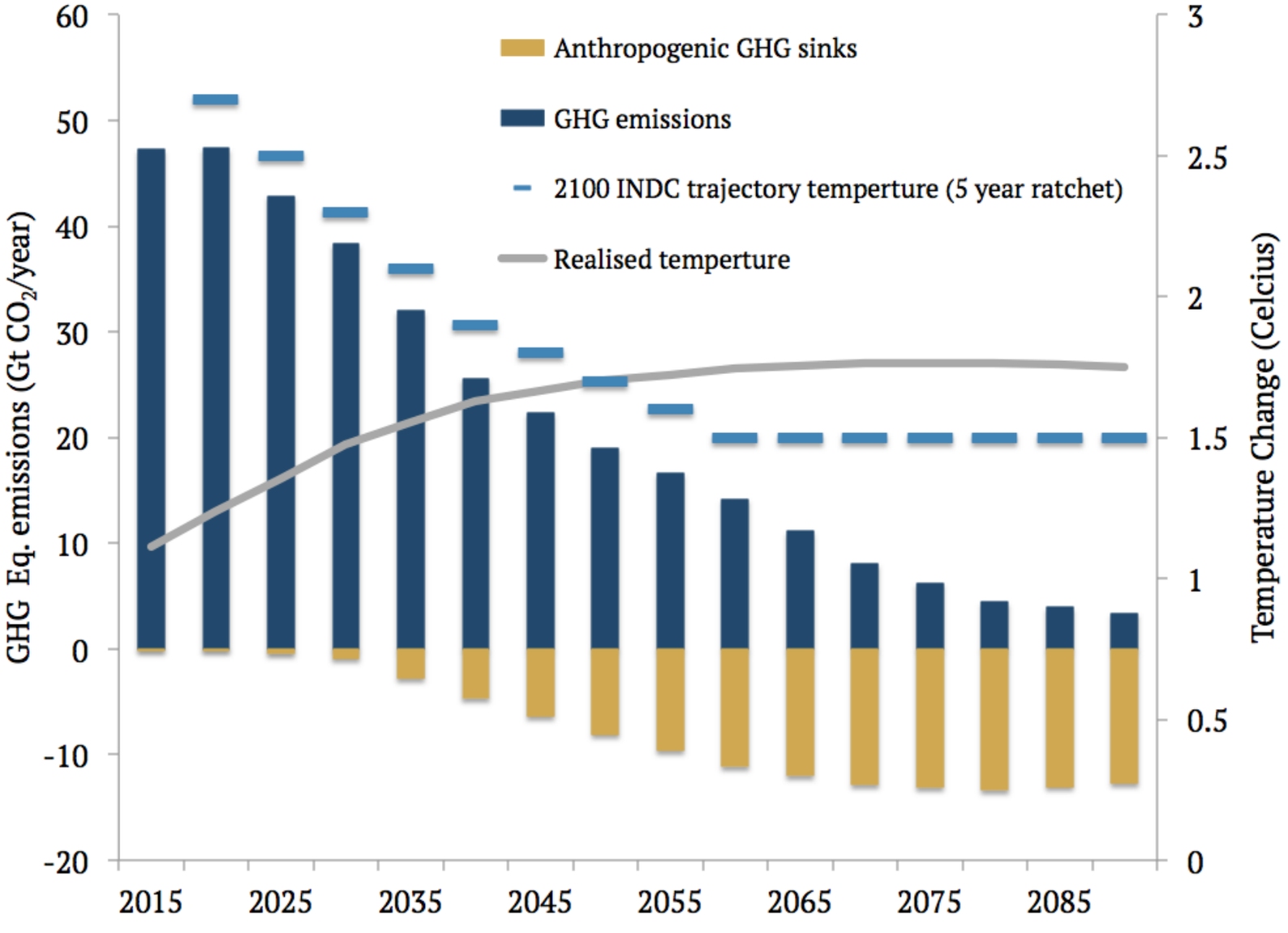
Please recycle

What might this look like?

One potential pathway



Forster (2015) - more info at www.carbonbrief.org/piers-forster-1-5c-is-a-brave-new-world

Implications of the Paris Agreement

A few important ones

» Compatible pathways require swift emission reductions

» Ratchet mechanism for targets to be set in place

» Substantial delivery of carbon sinks required

» Long term net zero target

"The government believes that we will need to take the step of enshrining the Paris goal for net zero emissions in UK law. The question is not whether but how we do it."

Andrea Leadsom

Minister of State for Energy

Current approaches to setting targets

For carbon intensity on construction projects

» Wide variation between clients (where whole life carbon is even considered)

» Different boundaries

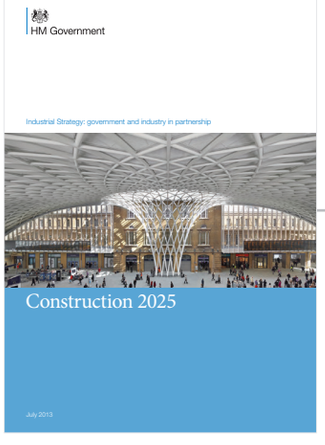
» Different baselines

» Different benchmarks

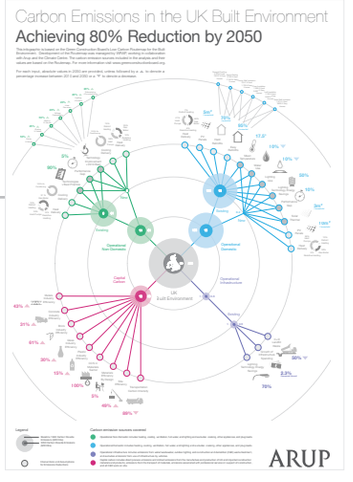
» No consistency with sectoral or national reduction targets

Aligning targets

How can national targets be translated to project level targets?



UK GHG emissions reduction targets



Construction sector GHG emissions reduction targets

?

Project level targets for clients, designers and regulators

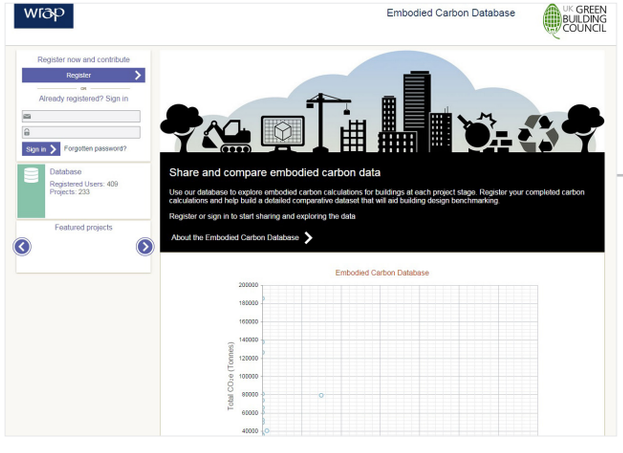
Bridging the gap

A model that integrates top down and bottom up emissions data

UK GHG emissions reduction targets

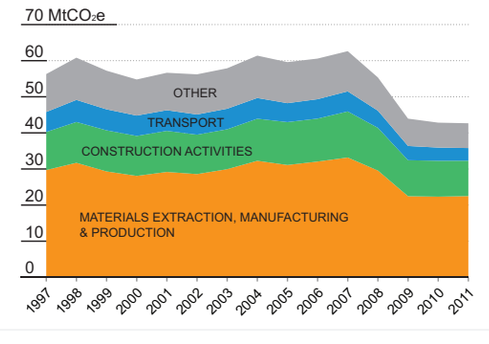
Construction sector GHG emissions reduction targets

