From targets to benchmarks: developing a UK Buildings Embodied Carbon Model

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Embodied carbon is significant

Carbon footprint of UK construction supply chain

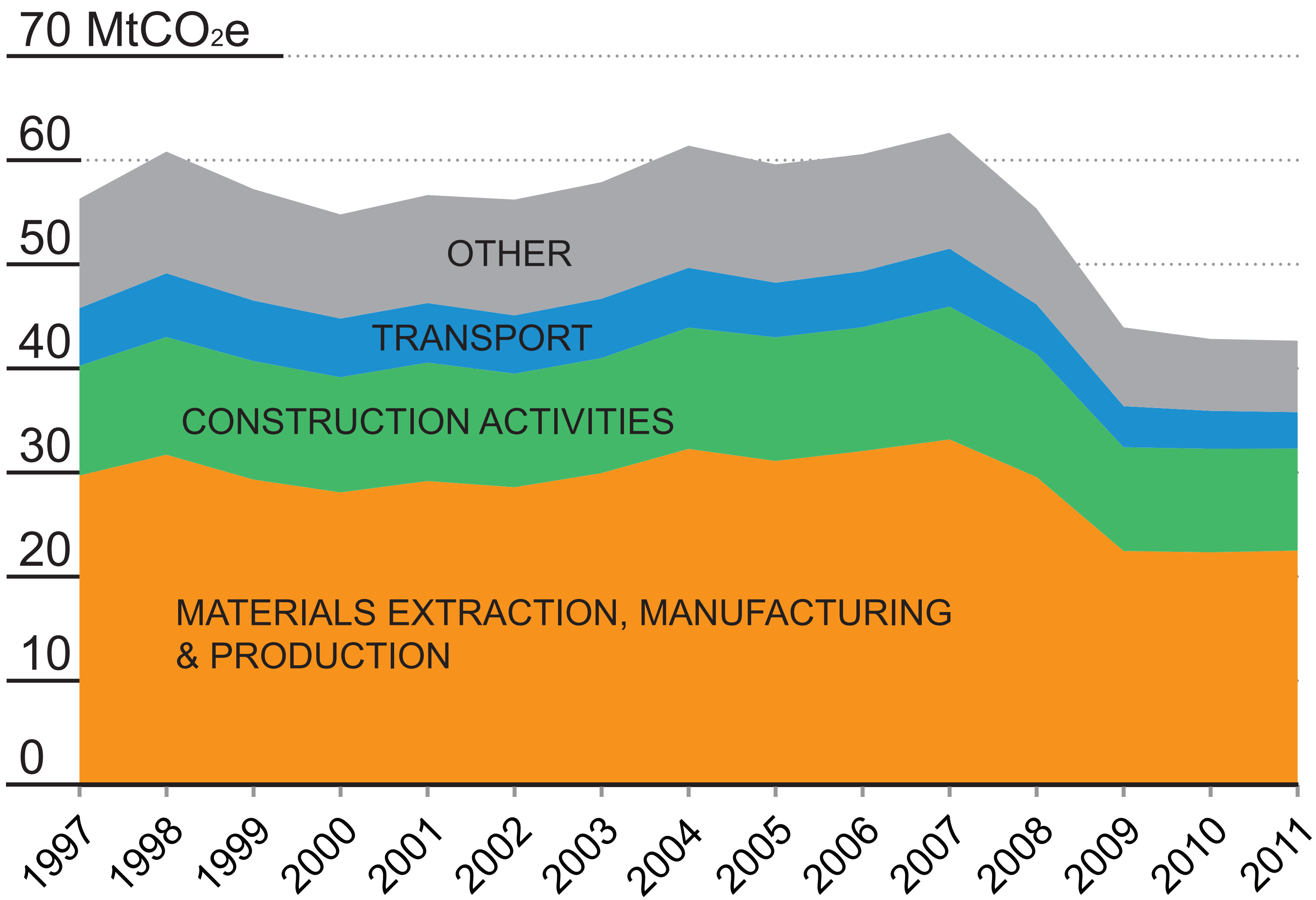
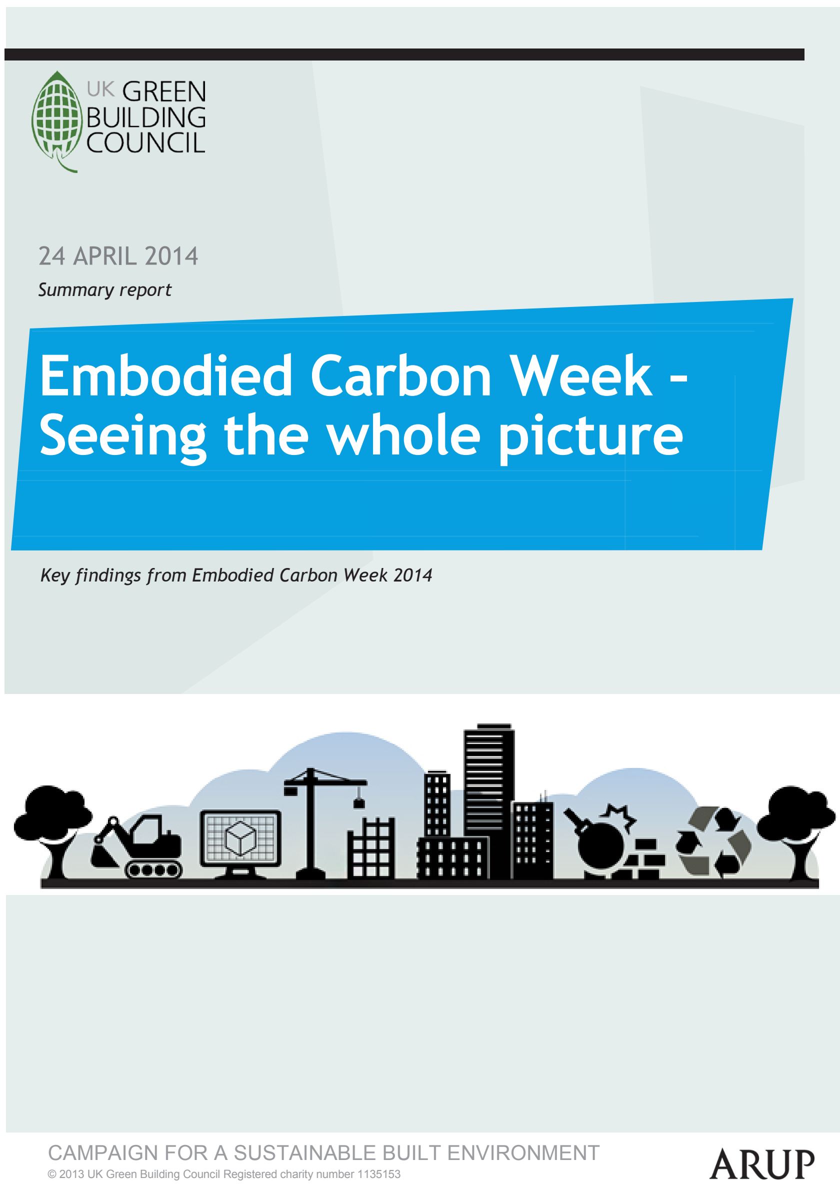


