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Aligning carbon targets for construction with (inter)national climate change mitigation commitments

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ABSTRACT

In the face of a changing climate, a growing number of construction firms are adopting carbon reduction targets on individual projects and across their portfolios. In the wake of the Paris Agreement, some firms are seeking a means of aligning their targets with sectoral, national and international mitigation commitments. There are numerous ways by which such an alignment can be achieved, each requiring different assumptions. Using data from the UK construction industry, this paper reviews current company commitments and progress in carbon mitigation; analyses the unique challenges in aligning construction targets, and presents a series of possible sectoral decarbonisation trajectories. The results highlight the disparity between current company targets and the range of possible trajectories. It is clear that a cross-industry dialogue is urgently required to establish an appropriate response that delivers both a widely-accepted target trajectory and a plan for its delivery. This paper is intended to stimulate and support this necessary debate by illustrating the impact of different methodological assumptions and highlighting the critical features of an appropriate response.

1. Introduction

The dangers posed by anthropogenic carbon emissions and a changing climate are well documented [1], yet in 2016 humanity emitted a further 36 $GtCO_2$ from fossil fuels and industrial processes [2]. In December 2015, 195 countries adopted the first legally binding global climate deal seeking to hold increases in 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” [3]. Current ‘do nothing’ scenarios project global temperature increases of 3.2–5.4 °C by 2100 [1] and even fulfilment of all signatories’ Nationally Determined Contributions put forward as part of the Paris Agreement implies a median warming of 2.6–3.1 °C by 2100 [4]. Limiting temperature increases to below 2 °C will likely require global emissions to peak by 2020 followed by rapid reductions [5], necessitating a significant ratcheting up of global emission abatement efforts as part of a periodic stocktake and commitment cycle. In addition to its headline temperature target, the Paris Agreement sets the goal of achieving “a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century”, i.e. ‘net zero’ emissions. This is in recognition of the fact that net carbon dioxide emissions will need to fall to zero in order to stabilise global temperature. It is expected that wealthier developed countries will achieve this net zero goal at an earlier date in line with the principle of common but differentiated responsibilities. The immense scale of the challenge involved in delivering these goals is frequently understated but is clearly illustrated by a range of recent roadmaps and scenario analyses. For instance, Rockstrom et al. set out one roadmap with a 75% probability of limiting warming to below 2 °C, if global greenhouse gas (GHG) emissions were halved every decade [6]. Such a radical transformation can only be achieved with the active participation of non-state actors, including corporate and privately owned companies. This will require companies to independently set long term reduction targets that are aligned with global mitigation goals [7,8].

The construction sector is the largest global consumer of resources [9] and is a major contributor to climate change through

Abbreviations: CCC, Committee on Climate Change; CCS, Carbon Capture and Storage; DBEIS, Department for Business, Energy and Industrial Strategy; EPD, Environmental Product Declaration; GCB, Green Construction Board; GHG, Greenhouse Gases; GIA, Gross Internal Area or Gross Internal Floor Area; IEA 2DS, International Energy Agency’s 2 °C Scenario; IEA B2DS, International Energy Agency’s Beyond 2 °C Scenario; IPCC, Intergovernmental Panel on Climate Change; NET, Negative Emissions Technologies; RICS, Royal Institution of Chartered Surveyors; SBT, Science Based Target; SDA, Sectoral Decarbonization Approach; WRAP, Waste and Resources Action Programme.

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the GHG emissions incurred both within its supply chains and from the operation of assets it creates [1]. Growing demand for buildings and infrastructure is driving significant increases in material extraction and emissions [10] and further unabated growth has the potential to undermine climate targets [11–13]. An additional challenge within this is enabling developing countries to grow, expanding infrastructure and buildings to support higher standards of living, whilst minimising the associated GHG emissions. Detailed analyses of the GHG emissions attributable to construction sector activities have been conducted for numerous countries, such as Sweden [14], Norway [15], China [16], Australia [17] and the UK [18]. A common trend across countries is an increasing share of project whole life carbon emissions coming from embodied rather than operational emissions [19].

There are a wide range of opportunities to reduce carbon emissions throughout a project's life cycle, including mitigation strategies to reduce embodied emissions in design and construction [20,21]; operation [22] and end of life management [23]. A growing body of guidance and standards has supported some exploitation of these opportunities [24]. Though many firms now undertake routine project carbon assessments, best practice in whole life carbon management is predominantly confined to a small number of multinational firms with significant organisational capacity and expertise. Even amongst these firms there is wide variation in common practices, including assessment and reporting procedures [25]. There are many barriers to the more widespread deployment of these mitigation options [26] and additional policy support is likely to be essential in the medium to long term [27,28]. Yet in spite of the observed barriers and limited drivers, numerous construction firms have publicly adopted carbon reduction targets. These targets vary widely in scope [29] and are typically determined by esoteric means, with many simply decided by individual CEOs, through comparison with competing firms, or copied verbatim from headline national mitigation commitments [30]. Few firms have targets that are truly aligned with sectoral, national or international mitigation commitments, though demand for such alignment has been growing of late. The means by which such an alignment can best be achieved is a subject of ongoing debate amongst industry and academic experts. This paper sets out some of the possible options, their implications and shortcomings, and illustrates the resultant pathways through a case study of the UK.

Section 2 provides context, describing the UK's national emission reduction targets and current construction industry practice. Section 3 discusses current approaches to target alignment and the unique challenges in aligning targets within the construction industry. Section 4 presents a set of illustrative sectoral trajectories and discusses their implications for industry practice. Section 5 concludes with a summary of the key considerations in setting an appropriate sectoral target.

2. Carbon targets and the UK construction sector

The UK construction sector faces the profound challenge of substantially reducing carbon emissions whilst meeting increasing demand for buildings and infrastructure [31]. Over the coming years the UK faces anticipated population growth (some 14 million additional people by 2050 [32]); that will require an additional 3.2 million households by 2037 [33]. This comes on top of an existing housing crisis with record property prices and a local authority housing waiting list exceeding 1.2 million at the time of writing [34]. Furthermore, 8 million 'non-decent' homes require urgent refurbishment [35] and broader targets require the retrofit of more than one home every minute until 2050 [36]. In the meantime an infrastructure pipeline worth around £600bn must be delivered [37], including additional investments in climate adaptation, such as flood defences, and a significant renewal and expansion of energy and communications infrastructure [31].

2.1. UK carbon reduction targets

Over the same period the UK Government is pursuing a legally binding target of reducing GHG emissions by 80% by 2050, set out in the 2008 Climate Change Act. Interim progress towards the 2050 target is aligned with a series of 5 year carbon budgets, currently set into law until 2032 (see Fig. 1). Existing policies are projected to be insufficient to meet the 4th and 5th Carbon Budgets and additional interventions are expected in the coming year [38].