Database of building LCA studies



UK Buildings and Infrastructure Embodied Carbon Model

UK MRIO model



Project level targets for clients, designers and regulators

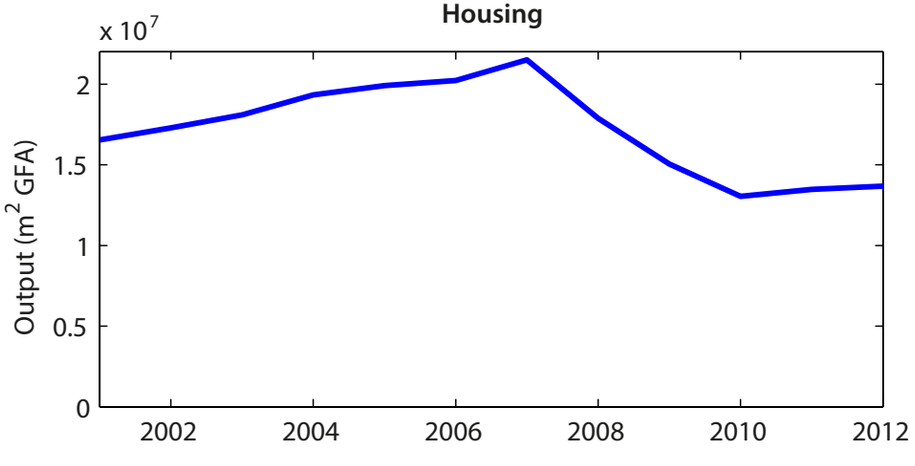
UK Buildings Embodied Carbon Model

Basic model structure

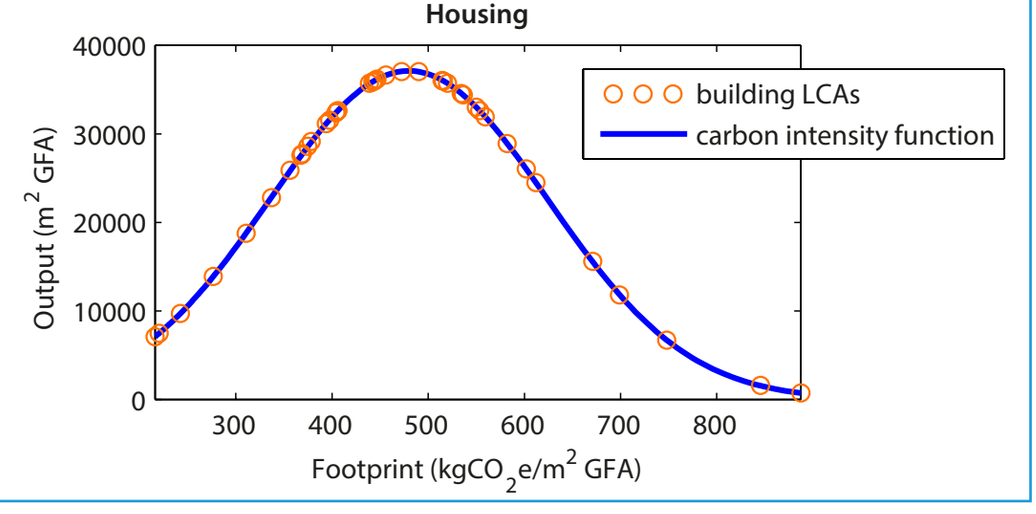
Building classes
Housing, factories, warehouses, education, health, offices, entertainment, retail, infrastructure, miscellaneous

Each building class is represented by

Output profile
Representing area of annual new build floorspace (GFA m^2).



Carbon intensity function
Function representing the range of observed embodied carbon footprints amongst buildings of that class. Based upon collected case studies and entries in WRAP embodied carbon database.



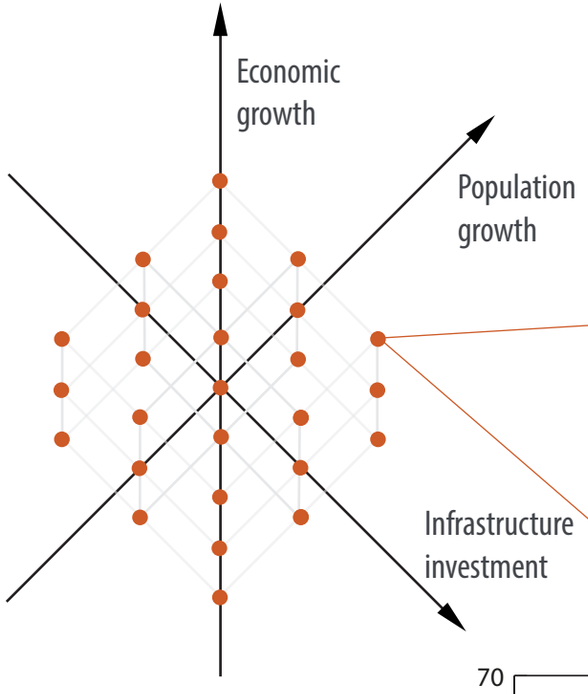
UK Buildings Embodied Carbon Model

Other features

- Callibration module that adjusts each carbon intensity function based on top down constraints (subsequent slides are based on callibration with data from 2001-2012)
- Future scenarios based upon projections of the output profile of each class
- Optional adjustment for decarbonisation of the electricity supply based upon DECC projections (with structural decomposition analysis used to estimate share of total sector emissions attributable to electricity usage)

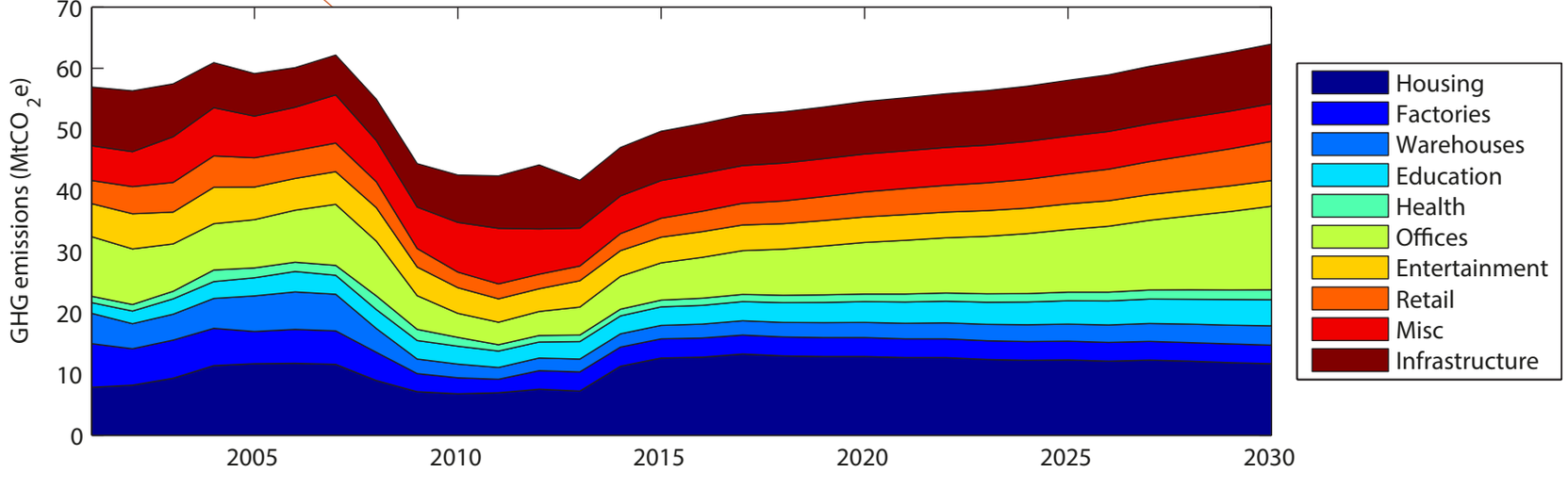
Model demand projections

27 projections (A-ZZ) for each building class up to 2030



Projection A

- Economic growth (1.7-3.1% per annum) throughout the analysis period.
- Population growth corresponding to the highest combinatorial variant of the ONS projections; household growth meets upper estimates of DCLG projections. Housebuilding increases to meet this demand.
- The increase in population is reflected in a corresponding increase in the service industry workforce with requisite increases in office and retail floorspace.
- Extensive investment in new infrastructure. All projects in the National Infrastructure Pipeline will be completed and high infrastructure investment levels will be maintained through to 2030.