Figure from Giesekam et al. Energy and Buildings 78 pp202-214 (2014)

Practitioners are interested

UKGBC Embodied Carbon Week and WRAP database


UK GREEN BUILDING COUNCIL

24 APRIL 2014

Summary report

Embodied Carbon Week - Seeing the whole picture

Key findings from Embodied Carbon Week 2014

CAMPAIGN FOR A SUSTAINABLE BUILT ENVIRONMENT

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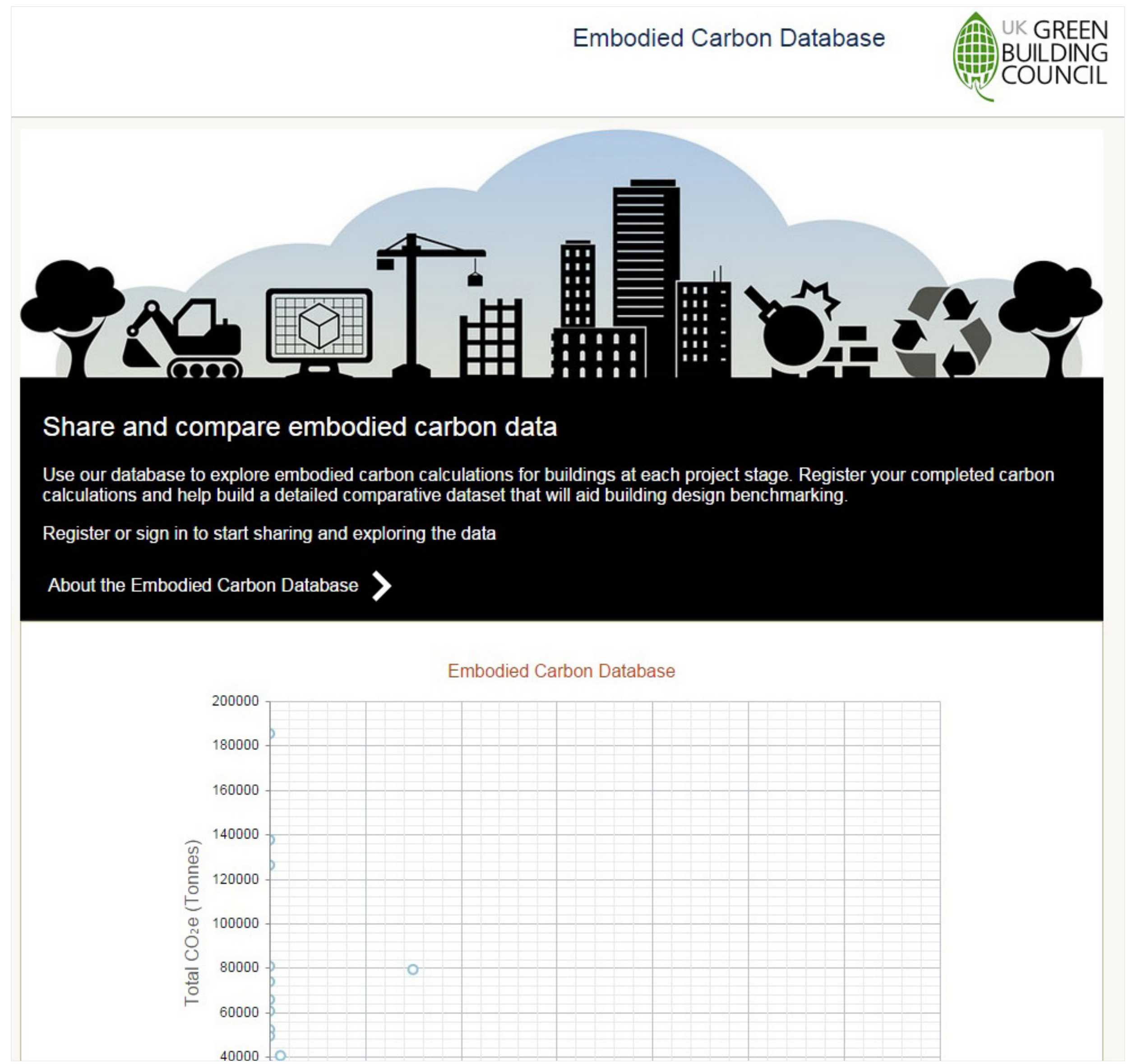
ARUP



Clients are interested

Large clients such as British Land, M&S, The Crown Estate etc.

» M&S commitment to addressing embodied carbon

91

Embodied carbon in buildings

Aim: By 2020, we will reduce the embodied carbon in UK and RoI new store builds by addressing the carbon 'hotspots' of walls, ceilings and floors where possible.

» British Land reduction requirements on large projects

» **FOR PROJECTS >£50m** Reduce embodied carbon in concrete, steel, rebar, aluminium and glass by 10% compared to the concept design

» The Crown Estate have added embodied carbon as one of their sustainability KPIs

5 Sustainability KPIs

5.1 Materials

KPI	Applies To
Embodied Carbon, $kgCO_2/m^2/yr$ (1)	All projects

» Prologis UK have had requirements to minimise and offset embodied carbon since 2009

Marks and Spencer (2014) Plan A Report 2014
British Land (2014) Supporting Communities and Enhancing Environments: Sustainability Brief for Developments
The Crown Estate (2013) Development Sustainability Principles

Regulators are (sort of) interested

Already precedents at local and international level

- » 6 local authorities (e.g. Brighton & Hove County Council) require embodied carbon estimates
- » Requirements for embodied carbon assessment in the Netherlands and Germany (and will shortly be introduced in several other countries)
- » Embodied carbon likely to be an indicator in new EU harmonised sustainability assessment framework
- » Embodied Carbon Task Force currently lobbying for inclusion of embodied carbon abatement as an Allowable Solution