The UK's 2050 target is broadly expected to be elevated in light of the Paris Agreement [39], with the then Minister of State for Energy intimating that a net zero emissions objective will enter into UK law: "the question is not whether, but how we do it".[1] Similar net zero emissions targets have already received parliamentary approval in other developed countries such as Sweden and Norway. In spite of this, the means by which a net zero emissions objective can be delivered and translated into specific targets has yet to be determined. The prospective date by which the UK should deliver net zero emissions is also heavily dependent upon interpretation of the Paris Agreement's Article 2.1a targets and the means of determining a fair allocation of the remaining global carbon budget. Current estimates, based on common interpretations, suggest that the target date for UK net zero carbon dioxide emissions should be within the range of 2045–2075 [39,40]. However, the means by which net zero domestic emissions could be delivered is unknown. The Committee on Climate Change (CCC), who provide independent monitoring and advice to Government, currently have no scenarios under which the UK can achieve net zero domestic emissions. Even "a full and successful roll-out of all options" identified by the CCC, results in GHG emissions in 2050 just over 90% lower than 1990 [39]. Achieving net zero will therefore require both deep mitigation and the widespread deployment of 'Negative Emissions Technologies' (NET), which extract and store carbon. The feasible level of NET that can be delivered in the UK is highly uncertain, with recent technical estimates of the order of 44–180 $MtCO_2e$ per year, which is around 8–32% of current total UK territorial GHG emissions [41]. The precise ceiling of this potential deployment is likely to determine the long term sustainable level that UK emissions must be reduced to through additional mitigation measures. For instance if, through deployment of NET, the UK could deliver 100 $MtCO_2$ per annum of additional carbon sinks, then it could continue to emit 100 $MtCO_2$ per annum from hard to mitigate sources, whilst still achieving the overall net zero objective. Though much is unknown at the present time, it appears likely that the UK will adopt a net zero emissions target in future and all interim strategies, roadmaps and decarbonisation trajectories should account for this.

2.2. The contribution of the construction industry

The potential contribution of the construction industry to low carbon development has been the subject of numerous reviews and strategy documents over the past 20 years [42–48]. Most recently the UK's principal construction strategy, Construction 2025 set a target of halving annual GHG emissions from the built environment by the middle of the next decade [49]. It is envisaged that this can be achieved alongside significant capital cost reductions, following the Infrastructure Carbon Review's conclusion that

[1] "The Government believe we will need to take the step of enshrining the Paris goal of net zero emissions in UK law—the question is not whether, but how we do it" - Andrea Leadsom, then Minister of State for Energy - Hansard HC Deb vol 607 col 725 (14 March 2016)

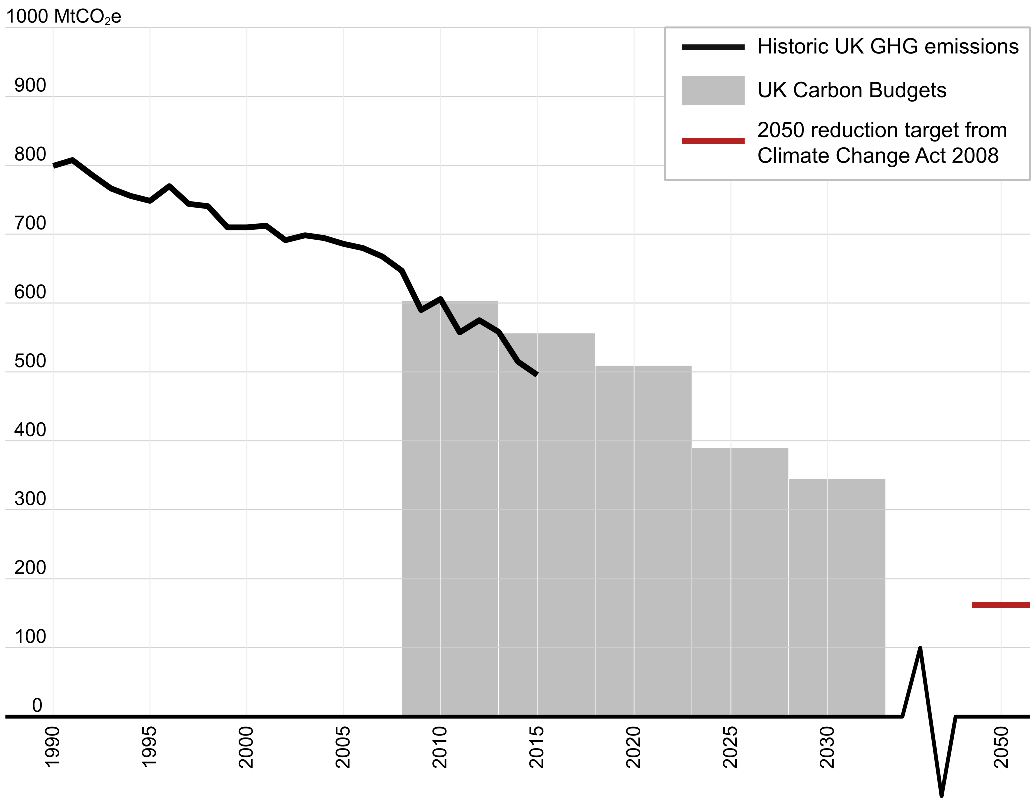

Fig. 1. UK historic GHG emissions 1990–2015, Carbon Budgets and 2050 target (All figures reported on a territorial basis based on data from DBEIS).

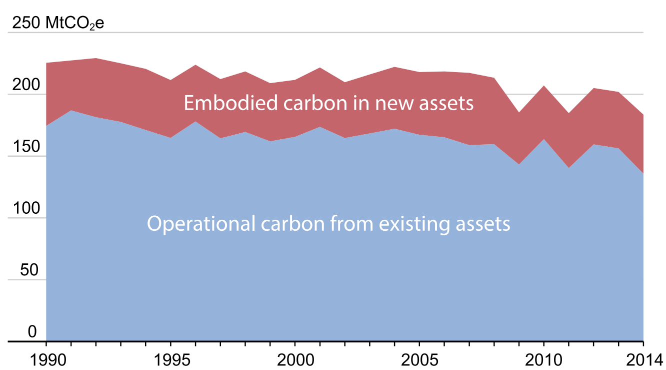

Fig. 2. UK built environment emissions 1990–2014 (reported on a consumption basis to boundaries described in [51]. Note: the figures are not seasonally adjusted and some of the variation in operational emissions is due to year on year temperature fluctuations.).