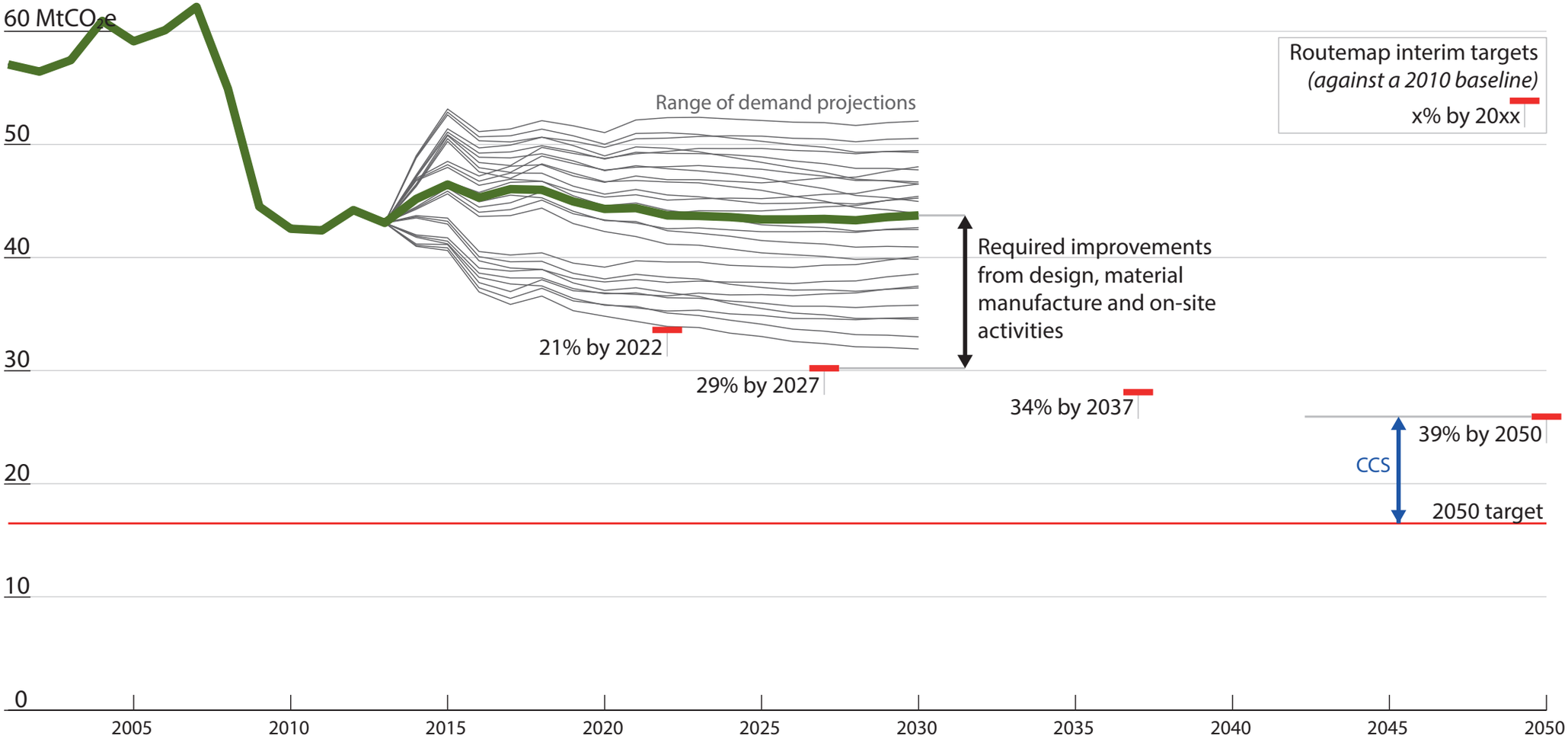


Future projections

Anticipated embodied emissions of UK construction 2001-2030

» 27 scenarios using UK Buildings and Infrastructure Embodied Carbon model

» **Including** improvements in grid intensity from DECC



Model limitations

Include

» Building carbon assessments in database have different system boundaries

» Building carbon assessments in database use different LCI datasets

» Small sample unlikely to be representative of the sector

» Model assumes carbon intensity function should be a normal distribution

» Current gaps in data filled with published benchmarks or economic data

» No explicit consideration of carbon sequestration

Intended model updates

Here are a few, more suggestions are welcome

» Addition of more building carbon assessments and subsequent disaggregation of classes

» Disaggregation of infrastructure class (as part of ITRC collaboration)

» Replacement of benchmark and price data with physical units were possible

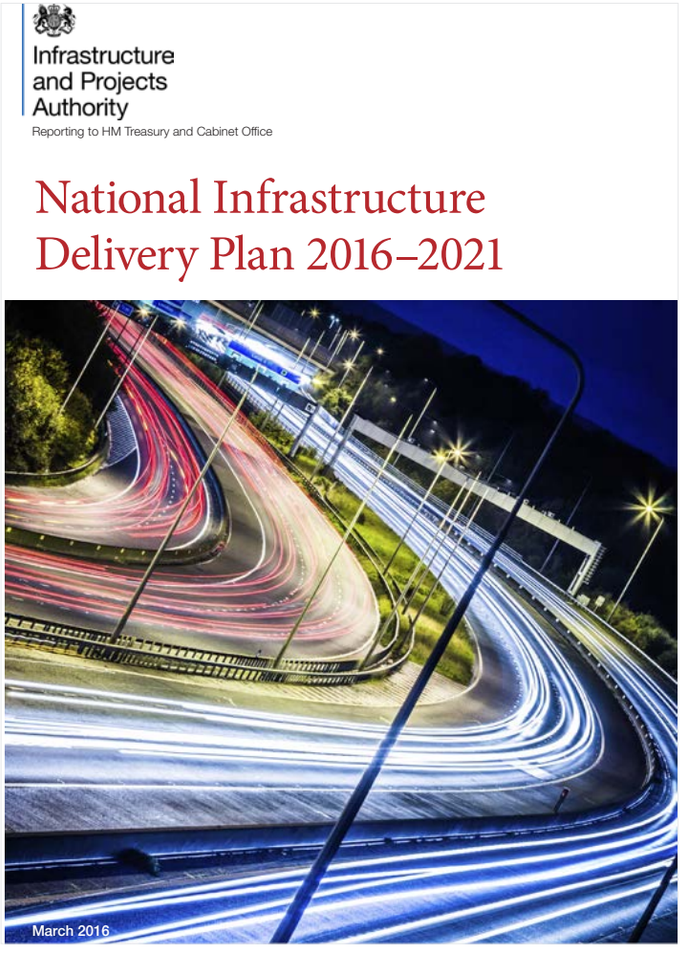
» Development of user interface

Scope for mitigation in infrastructure

Assessment of embodied carbon in NIP for CCC

» High level assessment projected ~244 $MtCO_2e$ associated with 2014 NIP

» Next step is to integrate embodied carbon into asset level demand projections



Assessment reported in CCC (2015) Meeting Carbon Budgets *Report to Parliament*

CIEMAP work in construction

Two key areas

» Assessing current and future material use and embodied carbon emissions

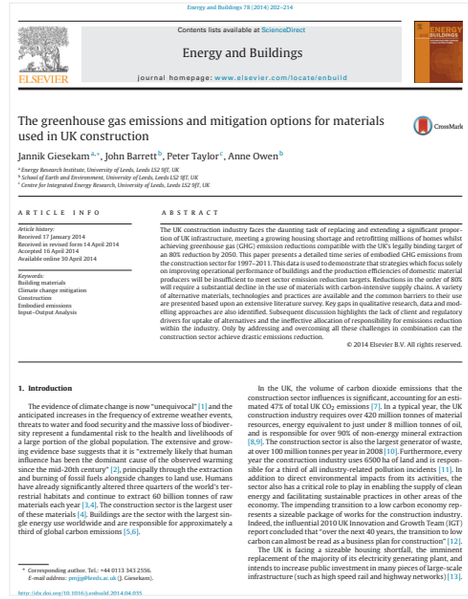
» **Understanding the barriers to greater material efficiency and the use of low carbon materials**

Within the industry

» Conducted surveys and interviews and undertaking an ongoing programme of stakeholder engagement

And amongst end users

» Upcoming collaboration between universities of York, Sheffield and Leeds assessing 'public perceptions and experiences of low carbon building materials'



Energy and Buildings 78 (2014) 202–214

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

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

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ARTICLE INFO

Article history:
Received 17 January 2014
Received in revised form 14 April 2014
Accepted 16 April 2014
Available online 30 April 2014

Keywords:
Building materials
Climate change mitigation
Construction
Embodied emissions
Input–Output Analysis

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.