Mentioned in the UK-GBC's 10 point plan for buildings in the next parliament

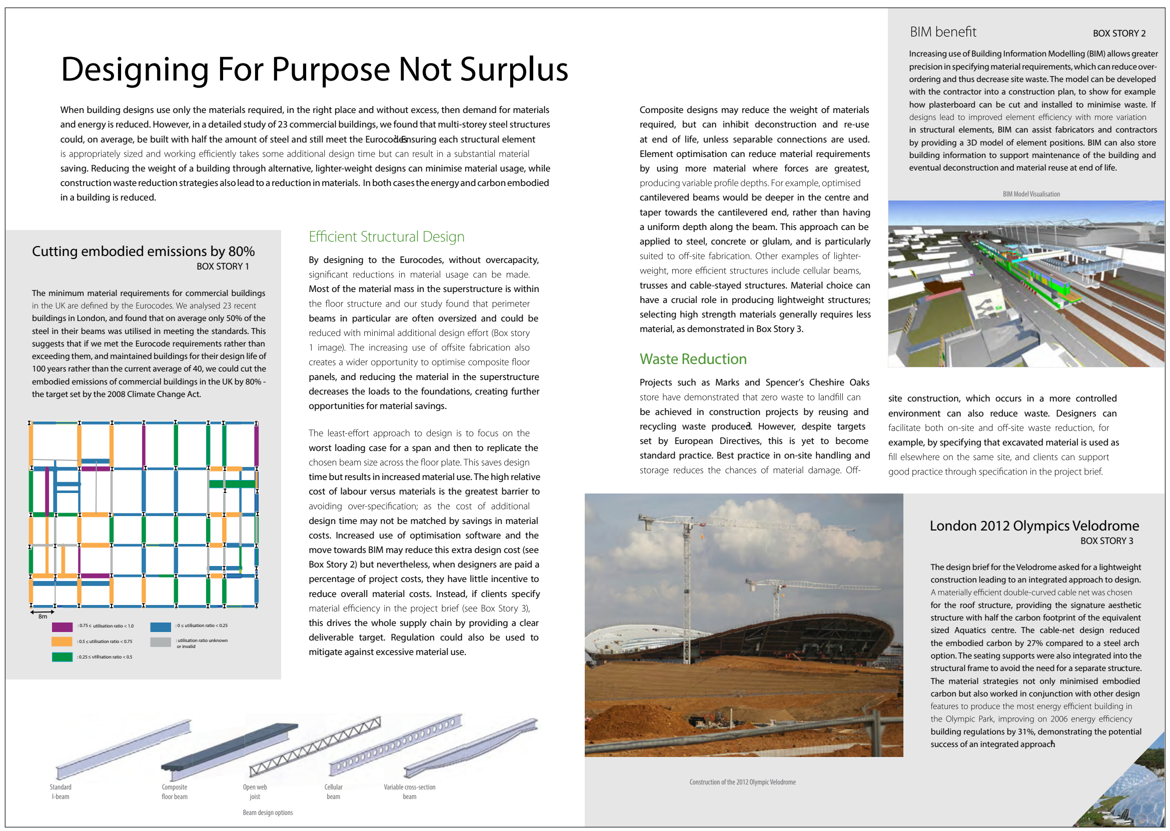
9 ANNOUNCE PLANS FOR FUTURE STANDARDS OF NEW HOMES AND NON-DOMESTIC BUILDINGS

The success of the zero carbon policy for homes has demonstrated the effectiveness of providing a long term trajectory for improving standards in new buildings. Government should build on the zero carbon targets, to plan for the inclusion of unregulated and embodied energy in building regulations, and ensure all new buildings help to drive community-scale energy solutions.

Strategies to reduce embodied carbon

Main strategies

- » Designing for purpose not surplus
- » Building life extension
- » Designing for deconstruction and re-use
- » Using alternative materials



Designing For Purpose Not Surplus

When building designs use only the materials required, in the right place and without excess, then demand for materials and energy is reduced. However, in a detailed study of 23 commercial buildings, we found that multi-storey steel structures could, on average, be built with half the amount of steel and still meet the Eurocodes.[1] Ensuring each structural element is appropriately sized and working efficiently takes some additional design time but can result in a substantial material saving. Reducing the weight of a building through alternative, lighter-weight designs can minimise material usage, while construction waste reduction strategies also lead to a reduction in materials. In both cases the energy and carbon embodied in a building is reduced.

Cutting embodied emissions by 80%

BOX STORY 1

The minimum material requirements for commercial buildings in the UK are defined by the Eurocodes. We analysed 23 recent buildings in London, and found that on average only 50% of the steel in their beams was utilised in meeting the standards. This suggests that if we met the Eurocode requirements rather than exceeding them, and maintained buildings for their design life of 100 years rather than the current average of 40, we could cut the embodied emissions of commercial buildings in the UK by 80% - the target set by the 2008 Climate Change Act.

8m

: 0.75 ≤ utilisation ratio < 1.0

: 0 ≤ utilisation ratio < 0.25

: 0.5 ≤ utilisation ratio < 0.75

: utilisation ratio unknown or invalid

: 0.25 ≤ utilisation ratio < 0.5

Efficient Structural Design

By designing to the Eurocodes, without overcapacity, significant reductions in material usage can be made. Most of the material mass in the superstructure is within the floor structure and our study found that perimeter beams in particular are often oversized and could be reduced with minimal additional design effort (Box story 1 image). The increasing use of offsite fabrication also creates a wider opportunity to optimise composite floor panels, and reducing the material in the superstructure decreases the loads to the foundations, creating further opportunities for material savings.

The least-effort approach to design is to focus on the worst loading case for a span and then to replicate the chosen beam size across the floor plate. This saves design time but results in increased material use. The high relative cost of labour versus materials is the greatest barrier to avoiding over-specification; as the cost of additional design time may not be matched by savings in material costs. Increased use of optimisation software and the move towards BIM may reduce this extra design cost (see Box Story 2) but nevertheless, when designers are paid a percentage of project costs, they have little incentive to reduce overall material costs. Instead, if clients specify material efficiency in the project brief (see Box Story 3), this drives the whole supply chain by providing a clear deliverable target. Regulation could also be used to mitigate against excessive material use.

Composite designs may reduce the weight of materials required, but can inhibit deconstruction and re-use at end of life, unless separable connections are used. Element optimisation can reduce material requirements by using more material where forces are greatest, producing variable profile depths. For example, optimised cantilevered beams would be deeper in the centre and taper towards the cantilevered end, rather than having a uniform depth along the beam. This approach can be applied to steel, concrete or glulam, and is particularly suited to off-site fabrication. Other examples of lighter-weight, more efficient structures include cellular beams, trusses and cable-stayed structures. Material choice can have a crucial role in producing lightweight structures; selecting high strength materials generally requires less material, as demonstrated in Box Story 3.

Waste Reduction

Projects such as Marks and Spencer's Cheshire Oaks store have demonstrated that zero waste to landfill can be achieved in construction projects by reusing and recycling waste produced[2]. However, despite targets set by European Directives, this is yet to become standard practice. Best practice in on-site handling and storage reduces the chances of material damage. Off-site construction, which occurs in a more controlled environment can also reduce waste. Designers can facilitate both on-site and off-site waste reduction, for example, by specifying that excavated material is used as fill elsewhere on the same site, and clients can support good practice through specification in the project brief.

BIM benefit

BOX STORY 2

Increasing use of Building Information Modelling (BIM) allows greater precision in specifying material requirements, which can reduce over-ordering and thus decrease site waste. The model can be developed with the contractor into a construction plan, to show for example how plasterboard can be cut and installed to minimise waste. If designs lead to improved element efficiency with more variation in structural elements, BIM can assist fabricators and contractors by providing a 3D model of element positions. BIM can also store building information to support maintenance of the building and eventual deconstruction and material reuse at end of life.