"reducing carbon reduces cost" [47]. Indeed, one of the principal objectives of the UK Government Construction Strategy 2016–2020 is to "enable and drive whole-life approaches to cost and carbon reduction" [50]. In 2013, the Green Construction Board's Low Carbon Routemap for the Built Environment provided a definition and baseline for UK built environment emissions, and set out the steps required to achieve an 80% reduction by 2050 [48]. However, a 2015 Progress Update showed the sector was already falling behind the target trajectory [51]. In 2014 UK built environment emissions totalled some 183.5 $MtCO_2e$ [24]. Roughly a quarter of these were attributable to embodied emissions incurred in the construction of new assets. The remaining three quarters were attributable to the operation of existing assets (see Fig. 2). Over recent years operational emissions have gradually declined owing to the retrofit of older properties, the construction of better performing new properties and decarbonisation of the electricity supply. Meanwhile embodied emissions have been increasing due to a growth in construction activity as the sector emerged from a deep recession in 2009, combined with the use of thicker building fabrics to meet revised Building Regulations. Delivering sector carbon reduction targets will require substantial reductions in both operational and embodied emissions [51].

2.3. Current carbon reporting and reduction commitments

Progress in accounting for and reducing embodied emissions has varied widely between sub-sectors of the industry and between firms within each sub-sector. For instance, significant progress has been made in the water industry [52], in large part driven by leadership from a small number of firms supported by an attentive regulator. Significant investments have been made in additional guidance, tools and standards for carbon management, as reviewed by Giesekam and Pomponi [24] and De Wolf et al. [25]. Sourcing accurate data reflecting the environmental impacts of products and construction processes remains a challenge [25,26,53,54]; however much recent progress has been made. For instance, the industry has now published over 3500 verified Environmental Product Declarations (EPDs) for construction products (with an additional 2400 unverified EPDs also available), over 40% of which were published in the last year [55]. Reductions in operational carbon emissions have largely been driven by policy interventions, such as amendments to Part L of the Building Regulations; but the recent removal of key policies, such as Zero Carbon Homes and the Green Deal, has undermined these efforts.

Collective industry commitments to reduce emissions have been made through initiatives such as the Infrastructure Carbon Review [47] and through organisations such as the now defunct UK Contractors Group [56]. Most major companies are now disclosing their emissions through schemes such as the Carbon Dis-

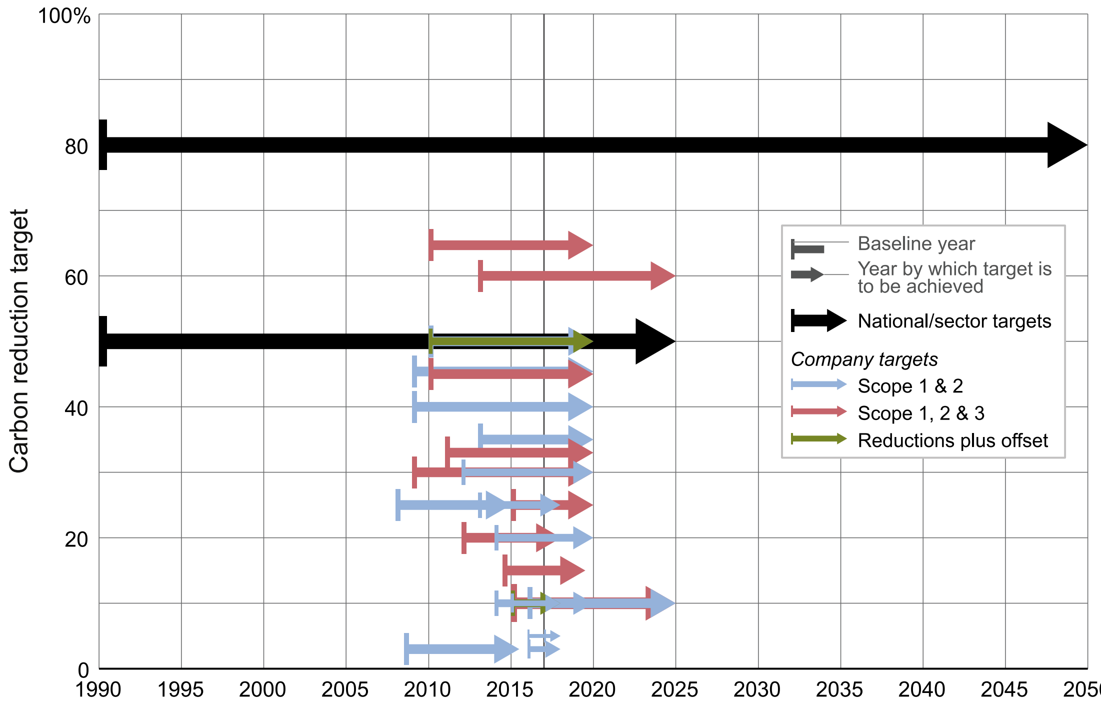

Fig. 3. Carbon reduction targets of selected UK construction firms representing total turnover of £88.4bn in 2016.

closure Project and many have publicly set reduction targets. Three scopes are typically defined for reporting purposes. Scope 1 emissions are direct GHG emissions that occur from sources that are owned or controlled by the company (e.g. the direct combustion of fuel in the operation of facilities). Scope 2 emissions are indirect emissions from generation of energy purchased by the company (e.g. emissions incurred in the generation of electricity or heat purchased by the company). Scope 3 emissions are other indirect emissions incurred as a consequence of the activities of a company, but at sources not owned or controlled by the company (e.g. emissions incurred upstream in a supply chain producing base materials used in the manufacture of a company's product). See the GHG Protocol Corporate Accounting and Reporting Standard [79] or DEFRA's Environmental Reporting Guidelines [80] for a more detailed description of each scope. Annual reporting of Scope 1 and 2 emissions is now a legal requirement for many quoted companies and public bodies in the UK, with some companies choosing to voluntarily report Scope 3 emissions.