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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 high way networks) [13].

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http://dx.doi.org/10.1016/j.enbuild.2014.04.035

BRI BUILDING RESEARCH & INFORMATION 2015
http://dx.doi.org/10.1080/09613218.2016.1086872

Routledge

RESEARCH PAPER

Construction sector views on low carbon building materials

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Keywords: alternative materials, CO_2 reduction, construction sector, embodied carbon, greenhouse gas emissions, market acceptance, professional knowledge

Introduction

The construction sector is the largest global consumer of materials, and buildings are the sector with the largest single energy use worldwide (Krausmann et al., 2009; De la Rue du Can & Price, 2008). Consequently, buildings are also responsible for 19% of global greenhouse gas (GHG) emissions (Intergovernmental Panel on Climate Change (IPCC), 2014). Recent studies have suggested that buildings offer the greatest abatement opportunities for reducing GHG emissions in the short-term (IPCC, 2014; McKinsey & Co., 2009). Policy-makers have responded to this through the introduction of regulation requiring improvements in building fabric and performance, such as the European Union (EU) Energy Performance of Buildings Directive. These regulations have principally focused on the operational GHG emissions associated with energy use in activities such as space heating, cooling and lighting. However, these regulatory drivers have not extended to the embodied carbon[1] associated with the initial production of structures (Figure 1).

A recent review of building life cycle assessments demonstrated that embodied carbon can account for anywhere between 2% and 80% of whole-life carbon emissions (Ibn-Mohammed, Greenough, Taylor, Ozawa-Meida, & Acquaye, 2013). The precise proportion depends upon a number of characteristics including building use, location, material palette, and assumptions about the service life and future energy supply. The proportion tends to be higher in certain structure types, such as industrial warehousing, where embodied emissions can contribute up to 90%

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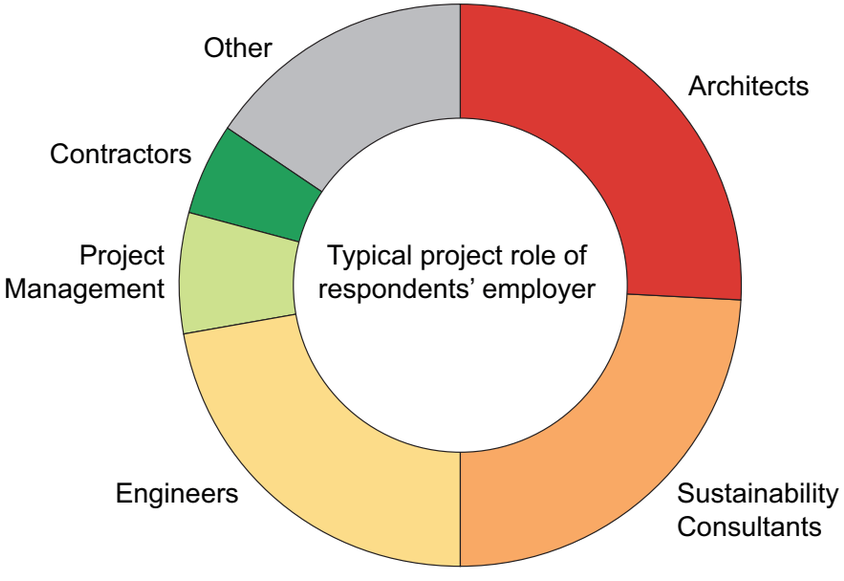
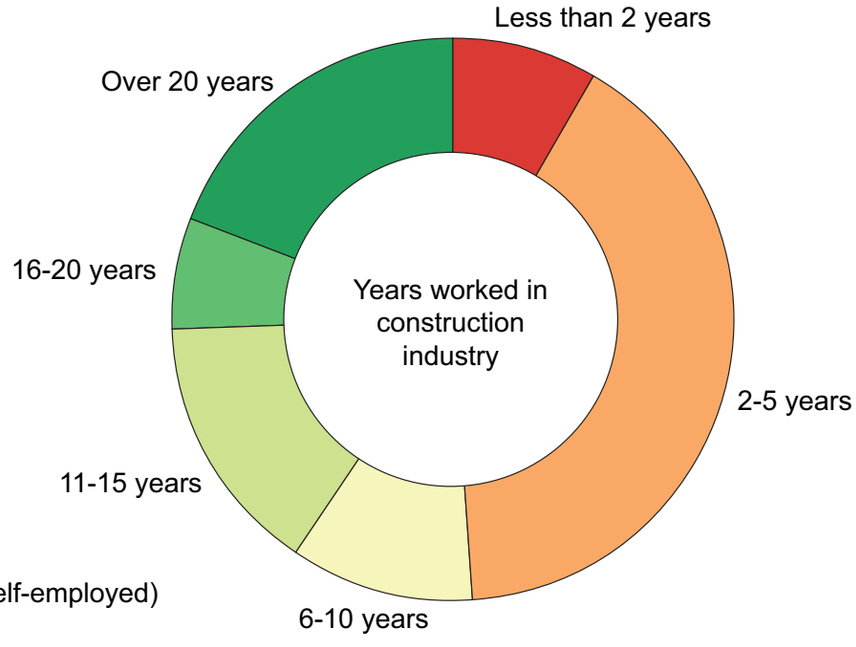
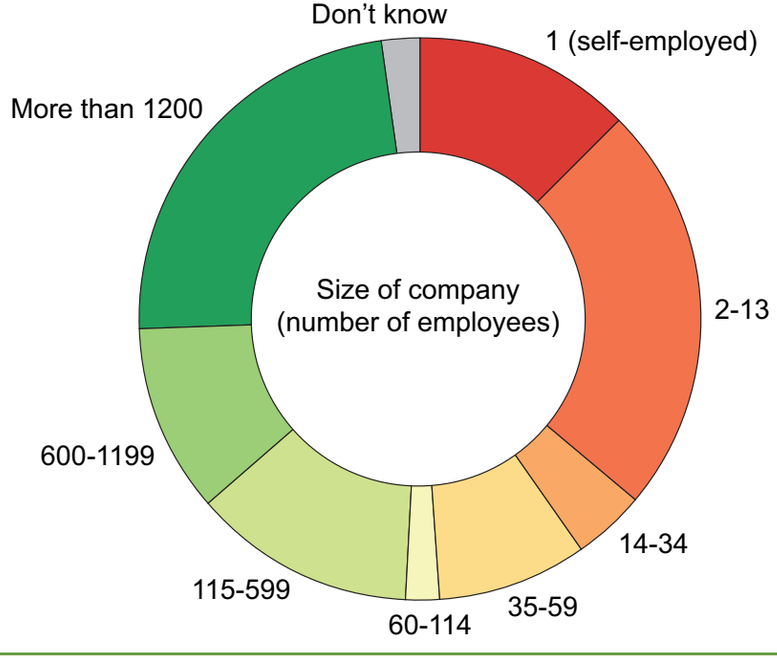
Giesekam et al. (2014) The GHG emissions and mitigation options for materials used in UK construction *Energy and Buildings*
Giesekam et al. (2016) Construction sector views on low carbon building materials *Building Research & Information*