BIM Model Visualisation

London 2012 Olympics Velodrome

BOX STORY 3

The design brief for the Velodrome asked for a lightweight construction leading to an integrated approach to design. A materially efficient double-curved cable net was chosen for the roof structure, providing the signature aesthetic structure with half the carbon footprint of the equivalent sized Aquatics centre. The cable-net design reduced the embodied carbon by 27% compared to a steel arch option. The seating supports were also integrated into the structural frame to avoid the need for a separate structure. The material strategies not only minimised embodied carbon but also worked in conjunction with other design features to produce the most energy efficient building in the Olympic Park, improving on 2006 energy efficiency building regulations by 31%, demonstrating the potential success of an integrated approach[3]

Construction of the 2012 Olympic Velodrome

Standard I-beam

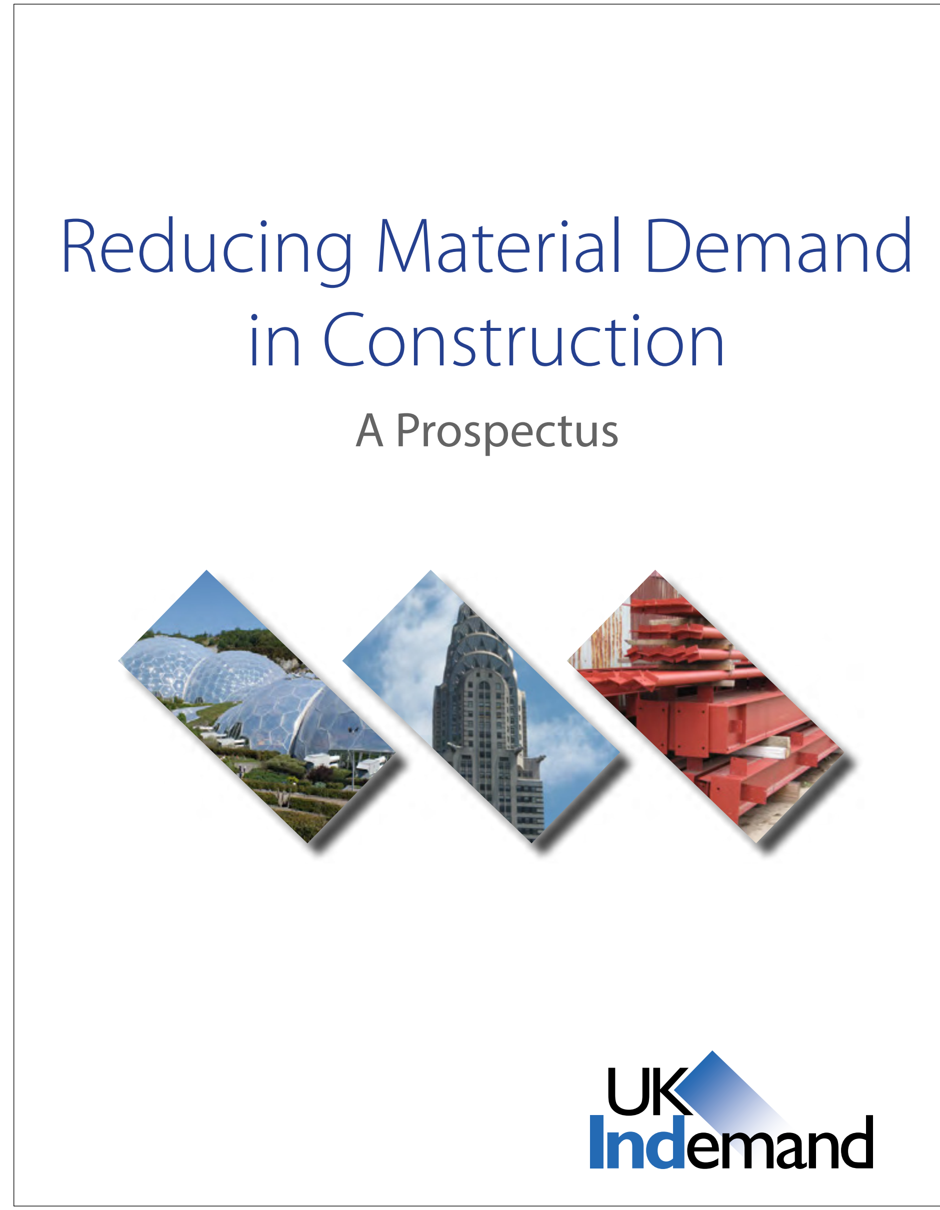
Composite floor beam

Open web joist

Cellular beam

Variable cross-section beam

Beam design options



Reducing Material Demand in Construction

A Prospectus

UK Indemand

Industry routemap

Requires 39% reduction in embodied carbon by 2050

The Low Carbon Routemap for the Built Environment

The **Green Construction Board**

March 2013

The Green Construction Board has developed the Low Carbon Routemap for the Built Environment to serve as a visual tool enabling stakeholders to understand the policies, actions and key decision points required to achieve the UK Government target of 80% reduction in greenhouse gas emissions vs 1990 levels by 2050 in the built environment. The Routemap also sets out actions, together with key performance indicators that can be used to deliver and measure progress in meeting the 2050 target.

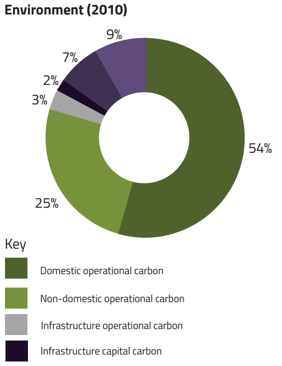
The Routemap covers both infrastructure and buildings sectors, and addresses segments of operational and capital (embodied) carbon emissions. The emissions covered by the Routemap are as follows:

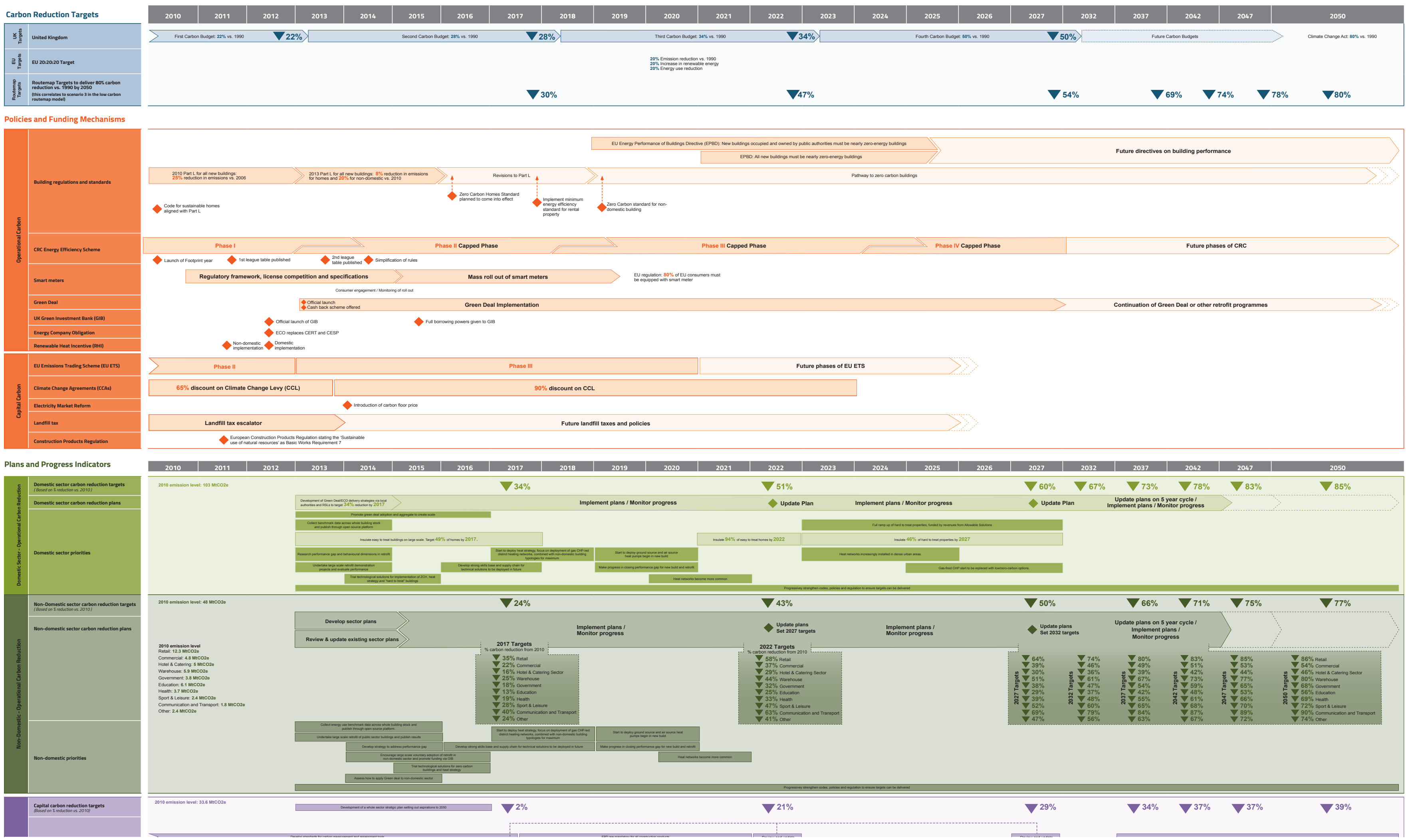
» Operational carbon in buildings: emissions from regulated energy use (excluding plug loads) for all domestic and non-domestic building sectors except industrial.

» Operational carbon in infrastructure: emissions from outdoor lighting, waste from construction, demolition and excavation, and water/wastewater. The use of transport infrastructure (by cars for example) is excluded. Some components of infrastructure that include buildings (such as railway stations) are included in the analysis, but appear under buildings.

» Capital carbon: covers emissions arising from the production and manufacture of materials (in the UK and abroad), transport of materials and people, all industry design and consultancy activities, and the emissions from on-site activities for the construction and demolition of buildings and infrastructure.

Breakdown of Carbon Emissions in the Built Environment (2010)



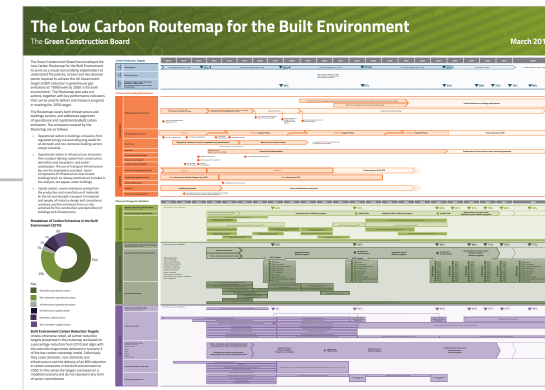


Aligning benchmarks with targets

How can UK targets be translated to project level benchmarks?

UK GHG emissions reduction targets

Construction sector GHG emissions reduction targets



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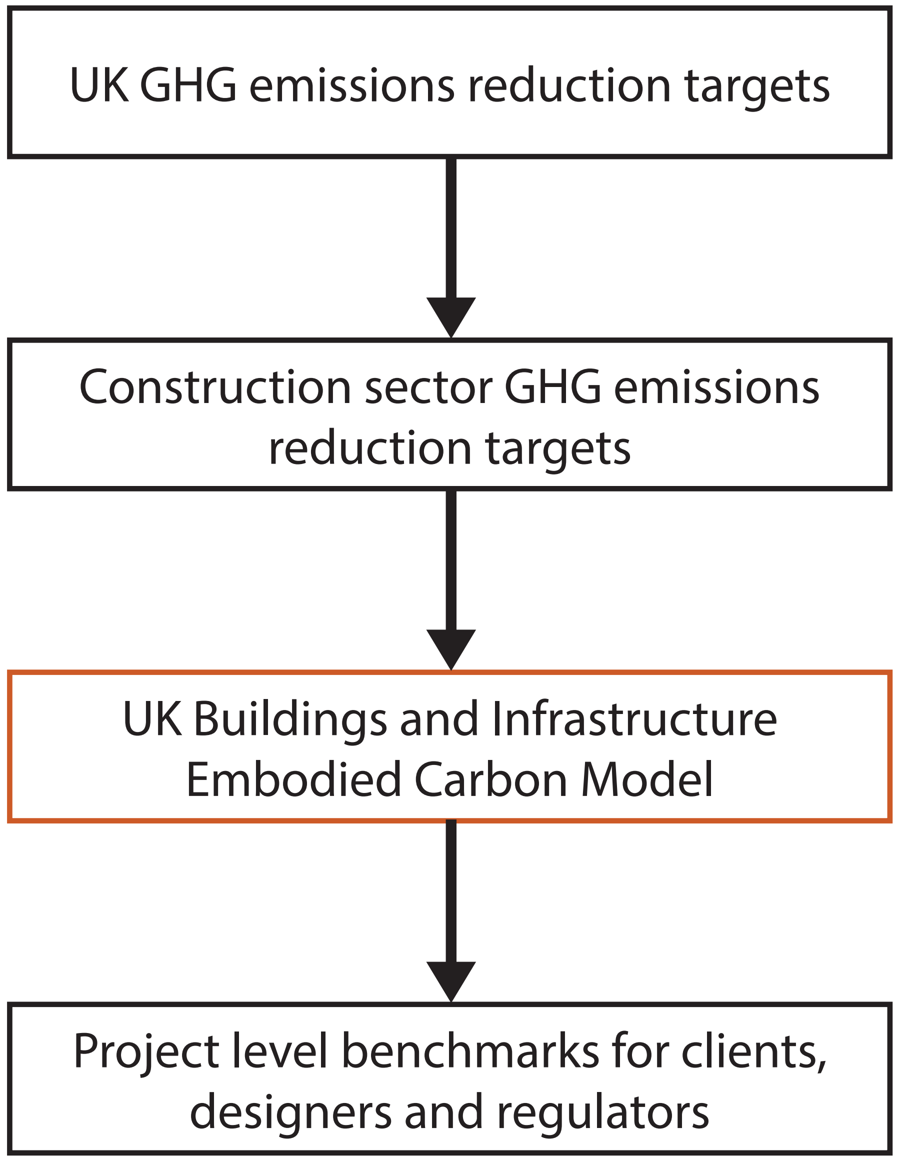
Project level benchmarks for clients, designers and regulators