Fig. 3 summarises the targets set by the UK's top 20 housebuilders[2] and largest 50 construction firms[3] by turnover, based upon a review of their annual reports and corporate social responsibility commitments conducted in July 2017. An equivalent figure for major infrastructure providers can be found in a recent UK Green Building Council report [30]. A small number of firms, such as Hammerson [57], Berkeley [58] and WSP [59], have made commitments to be carbon-neutral or net-positive in future – through the use of carbon offsetting schemes – but they represent the minority of UK practice. It should be noted that Fig. 3 is comprised of company targets covering a variety of scopes and activities, and is not an amalgamation of the project targets being set by these companies. Therefore, though this figure does not reflect the full range of mitigation options being pursued, nor provide a basis for calculating a precise carbon reduction commitment from the industry, it does indicate the general scale of ambition amongst UK industry leaders. 26 of the 66[4] companies reviewed had publicly set carbon reduction targets. 2 more were in the process of preparing targets at the time of writing. The remaining 38 are reporting carbon in some form but have not publicly specified reduction targets. Most have made general commitments to carbon reduction, such as qualitative statements, undertaking exemplar projects or providing public support for regulatory ambitions.

Even from a cursory inspection of this figure, there is a clear misalignment between the targets currently set by individual companies and the required long term emissions reduction trajectory. Most company targets are short term – predominantly out to 2020 – and generally exclude Scope 3 emissions. For many built environment firms, such as major property developers, Scope 3 emissions are significantly greater than Scope 1 and 2 emissions, and often present the greatest opportunities for mitigation through changes in design. The exclusion of Scope 3 emissions from reporting and associated targets may limit the range of mitigation solutions pursued and consequently reduce the rate of sectoral carbon reduction that can be achieved. Though a small number of firms are setting highly ambitious targets, the majority are not setting any targets. The targets set by housebuilders are typically less ambitious than those of the other construction firms. Generally most reduction plans are linked to set investment periods, with no long-term targets beyond current investment plans. Few targets appear to be linked to any broader sectoral or national target.

To rectify this problem there have been calls within the industry for development of a common sector target trajectory from which commensurate targets for individual companies and projects can be derived [30]. This begs the question, by what means should company, sectoral, national and international targets be aligned?

[2] According to http://www.building.co.uk/data/market-data/league-tables/top-20-housebuilders-2016/5082787.article.

[3] According to http://www.theconstructionindex.co.uk/market-data/top-100-construction-companies/2016.

[4] 66 reflects recent mergers and acquisitions that have reduced the total from 70 at the end of 2016.

3. Target alignment

A small number of companies across a range of sectors have already sought to align their carbon targets with national and international commitments [81,82]. These firms have adopted a range of approaches from a simple replication of international targets to more nuanced schemes, such as the Science Based Targets initiative. The following section begins by briefly reviewing the approaches currently in use (Section 3.1). This is followed by a discussion of the unique challenges faced in aligning targets within the UK construction industry (Section 3.2). In respect to this application, the principal limitations of current approaches are further discussed in Section 3.3, before an alternative approach is proposed in Section 3.4.

3.1. Current approaches

Targets can be aligned by a number of approaches, which vary in sophistication, ethical and scientific defensibility. At the simplest level, some companies have chosen to adopt carbon reduction targets that are copied verbatim from recommendations for global reductions based upon analysis by the IPCC of the carbon budgets that could restrict warming to 2 °C. Implicitly this assumes an equal proportional responsibility for emissions reduction from all sources, regardless of geography, historic responsibility or scope for mitigation. Other companies have copied targets from national commitments, such as the UK's 2008 Climate Change Act. NGOs and non-profit organisations have launched a number of initiatives encouraging companies to adopt more sophisticated approaches, such as aligning targets relative to a company's contribution to global GDP, or incorporating some consideration of historic emissions [81]. The most prominent such initiative, which is gaining traction within UK industry, is the Science Based Targets (SBT) initiative [60].

The SBT initiative is a partnership between CDP, UN Global Compact, WRI and WWF aimed at encouraging adoption of company carbon reduction targets consistent with keeping global temperature increases below 2 °C. At the time of writing in November 2017, 82 companies had approved SBT, with a further 239 committed to the development of such a target [61]. A minority are involved in construction and property development. Ferrovial, Landsec [62], Gecina, TODA Corporation and Host Hotels & Resorts have already set targets, whilst a further 27 firms involved in 'Real estate', 'Building products', 'Homebuilding', 'Construction materials' and 'Construction and engineering' had committed to set targets at the time of writing. A number of these firms, such as Laing O'Rourke, ISG and Bennetts Associates, are based in the UK.

These SBT are developed based upon a range of approved approaches, including the SDA (Sectoral Decarbonization Approach) [8], C-FACT (Corporate Finance Approach to Climate-Stabilizing Targets), CSO (Context-based carbon metric), GEVA (GHG emissions per unit of value added), and CSI (Climate Stabilization Intensity Targets) approach [63]. Amongst these the SDA has proved the most popular so far, particularly amongst firms in the built environment. Though each approach is different, they predominantly follow a common sequence:

1) Start from an estimate of the remaining cumulative global carbon budget (e.g. for a > 66% probability of keeping warming below 2 °C, ~1010 $GtCO_2e$ from 2011).
2) Select a future emissions scenario consistent with this budget (such as the International Energy Agency's 2 °C Scenario - IEA 2DS).
3) Allocate remaining emissions between companies on a contraction or convergence basis.
4) Translate this pathway into specific interim company targets for reductions in carbon intensity or absolute emissions.

The resulting targets are submitted for validation by the initiative. Although longer term target setting is encouraged, the targets submitted for validation only cover up to a maximum of 15 years and progress against the targets is not currently monitored by the initiative (though annual public reports are published by all the firms involved).

Each of these four steps involves fundamental choices with profound implications. For example the selection of a budget consistent with 1.5 °C or 2 °C of warming; and selection from the several allocation approaches (used to break down reductions from the sector to company level) set out in the SBT manual [63]. The efficacy of each of these choices and approaches can be debated, but that is not the focus of this paper. Some within the construction industry have advocated for development of an SBT for 'UK infrastructure' or the 'UK built environment' which could in turn be translated into commensurate company targets [30]. However, there are numerous challenges in calculating such a trajectory. These challenges reflect the unique characteristics of the sector's structure, product and reporting procedures, as well as its role in decarbonisation of the UK economy. Collectively these provide cause for concern, and any collective industry effort to establish such a target should address these challenges.

3.2. Unique challenges for construction firms

The unique challenges in aligning targets for firms in the construction sector include:

- Poor sector representation in global pathway analyses.
- Heterogeneity of sector output and divided responsibilities.
- Asset longevity.
- High proportion of Scope 3 emissions and heavy dependence upon imported materials.
- Misaligned reporting boundaries.
- Shortage of benchmark data.
- Limited mitigation opportunities for certain critical inputs.
- Role in setting boundary conditions for decarbonisation of other sectors.
- Capacity to deliver carbon storage and negative emissions.