Survey demographics

47 responses; range of professions, companies and experience



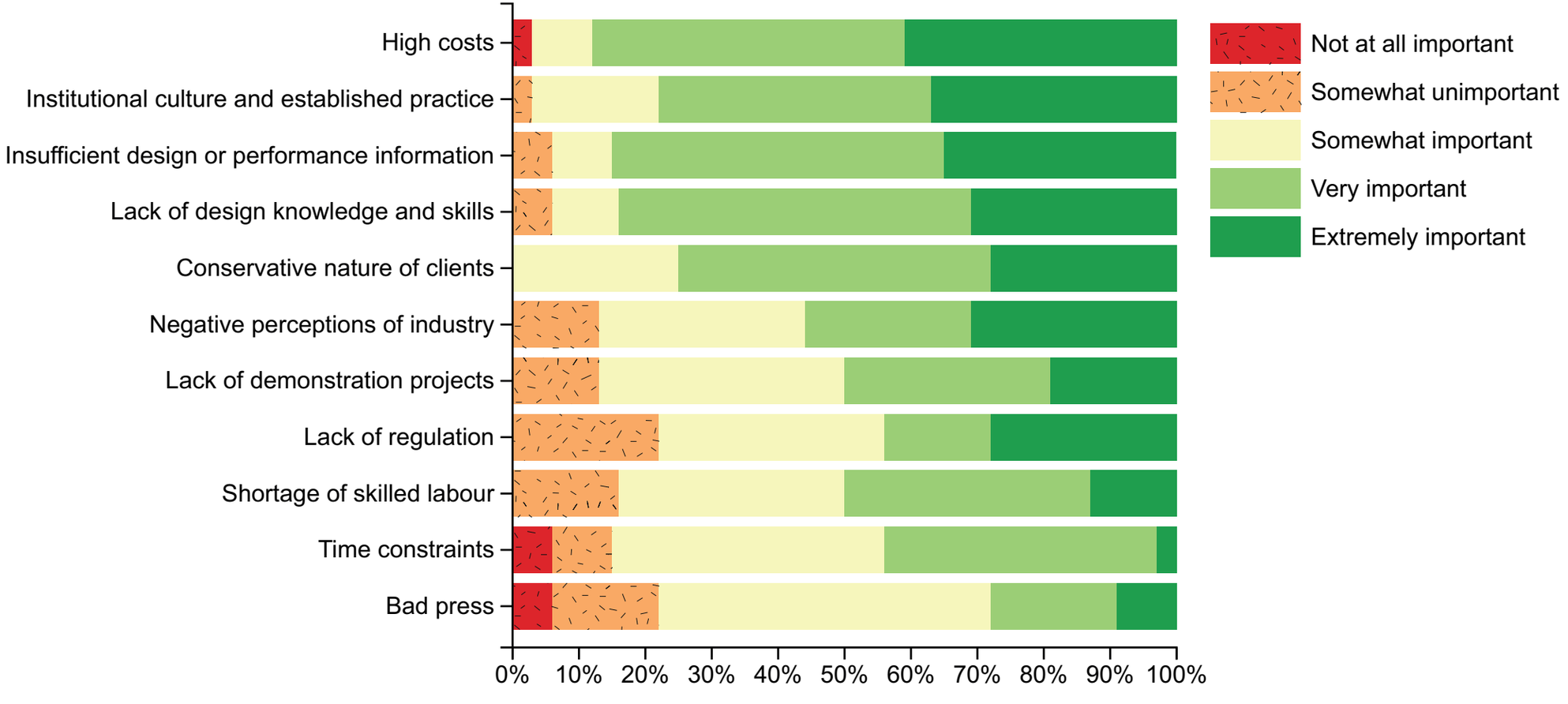




Survey results

General barriers

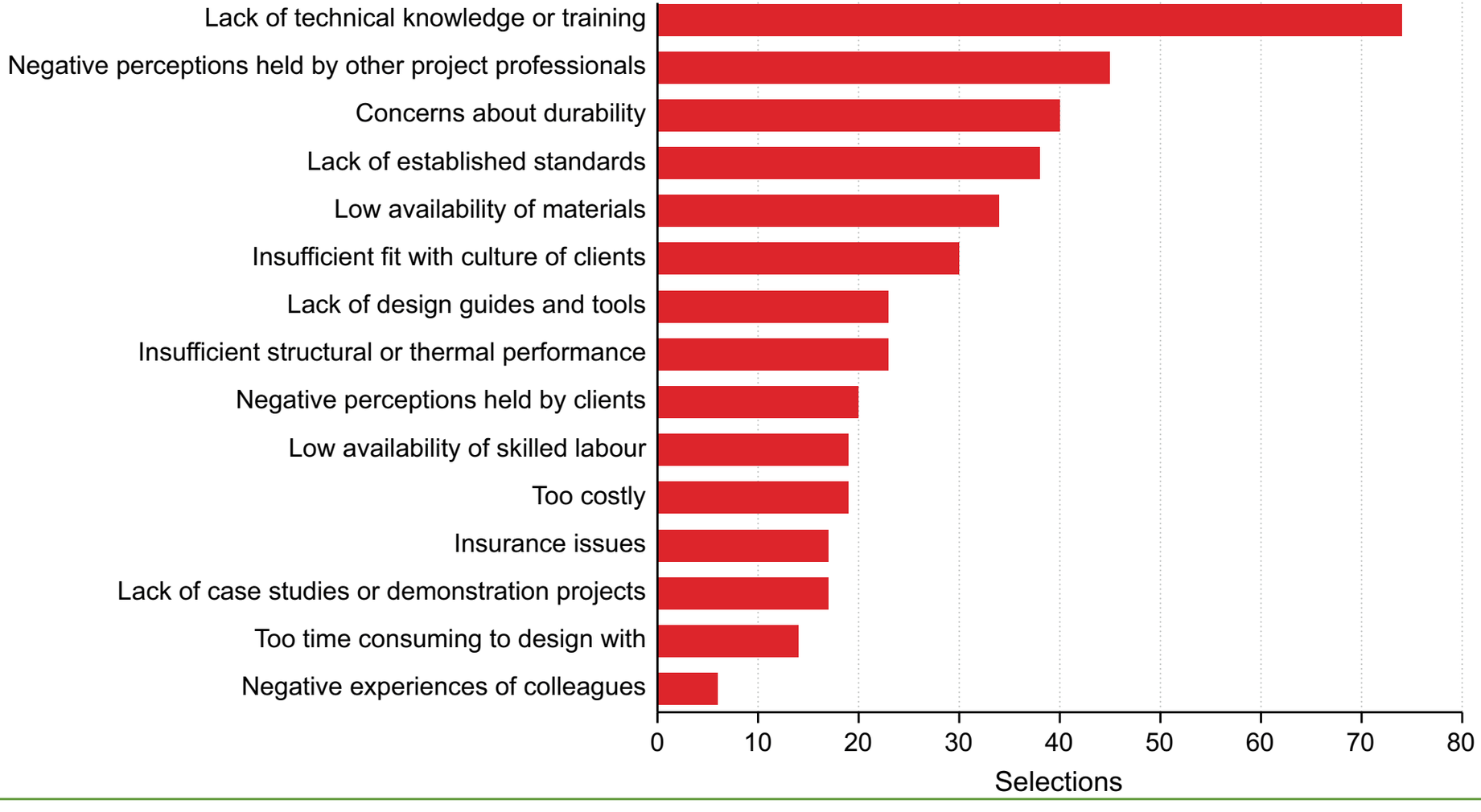
Responses to survey question #19:
Thinking more generally about alternative materials in construction, how important do you believe the following factors are in preventing their use?



Survey results

Specific experiences

Responses to survey question #17:
You stated that you are aware of but have not used the following materials on a project. Why have you chosen not to use these materials?