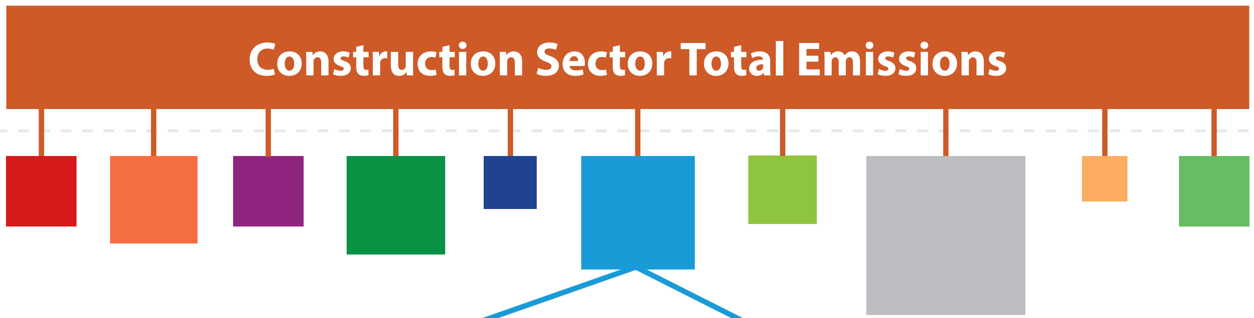
Bridging the gap

A model that integrates top down and bottom up emissions data



Buildings Embodied Carbon Model

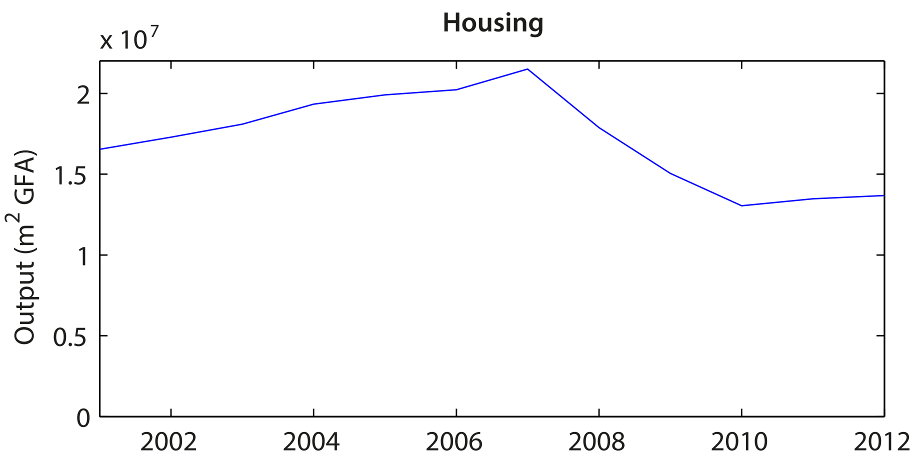
Model structure



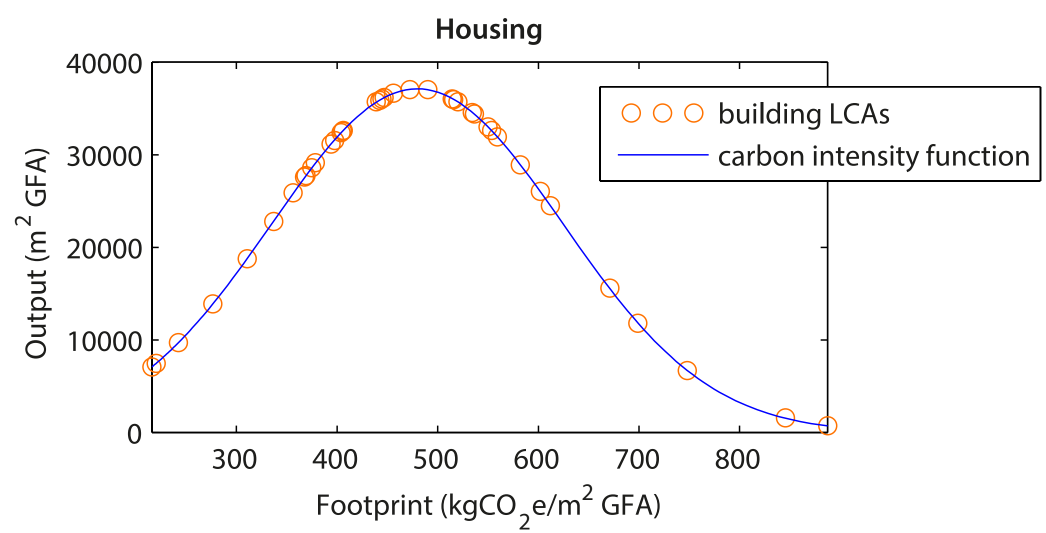
Building classes
Housing, factories, warehouses, education, health, offices, entertainment, retail, infrastructure, miscellaneous

Each building class is represented by

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

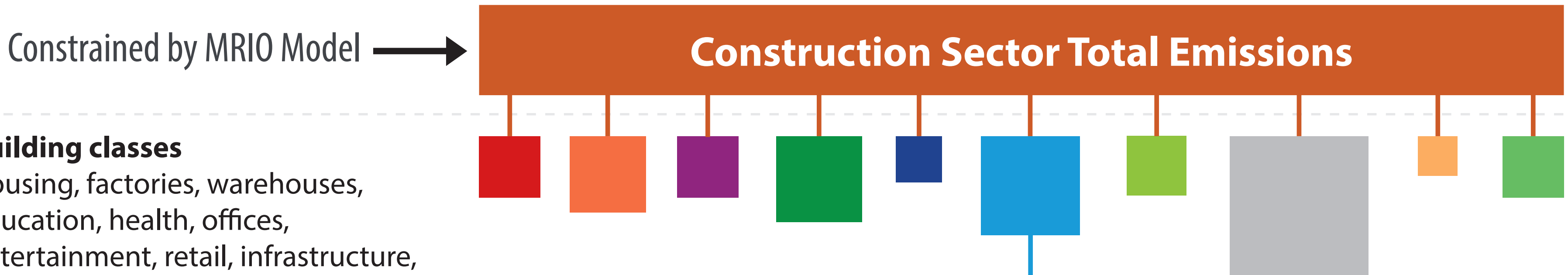


Carbon intensity function
Function representing the range of observed embodied carbon footprints amongst buildings of that class. Based upon collected case studies and entries in WRAP embodied carbon database.