This list represents the authors' views on the main challenges facing the UK industry, based upon discussions with construction firms and early adopters of SBT. As more firms develop and implement SBT, it is likely that this list will evolve and grow. Let us consider each of these currently foreseen challenges in turn.

3.2.1. Poor sector representation in global pathway analyses

Despite its significance, the construction sector is rarely an explicit sector in global emissions scenario analyses. These analyses tend to consider the impact of 'buildings' solely in operation. The constituent inputs to construction are usually outputs of an aggregated 'industry' or sequence of major producers, such as 'steel' and 'cement'. Similarly, the transport of these materials in production and to site is usually amalgamated into an overarching 'transport' sector alongside domestic travel. Consequently in analyses which use off-the-shelf future emissions scenarios, such as the SBT SDA approach, pathways for construction firms are typically based upon categories such as the IEA's 'Other industry' or 'Buildings, agriculture, fishing, non-specified other', which includes a wide range of manufacturing and food producers in addition to construction. Thus, in most cases, these analyses poorly reflect the mitigation potential and associated costs within the construction sector, and portray output trajectories that are not truly indicative of what can be achieved. Such analyses do not provide a sound future emissions scenario upon which company targets can be based.

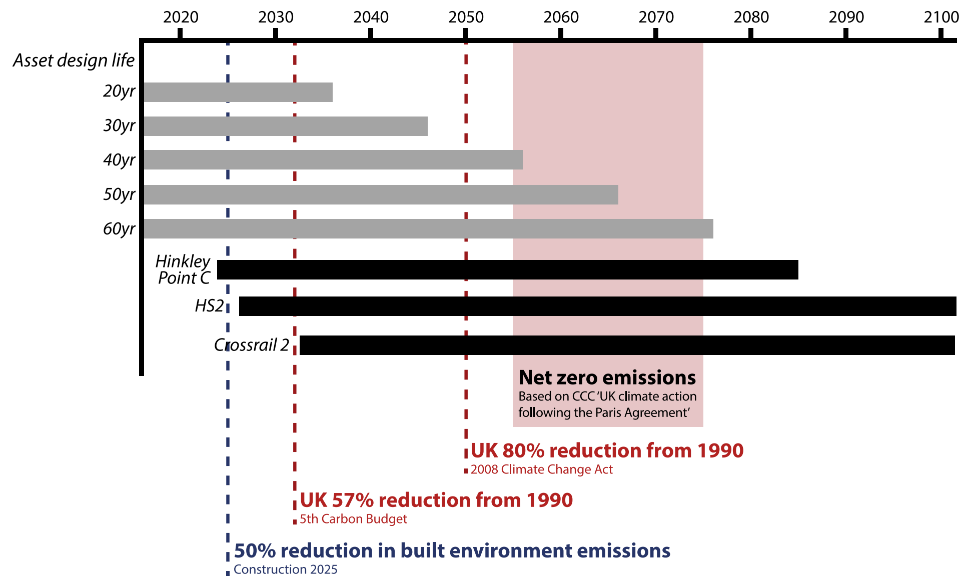

Fig. 4. UK carbon reduction targets and selected project design lives.

3.2.2. Heterogeneity of sector output and divided responsibilities

The output of the construction industry is highly diverse, comprising a wide variety of buildings and infrastructure assets. Even defining a boundary encompassing all the firms included within the construction industry can prove challenging. This wide range of outputs are paralleled by an equally broad range of development approaches and ownership arrangements. Typically numerous actors are involved in the conception, design, delivery, ownership, use, maintenance and decommissioning of a built environment asset, and the responsibilities and influence of each party can be difficult to discern. For example, clients may set targets for the embodied and operational carbon of their project – which is a challenge in itself – but will then rely on the design team and contractor to be able to deliver a building that meets these targets. If the building is leased, the operational energy will likely be outside of the control of the original client and in the hands of the tenant, who may use the building in different ways to those anticipated. This model is also predicated on an informed client. Where the client is not setting targets, the onus is on the design team and contractor to explore opportunities for whole life carbon reduction, and then try to persuade their client of the benefits of this approach, which is a significant challenge in a predominantly cost driven industry. Furthermore, establishing common benchmarks across the range of actors and project types can prove difficult, with each actor and sub-sector desiring bespoke solutions that reflect their deliverables. For instance, carbon benchmarking can occur across a range of units, from $kgCO_2e/m^2$ GIA for a commercial property developer, to $kgCO_2e$/km of pipeline constructed to $kgCO_2e/m^3$ of waste water treated to $kgCO_2e$/passenger through a transport hub. Thus, the many challenges that come with the complexity of the sector cannot be underestimated and a means of reflecting these divided responsibilities must be considered in any collective approach to SBT development.

3.2.3. Asset longevity

Built environment assets typically have multi-decadal design lives, which they often outlive. The age distribution of the current UK building stock indicates that many houses and non-domestic properties constructed in previous centuries are still in use today and will likely continue to be in use into the next century. The same is true of major infrastructure assets which are often designed for anticipated operating periods exceeding 50 or 100 years. Given the longevity of these design lives, most built environment assets being designed today will still be operational in the period by which the UK must achieve net zero emissions, as indicated in Fig. 4. Once these assets are in place, they lock-in operational emissions that will be incurred in coming decades, barring additional retrofit measures which will incur further embodied emissions.

Consideration also needs to be given to the adaptability and deconstructability of the buildings designed. In the first instance to ensure buildings can respond to changing needs, thus increasing their lifespan, and in the second instance to enable the reuse of components and materials. By planning effectively now, the demand for future buildings and materials can be reduced. This is crucial when considering that in around fifty years, at the potential end of life of these structures, humanity will need to be operating at near zero GHG emissions. Given the timescales involved, it is imperative that the performance of current designs is considered relative to these longer term carbon reduction targets.

3.2.4. High proportion of Scope 3 emissions and heavy dependence upon imported materials

The UK construction industry is heavily dependent upon imported materials, including several million tonnes of steel per annum, over a million tonnes of cement and nearly all aluminium products. Consequently, in total, around 40% of the embodied emissions associated with UK construction supply chains occur outside UK borders [18]. Furthermore, responsibility for these emissions is widely distributed along lengthy supply chains. As a result the Scope 3 emissions incurred in the development of a construction project will often outweigh the Scope 1 and Scope 2 emissions under the influence of an individual actor. Therefore the inclusion of Scope 3 emissions is an essential part of addressing the construction industry's full impacts and leveraging the greatest reduction opportunities.