Survey results

Principal barriers

» Perception of high costs

» Dearth of knowledge, understanding and skills

» Lack of quality benchmark data

» Availability of product carbon information

» Insufficient allocation of responsibility for embodied carbon reduction

» Industry culture

» Low value of materials

» Negative perceptions of low carbon materials

» Lack of demonstration projects and product testing

Survey results

Features of projects with successful adoption of novel materials

» Highly motivated client

» Early engagement of full supply chain

» Targets and contractual obligations that ensure alignment of value chain

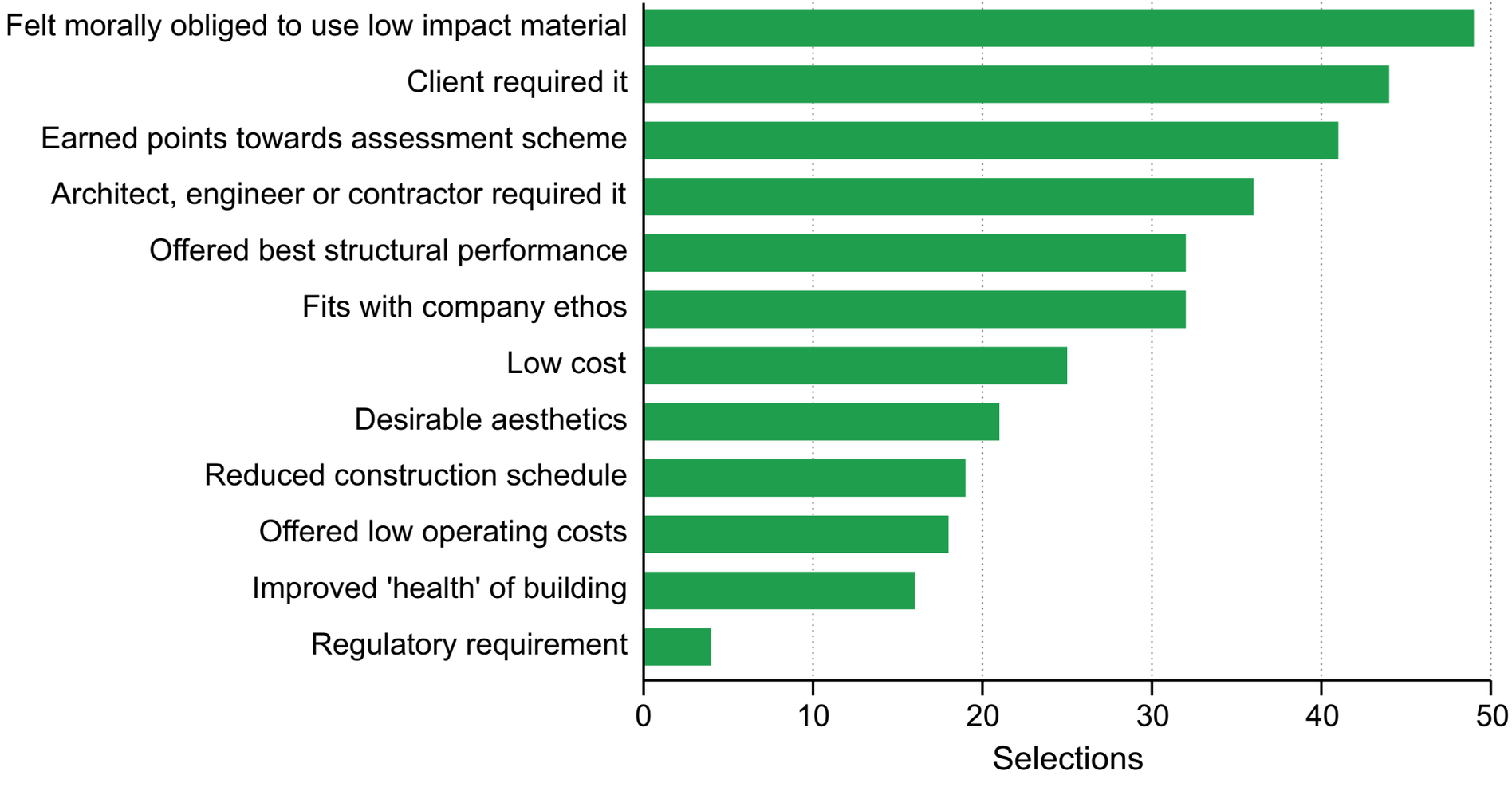
» Novel materials positioned as integral to satisfaction of project constraints

» Frequent communication and knowledge shared across project team

Survey results

Current drivers

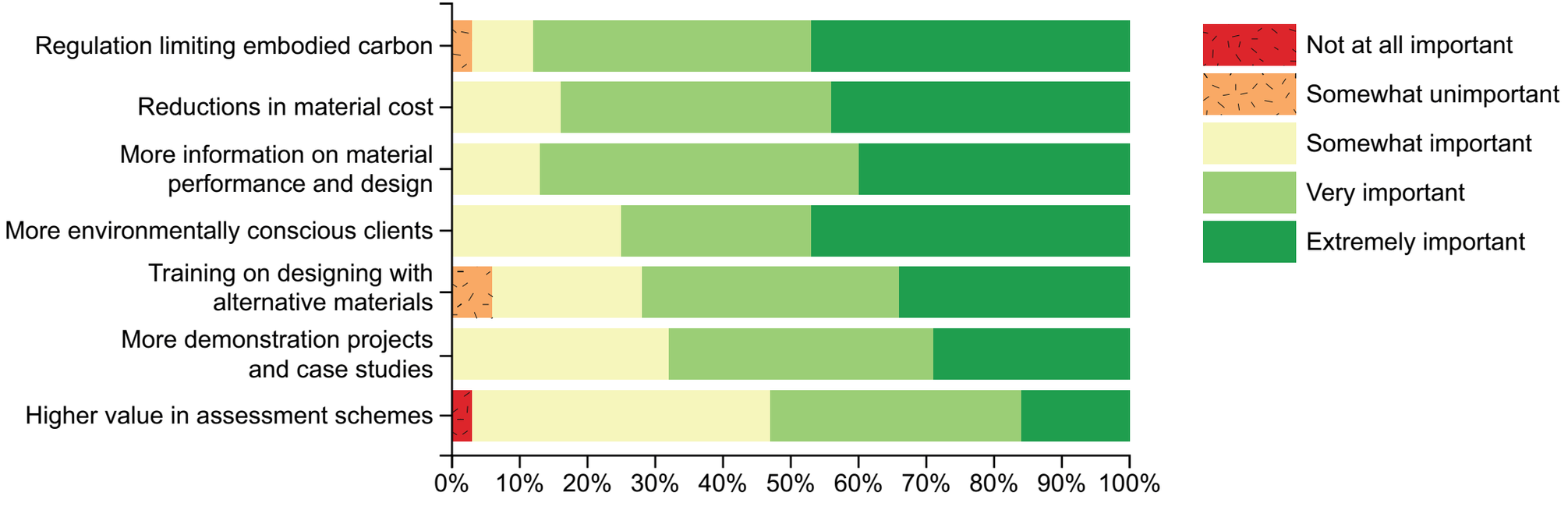
Responses to survey question #13:
Thinking about the projects on which you used these materials. Why did you choose to use each material?



Survey results

Potential drivers

Responses to survey question #21:
How important do you believe the following developments could be in encouraging greater use of alternative materials and construction products?



Interview results

The importance of drivers

> *"Architects and engineers want to produce better buildings. If by managing embodied carbon, as well as operational carbon, you're producing a better building then there'll be no resistance at all. But you've got to think about the drivers for that. The drivers need to be cost and regulatory.* ***If you've got the drivers there it'll just get done****. No-one will even begin to question it."*
>
> Chair of embodied carbon task force

Why use sustainable materials?

Potential benefits

» Improved resource efficiency

» Embodied/capital carbon reduction

» Improved air quality and occupant health

» Better resource security

» Greater energy efficiency

» Improved social sustainability (e.g. local employment) etc.

Drivers and incentives

» Cost savings

» Credits in environmental assessment schemes (BREEAM, LEED etc.)