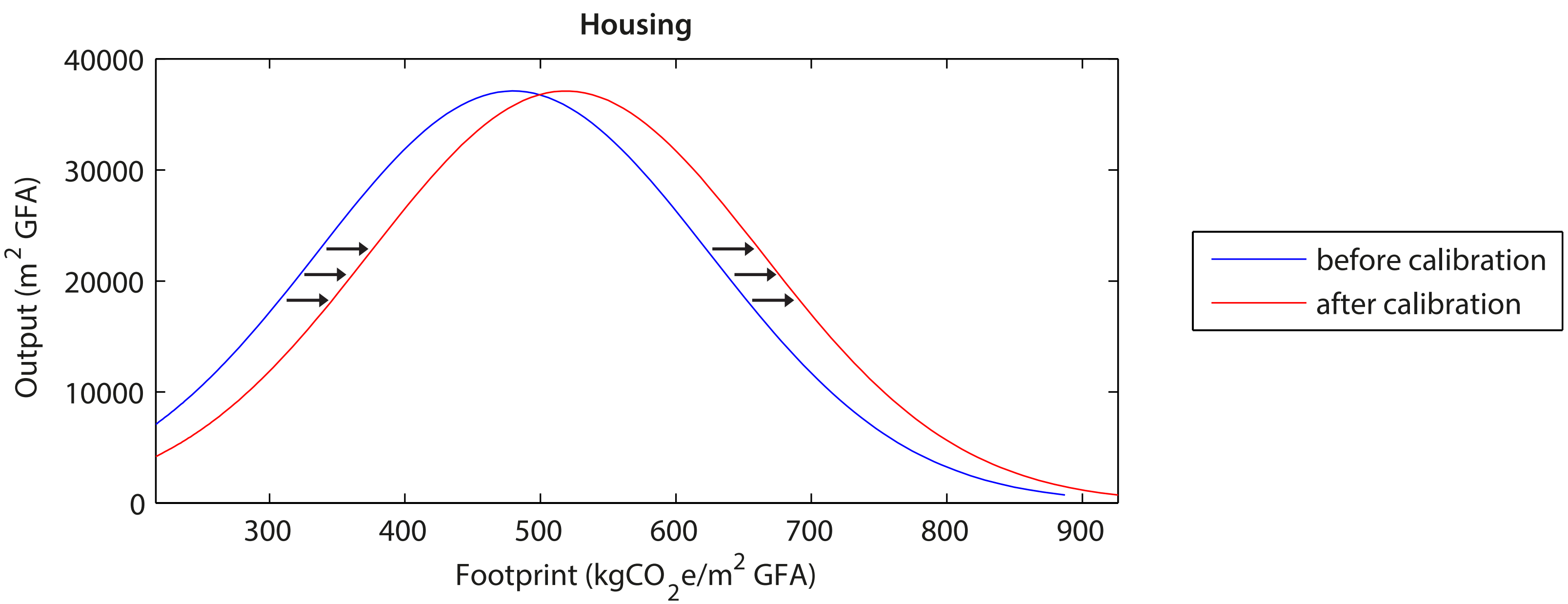
Model calibration

Linking top down and bottom up emissions data



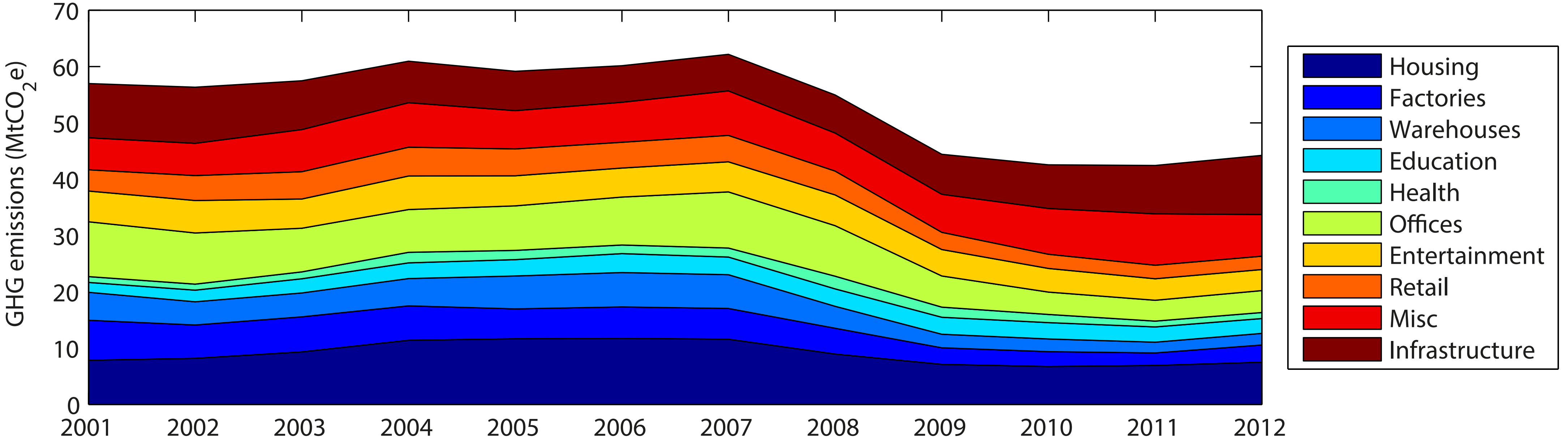
Building classes
Housing, factories, warehouses, education, health, offices, entertainment, retail, infrastructure, miscellaneous

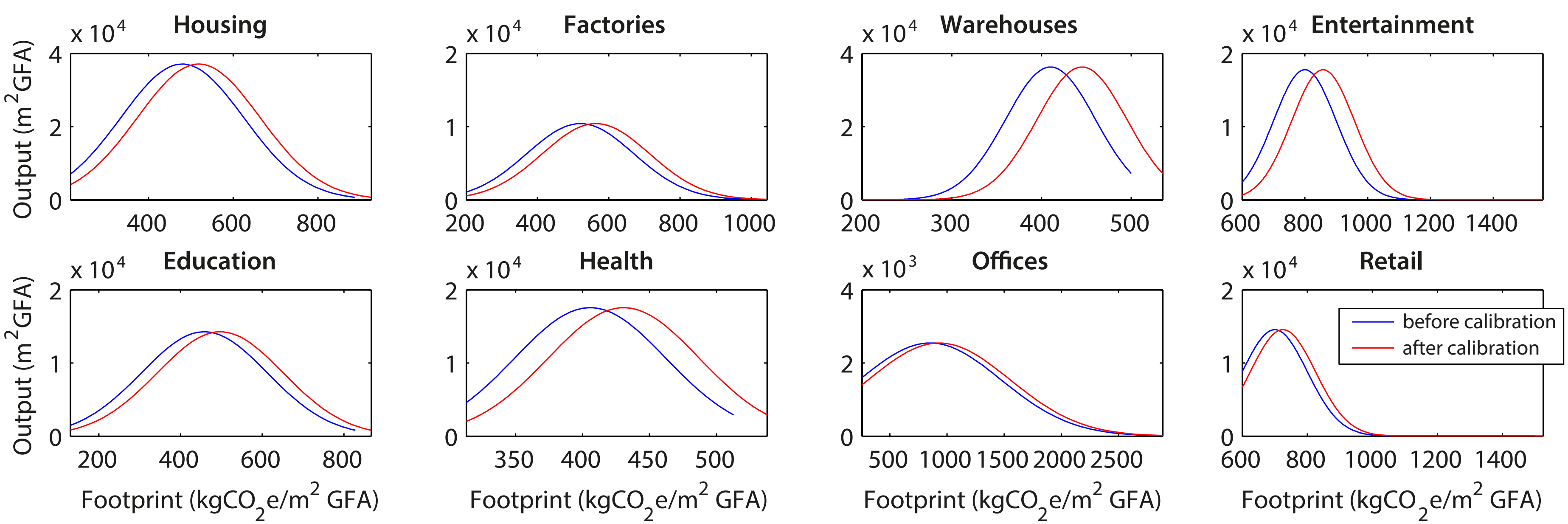
Carbon intensity function
Function for each class is calibrated based on top down emissions constraints.