In spite of this, SBT approaches predominantly focus upon Scope 1 and Scope 2 emissions. Although Scope 3 emissions are included where significant (>40% of total emissions), guidance from the initiative states that "Scope 3 targets generally need not be science-based, but should be ambitious and clearly demonstrate how the company is addressing the main sources of GHG emissions within their value chain in line with current best practices" [63]. Given the significance of Scope 3 emissions for the UK construction industry, any collective approach that failed to address these in line with a 2 °C scenario would clearly be inconsistent with national and global mitigation goals.

3.2.5. Misaligned reporting boundaries

The reporting boundaries for carbon emissions adopted at project, company, sector and national level are fundamentally misaligned. At a project level, assessors typically adopt a consumption-based assessment approach including all emissions incurred in the project supply chains regardless of the geographical point of origin. These project assessments will include some subset of the life cycle stages set out in BS EN 15978: Sustainability of construction works — Assessment of environmental performance of buildings — Calculation method [64], though no single common boundary is used in practice [65]. At a company level reporting boundaries are typically dictated by regulatory requirements, which generally require only emissions incurred across a limited subset of activities. At a sector level the boundary in the three major UK assessments to date has varied, though all have adopted a consumption-based accounting perspective [48,66,67]. Meanwhile, at a national level, emissions are reported on a territorial basis, omitting any emissions incurred in overseas supply chains. Corresponding carbon reduction targets are also set across each of these differing boundaries. Companies operating internationally also face the question of what boundaries should be drawn and if and how differentiated responsibilities should be taken into account depending on which country they are operating in. Translating between these disparate boundaries is thus a non-trivial activity and any common sectoral trajectory must clearly state the boundaries adopted.

3.2.6. Shortage of benchmark data

It remains difficult to effectively benchmark performance within the built environment, particularly for the embodied emissions associated with initial construction, which is often responsible for the largest volume of emissions that can be influenced by contractors and developers. Recent work by WRAP [68], the Carbon Leadership Forum [69], RICS [70] and De Wolf et al. [71], has sought to address this, but it will likely be many years before benchmark data is available for a broad range of project types. In the meantime it will remain difficult to set project embodied carbon reduction targets, which are a key means of delivering any company's reduction commitments [29]. Even once this benchmark data is available, further work will be required to understand what the embodied carbon reduction potential is of different assets types.

3.2.7. Limited mitigation opportunities for certain critical inputs

Though a wide range of low carbon materials can be used across numerous applications, the construction industry is fundamentally dependent upon certain carbon-intensive materials for specific tasks. Many of these materials, such as steel and cement, have significant emissions resulting from essential chemical processes in the production of the material, which are prohibitively expensive to capture with current technology. The UK Government explored a wide array of mitigation options for these materials in a set of Industrial Decarbonisation and Energy Efficiency Roadmaps published in 2015 [83]. However, few of the options identified in this process are commercially viable, and limited near term reductions are foreseen in the recently published joint Government and industry Action Plans [84]. In the long term significant reductions in the costs of industrial Carbon Capture and Storage (CCS) may facilitate more widespread deployment but this is only likely to cover a portion of total emissions from certain facilities that are both large in scale and geographically clustered with other emitters [72]. Furthermore, the significant cost and competitiveness implications of attempting to deploy CCS to mitigate process emissions, particularly from cement production, mean that mitigation options in other sectors with a lower marginal cost per tonne of carbon are likely to be prioritised for support by the UK government. Therefore a non-trivial level of industrial emissions are likely to continue and, even in the very long term, net zero emissions are unlikely to be achieved within the construction sector and its supply chains. More work must be done to understand the practical limits to achieving ultra-low carbon buildings and infrastructure, and the viability of their supply chains. In the meantime any collective trajectory must reflect the limited options that are presently available.

3.2.8. Role in setting boundary conditions for decarbonisation of other sectors

The outputs of the construction industry, in particular infrastructure assets, have a critical role in shaping future development pathways and supporting the decarbonisation of other sectors, such as transport. For instance, switching to lower carbon forms of transport requires the availability of different modes and additional infrastructure to ease existing congestion. As national infrastructure is increasingly viewed as an interdependent system-of-systems, it becomes increasingly difficult to disentangle critical infrastructure choices from decarbonisation trajectories. Ultimately, the long term development pathways the UK selects for its infrastructure will determine the scale and pace of emissions reduction that is achievable. Clearly, any desirable trajectory must not promote options that can deliver short term carbon reduction targets but lock-in high-emitting infrastructure that may ultimately prevent delivery of the long term net zero emissions goal [73]. Though much laudable work has been done to explore different long term pathways [74], these analyses have yet to consider the emissions embodied in delivering and maintaining this new infrastructure. Whether these emissions are best considered separately as part of a bespoke built environment trajectory, or integrated as part of a holistic analysis of UK national emissions, remains a subject of debate.

3.2.9. Capacity to deliver carbon storage and negative emissions

The achievement of net zero emissions is fundamentally dependent upon the development of additional carbon sinks at scale. The built environment represents one of the largest potential stores of carbon through the use of biogenic building materials, as recognised in public campaigns such as Wood for Good's 'Build with Carbon' [78]. Indeed the increased use of wood in construction is now included in the CCC's UK decarbonisation scenarios [39]. Albeit the relative costs of using biogenic materials compared with steel, concrete and masonry are highly dependent upon project circumstances, in all cases the costs of switching to lower carbon building materials are likely to be substantially cheaper than delivering other NET such as Direct Air Capture or Bioenergy with Carbon Capture and Storage (BECCS) [75]. Thus, the delivery of a substantial built environment carbon sink represents a relatively cost effective route to achieving net zero emissions. The introduction of policy instruments that internalise the external costs of carbon emissions, or value the benefits of sequestered carbon, could in future encourage a structural change towards the use of wood and other biogenic building materials [76]. Any industry wide decarbonisation trajectory should therefore recognise not just the opportunity to mitigate emissions but also the opportunity to sequester carbon. Furthermore, any associated action plan should seek to incentivise and allocate responsibility to those actors that can specify the use of materials that act as carbon stores.