» Green reputation

» Moral convictions

» Client demands

Drivers of low carbon construction

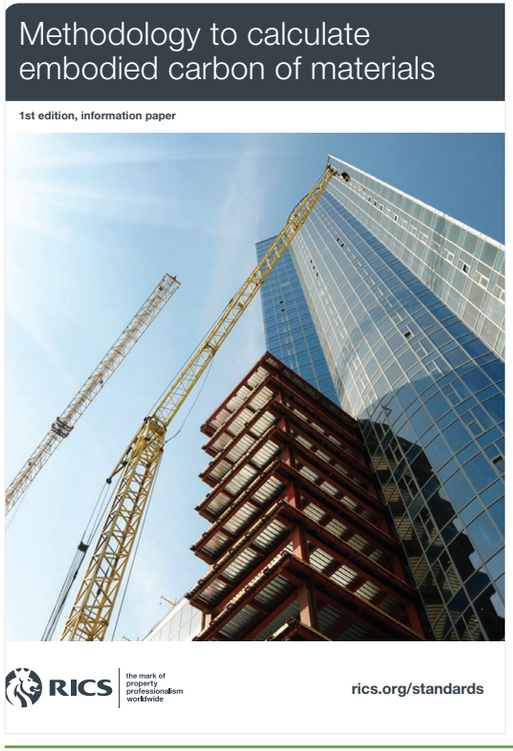
Client demands and leadership from industry

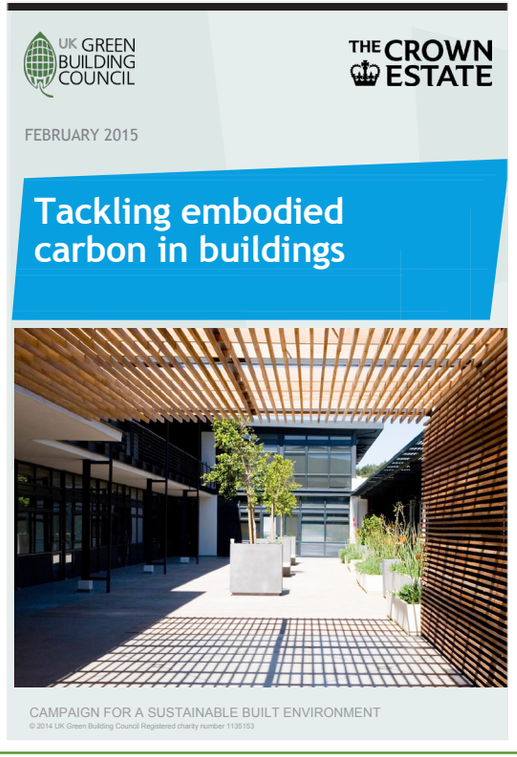
» 50+ organisations signed up to Infrastructure Carbon Review

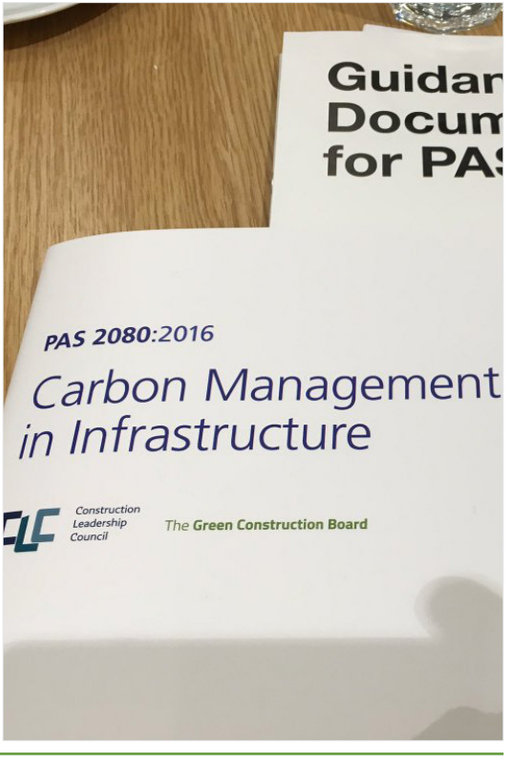
» 30+ organisations with commitments to measure or reduce embodied carbon in buildings

» 10+ Local Authorities interested

» Wealth of recent guidance documents



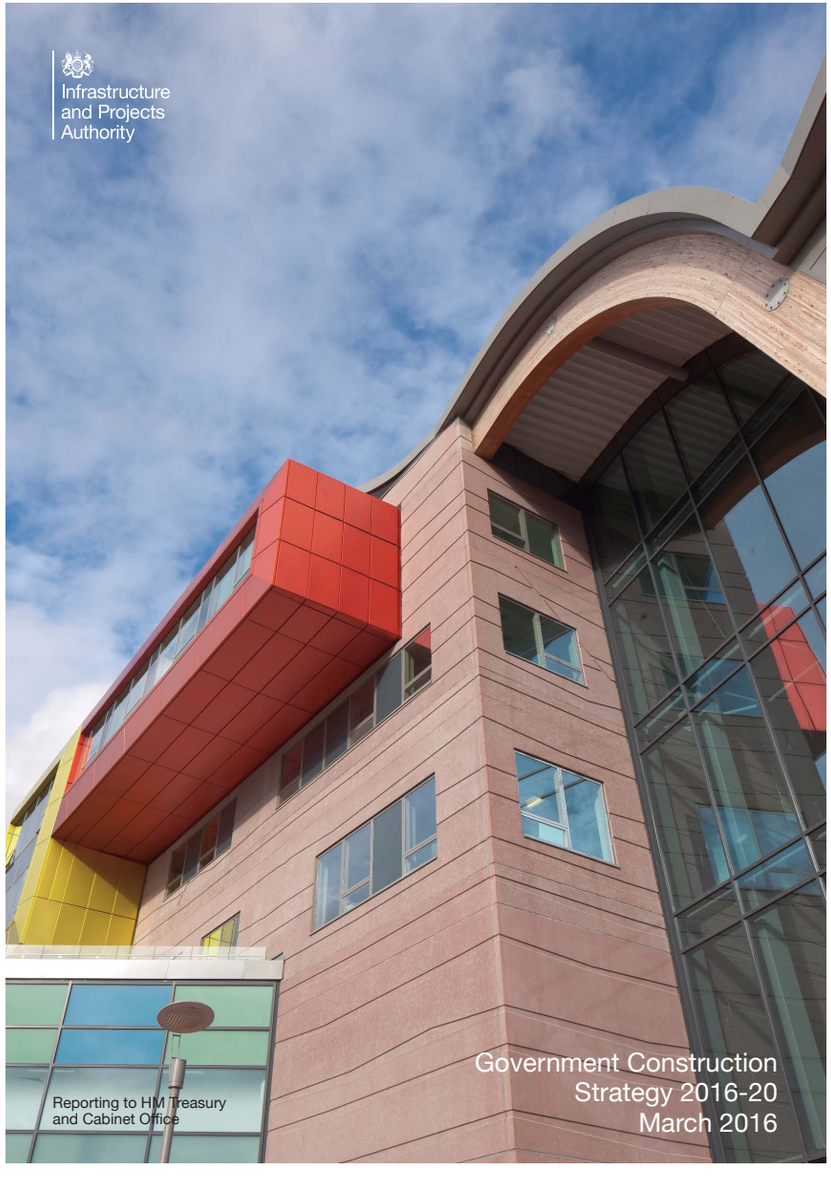




Government Construction Strategy

For the current parliament

- One of the principal objectives is to *"enable and drive whole-life approaches to cost and carbon reduction"*
- Objective 3.6 is to *"Develop data requirements and benchmarks for measurement of whole-life cost and whole-life carbon (embodied and operational)"*
- *"Government contracts will encourage innovative sustainability solutions on carbon reduction where value can be demonstrated"*
- Aim of ultimately forming *"recommendations for a future approach"*



How to turn targets into drivers?