Model calibration

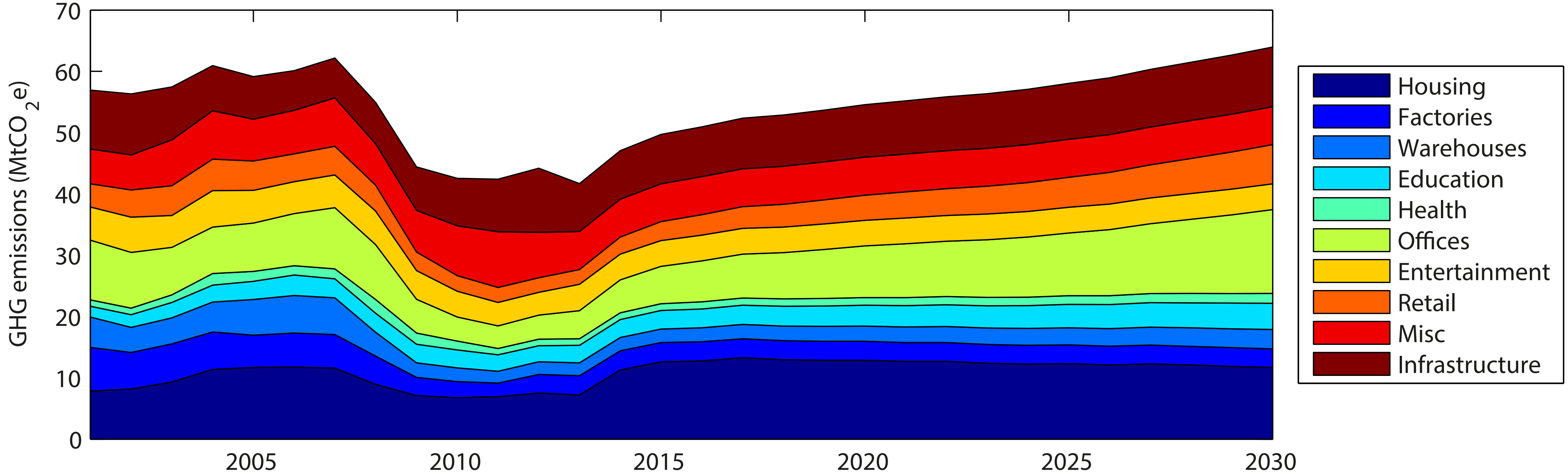
Model has initially been calibrated using data for 2001-2012



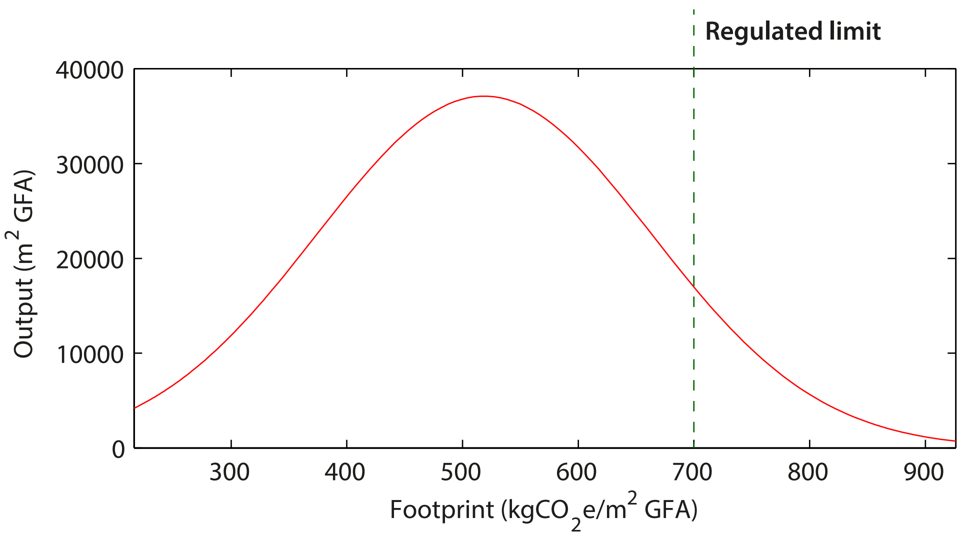


Scenario analysis

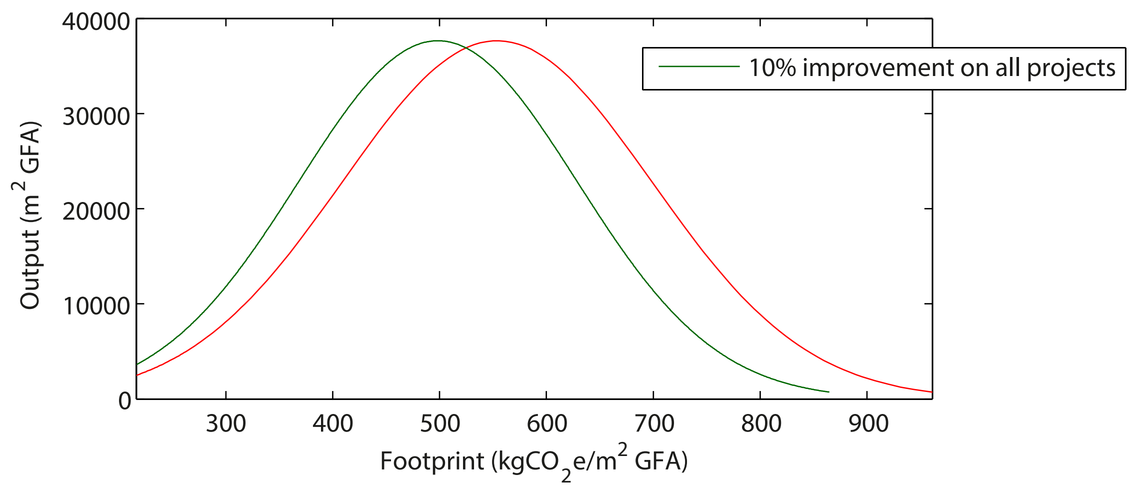
Model can be used to estimate future emissions



Estimate impact of introducing a limit through regulation



Estimate impact of design improvements



Model limitations

Include

» Building LCAs in database have different system boundaries

» Building LCAs in database use different LCI datasets

» Small sample of building LCAs unlikely to be truly 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

Intended model updates

Here are a few, more suggestions are welcome

- Addition of more building level LCAs
- Disaggregation of infrastructure class
- Replacement of benchmark and price data
- Addition of 2013 emissions data (July)
- Development of user interface
- Analysis of a range of future scenarios

Summary

Action on embodied carbon is required

- Embodied carbon emissions from construction are substantial and growing
- Clients and practitioners are increasingly interested in the topic
- Future regulation (of some form) is likely
- Reductions are required to meet Low Carbon Routemap targets
- Challenge remains in linking sector targets with project level benchmarks
- The UK Buildings Embodied Carbon Model attempts to bridge this gap by linking the best available top down and bottom up data in a flexible framework