3.3. Other shortcomings of applying the SBT SDA to the UK built environment

There are a few other reasons to be sceptical of the appropriateness of simply applying current variations of the SDA to develop a

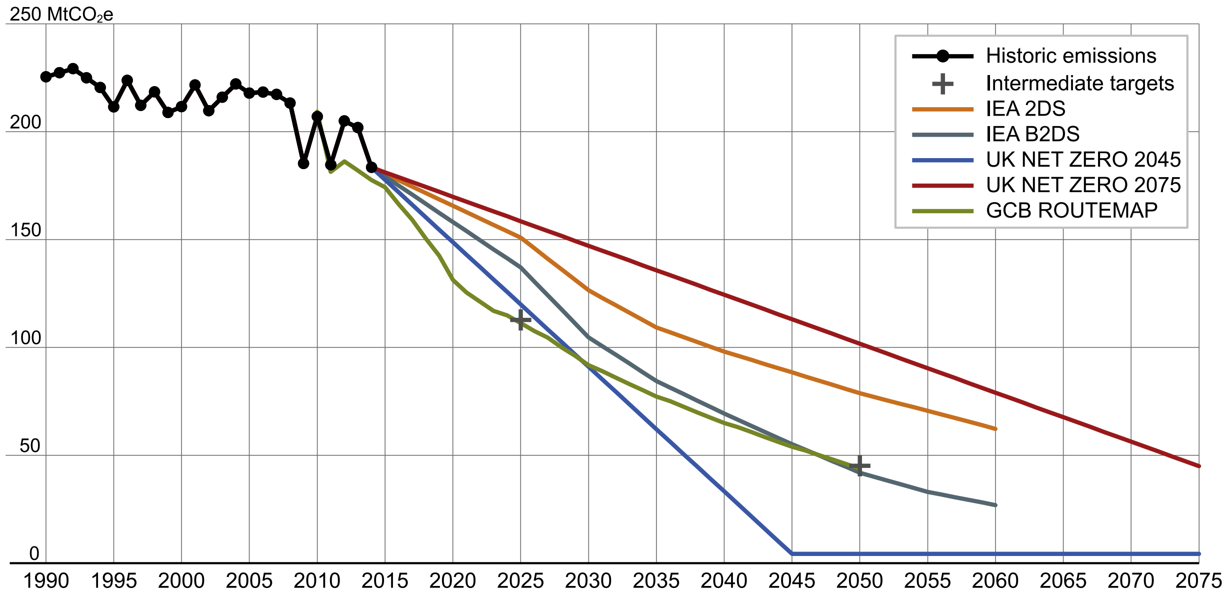

Fig. 5. Example decarbonisation trajectories for the UK built environment.

SBT for the UK built environment. Firstly, the SDA does not recognise the "common but differentiated responsibilities" between nations recognised in the Paris Agreement, preferring to construct pathways consistent with a global convergence, and thus inconsistent with UK national commitments. Secondly, this approach does not recognise the historic responsibility of companies for past emissions, as described by Bjørn et al. [82] Thirdly, the pathways calculated under the SDA are typically based upon a truncated timeline (generally to a 2050 end point) and extrapolated into linear reduction trajectories. This encourages an incrementalist approach to carbon reduction, which focuses on modest year on year reductions rather than promoting step changes in practice. Driven by a long term focus on cost and risk reduction, exacerbated by narrowing profit margins in the wake of the recession, the UK construction industry has historically adopted a cautious and highly incrementalist approach to innovation. This has resulted in a form of path-dependent development that has locked-in dominant technologies and processes, restricted the range of solutions explored and the capacity of construction firms to make radical changes to processes and structures [77]. Achieving deep carbon reductions will necessitate a much more radical approach to innovation, which sectoral and company targets must reflect.

If it is not already apparent, the significance of these unique challenges and other shortcomings is immediately evident through comparison with other industries, for example the production of chocolate bars. Chocolate bars have a short lifespan with high turnover, cannot be a store of carbon, and the requisite energy and material inputs could all potentially come from renewable sources. Changes in the production technologies and processes of chocolate bars can generally be implemented by a single or small group of actors over a short period of time. Furthermore, changes in the output of chocolate bars will not significantly affect the decarbonisation efforts of other industries or provide boundary conditions which limit the reductions that can ultimately be achieved. Therefore whilst the current SDA to SBT development may be suitable for chocolate bars, an alternative or adapted approach may be required for construction.

3.4. An alternative approach

One possible alternative would start from an estimate of potential carbon sinks and deployment of NET under a time frame consistent with achieving net zero emissions. This would provide a ceiling figure for remaining UK annual emissions under a sustainable long term net zero scenario. That remaining annual emissions budget would then be allocated amongst hard to mitigate sectors through a cross-sector dialogue based upon the maximum mitigation potential within each sector. The portion allocated to the built environment would then be translated into a long term reduction trajectory that is consistent with stabilising global temperature increases. Developing a detailed trajectory by such an approach would ideally require both a deeper understanding of the scope for deployment of additional carbon sinks, and a concerted effort to establish a cross-sector dialogue. Such a dialogue would likely need to be facilitated by a respected independent party, such as the CCC or the Carbon Trust. In the meantime, it is possible to calculate approximate example trajectories based upon current understanding and a series of plausible assumptions.

4. Example decarbonisation trajectories

By way of illustration, the impact of the various assumptions and approaches described in the preceding section can be seen in the indicative trajectories depicted in Fig. 5. Their bounds broadly represent the corridor within which UK built environment emissions must remain to be deemed consistent with the goals of the Paris Agreement. These trajectories are calculated based upon the assumptions set out in Table 1 and described in further detail in the Supporting Information. Table 2 sets out the corresponding carbon reduction targets against the most ambitious (UK NET ZERO 2045) and least ambitious (UK NET ZERO 2075) decarbonisation trajectories. Corresponding targets for the other example trajectories can be found in the Supporting Information.

A number of simple observations can be made from Fig. 5 and Table 2. Firstly, all the example trajectories require a more rapid rate of carbon reduction than has been delivered historically. Secondly, a linear reduction trajectory from the status quo will not deliver the interim Construction 2025 target, no matter the end point of that trajectory. Thirdly, national decarbonisation targets will be missed if UK firms only seek to align their company targets with the IEA 2DS trajectory.

A simple comparison between the headline carbon reduction rates presented in Table 2 and the targets currently set by the largest UK companies (summarised in Fig. 3) is also illuminating.

Table 1
Description of example decarbonisation trajectories.

Trajectory	Description
IEA 2DS	Reductions consistent with IEA 2 °C Scenario (2DS)
IEA B2DS	Reductions consistent with IEA Beyond 2 °C Scenario (B2DS)
UK NET ZERO 2045	Trajectory based upon UK achieving net zero emissions by 2045, with NET capacity towards lower end of current technically feasible projections. The built environment is allocated 10% of the remaining emissions budget beyond the net zero date.
UK NET ZERO 2075	Trajectory based upon UK achieving net zero emissions by 2075, with NET capacity at the maximum of current technically feasible projections. The built environment is allocated 25% of the remaining emissions budget beyond the net zero date.
GCB ROUTEMAP	Trajectory based upon achieving an 80% reduction in UK built environment emissions against a 1990 baseline as per 2013 Green Construction Board Low Carbon Routemap for the Built Environment (updated using 2017 baseline figures).