Industry and academia must address the following

» Ownership of the issue (within industry and within government)

» Advocacy

» Evidence gathering

» Developing the narrative

» Demonstrating leadership

The policy problem

In short

» Embodied emissions are a significant proportion of total emissions

» We don't know how much they will need to reduce by

» We need actions and policy that is more resilient to the political cycle than recent examples (Zero Carbon Homes, Code for Sustainable Homes, Green Deal)

» We need an approach that connects short-term actions and policy to long-term systemic changes

» We need an approach that can be flexible in the face of deep uncertainty

» We need a forward-looking approach to create an environment that enables business decision making

Dynamic Adaptive Policy Pathways

Introducing a new approach to fill the policy void

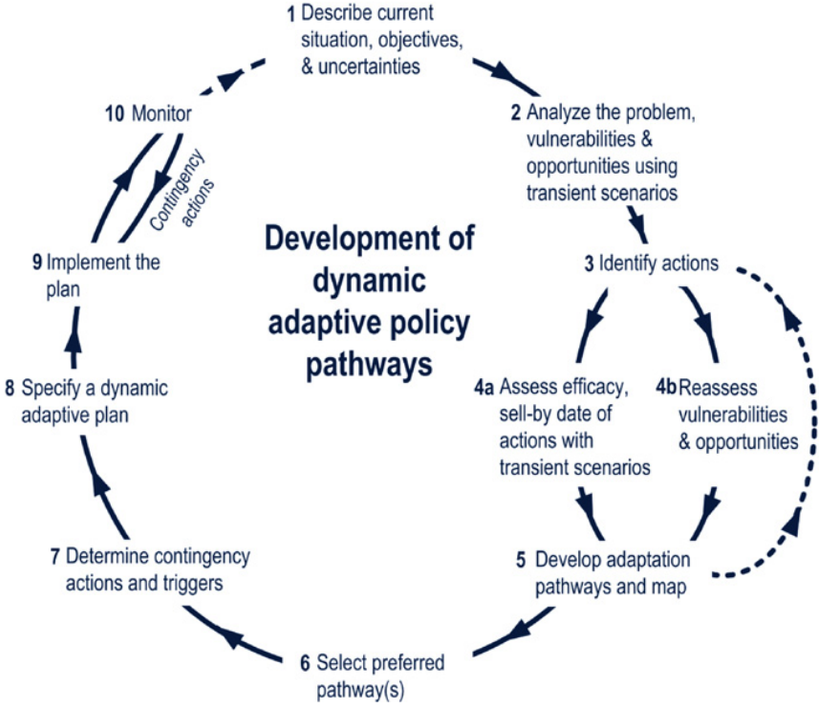


Fig. 4. The Dynamic Adaptive Policy Pathways approach.

Fig. 6. Adaptation pathways map for fresh water supply from the IJsselmeer area.

Developing the approach

Workshop with industry practitioners

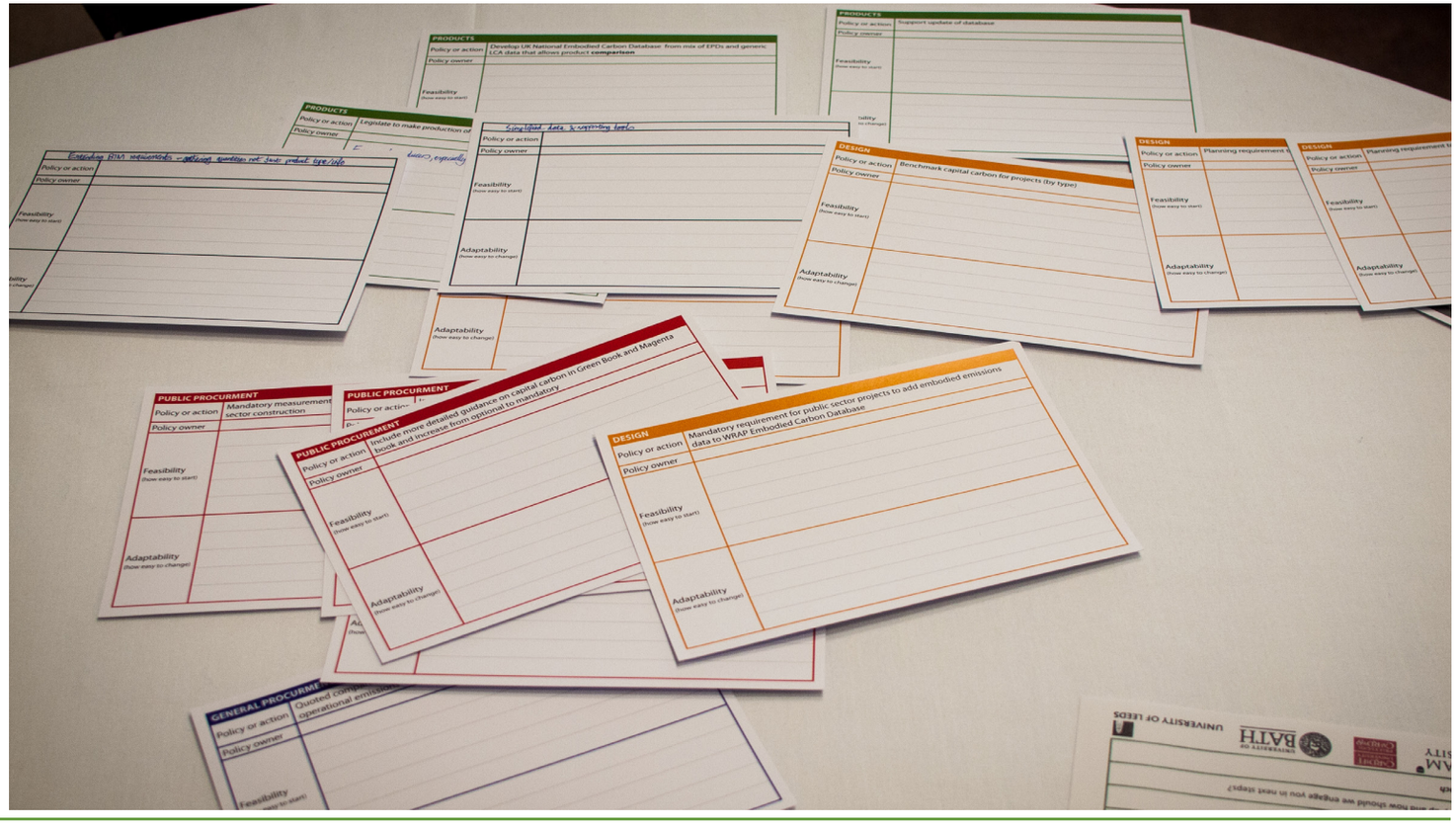
» Small, focussed workshop at Royal Academy of Engineering on 11/09/15

» Session 1 - review of policy options

» Session 2 - sequencing policies, considering adaptability and implementation

» Focus upon understanding feasibility, flexibility, and responsibility

Supply chain area	Policy/action
Products	Develop UK National Embodied Carbon Database from mix of EPDs and generic LCA data that allows product **comparison**
	Support update of database
	Legislate to make production of EPDs mandatory
	Legislate to achieve minimum EPD standards with penalty for exceedance/ incentive for going under
	Develop certification systems for alternative materials
	Provide guidance and supporting training in use of alternative materials
	Promotion and advocacy for alternative materials
	Q. What support do small manufacturers of alternative materials need to reduce failure rate?
Public procurement and regulated sectors	Develop approach for performance-based specification across all sectors and construction types
	Extend the public sector green procurement framework to be more rigorous and relevant to construction
	Mandatory measurement and reporting of capital carbon on public and regulated sector construction
	Include more detailed guidance on capital carbon in Green Book and Magenta book and increase from optional to mandatory
	Include explicit calculation and reporting of capital carbon in National Infrastructure Plan
General procurement	Extend WRAP's work on Carbon Efficient Procurement to make embodied emissions mandatory and to strengthen methods
	Promote strengthened work on Carbon Efficient Procurement
	Quoted companies must report GHGs embodied in new buildings in addition to operational emissions
	Q. How do we address end user perceptions of low embodied carbon materials?
Design	Voluntary requirement for large contractors to add embodied emissions data to WRAP Embodied Carbon Database
	Mandatory requirement for public sector projects to add embodied emissions data to WRAP Embodied Carbon Database
	Planning requirement to report capital carbon
	Benchmark capital carbon for projects (by type)
	Legislate to achieve minimum capital carbon standards with penalty for exceedance/ incentive for going under
	Planning requirement to report measures to design for deconstruction
Build	Minimum efficiency standard for site accommodation
	Emissions standards for construction plant
End of Life	Mandatory labelling of products that have potential for re-use
	Develop database of materials in use that are suitable for re-use at end of life
	Q. How do we deal with the transfer of ownership when considering how to retain value of materials at the end of their life?



Summary

CIEMAP upcoming work

- Further development of the UK Buildings and Infrastructure Embodied Carbon model
- Carbon assessment of infrastructure scenarios for National Needs Assessment
- Developing potential policy responses for whole life carbon reduction
- Understanding public perceptions and experiences of low carbon building materials
- Please send all comments & ideas for collaborations to J.Giesekam@leeds.ac.uk