Table 2
Interim carbon reduction targets under most and least ambitious example decarbonisation trajectories. Each pair of numbers refers to the percentage reduction required in total built environment emissions under the UK NET ZERO 2075 and UK NET ZERO 2045 decarbonisation trajectories.

Target year								
		2015	*2020*	*2025*	*2030*	*2035*	*2040*	*2045*
Baseline year	*1990*	20–21%	25–34%	30–47%	35–60%	40–72%	45–85%	50–98%
	1990	20–21%	25–34%	30–47%	35–60%	40–72%	45–85%	50–98%
	1991	20–22%	25–35%	30–47%	35–60%	40–73%	45–85%	50–98%
	1992	21–22%	26–35%	31–48%	36–60%	41–73%	46–85%	51–98%
	1993	19–21%	24–34%	30–47%	35–60%	40–72%	45–85%	50–98%
	1994	18–19%	23–33%	28–46%	33–59%	38–72%	44–85%	49–98%
	1995	14–16%	20–30%	25–43%	30–57%	36–71%	41–84%	47–98%
	1996	19–21%	24–34%	29–46%	34–59%	39–72%	44–85%	49–98%
	1997	15–16%	20–30%	25–43%	31–57%	36–71%	41–84%	47–98%
	1998	17–19%	22–32%	27–45%	33–58%	38–72%	43–85%	48–98%
	1999	13–15%	19–29%	24–43%	30–56%	35–70%	40–84%	46–98%
	2000	14–16%	20–30%	25–43%	30–57%	36–71%	41–84%	47–98%
	2001	18–20%	23–33%	28–46%	34–59%	39–72%	44–85%	49–98%
	2002	14–15%	19–29%	24–43%	30–57%	35–70%	41–84%	46–98%
	2003	16–18%	21–31%	27–44%	32–58%	37–71%	42–85%	48–98%
	2004	18–20%	24–33%	29–46%	34–59%	39–72%	44–85%	49–98%
	2005	17–18%	22–32%	27–45%	32–58%	38–71%	43–85%	48–98%
	2006	17–19%	22–32%	27–45%	33–58%	38–72%	43–85%	48–98%
	2007	17–18%	22–31%	27–45%	32–58%	37–71%	43–85%	48–98%
	2008	15–17%	20–30%	26–44%	31–57%	36–71%	42–84%	47–98%
	2009	2–4%	8–20%	14–35%	21–51%	27–66%	33–82%	39–98%
	2010	12–14%	18–28%	23–42%	29–56%	34–70%	40–84%	45–98%
	2011	2–4%	8–19%	14–35%	20–51%	26–66%	33–82%	39–98%
	2012	12–13%	17–27%	23–41%	28–56%	34–70%	39–84%	45–98%
	2013	10–12%	16–26%	21–41%	27–55%	33–69%	38–84%	44–98%
	2014	1–3%	7–19%	14–35%	20–50%	26–66%	32–82%	38–98%

18 of the 66 firms surveyed have targets which meet or exceed the headline reduction rate implied by the UK NET ZERO 2045 trajectory. A further 5 companies have targets which exceed the UK NET ZERO 2075 trajectory but are below the rate required by the UK NET ZERO 2045 trajectory. The remaining 43 companies either have targets that are less ambitious than that implied by the least ambitious example trajectory presented here, or have no target at all. This simple comparison does not indicate if current sector targets are collectively adequate, as it does not account for the differing market shares and accounting boundaries of the companies; however, it does provide a rough indication of how current company targets compare with plausible sectoral trajectories.

All of these points suggest that greater ambition and additional policy support for mitigation is urgently required if sectoral targets are to be delivered. Furthermore, the difference in cumulative emissions between the trajectories is substantial, as summarised in Table 3. For instance, simply following a trajectory based upon IEA 2DS could result in over a gigatonne of additional cumulative emissions by 2050 compared with adopting the GCB ROUTEMAP trajectory.

As the required reduction rates vary substantially between scenarios, so do the corresponding mitigation options. This has profound implications for the required rate of deployment of low carbon materials, technologies and practices. Though the trajectories are fairly similar through the early 2020 s, they diverge substantially by the mid-2030 s. This implies that under the more ambitious trajectories, ultra-low carbon options such as cement free concrete, industrial CCS and high rise timber structures would have to be commonplace within just two decades. Achieving such a fast rate of deployment in a notoriously conservative industry would likely require substantial investment in skills and training; radically increased support for innovation to demonstrate alternative materials at scale; and additional regulatory drivers for those less willing to adopt new technologies. Such a transition would also require a fundamental leap of faith from early adopters and a profound

Table 3
Cumulative emissions under example decarbonisation trajectories.

Trajectory	Cumulative UK built environment emissions (2015–2050) $MtCO_2e$
IEA 2DS	4473
IEA B2DS	3709
UK NET ZERO 2045	2845
UK NET ZERO 2075	5094
GCB ROUTEMAP	3314

shift in the industry's perception of what can be delivered. Under the deeper decarbonisation trajectories, the "common industry view that imperceptibly slow change is typical and radical change almost unimaginable" [26] would no longer be tenable.

Ultimately, the value in determining a sectoral carbon reduction trajectory is inextricably linked to the measures that will generate confidence that the trajectory can be delivered. The challenge of this shift in approach cannot be underestimated, in a large and fragmented industry, with complex international supply chains, there is an immediate need for a coordinated legislative approach, supported by investment, upskilling and technology acceleration. If the UK construction industry is intent on generating a credible trajectory that will meet the requisite carbon targets, it must consider the simultaneous introduction of novel measures that could support its delivery. Otherwise many within the industry will immediately deem the proposed trajectory implausible, or even impossible, undermining the value of its development. Indeed, when the Green Construction Board's Low Carbon Routemap for the Built Environment was published in 2013, the Government's then chief construction advisor Paul Morrell stated that "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". When generating a refreshed trajectory that reflects the interim changes (such as the Paris Agreement), it is imperative that the industry also generates an accompanying action plan that can provide confidence that the trajectory can be delivered.

5. Conclusions

The full implications of the Paris Agreement for the construction industry are profound, yet poorly understood and rarely specifically interpreted into long-term targets for individual firms. For many countries, such as the UK, the Paris Agreement implies the transition to a net zero carbon economy shortly after mid-century. This will require both deeper mitigation than the currently targeted 80% national GHG emissions reduction by 2050 and substantial deployment of NET. Delivering such a transition requires that short term national, sectoral and company emission reduction targets are nested within longer-term pathways and strategies that are consistent with deep decarbonisation and the delivery of a net zero emissions UK. If strategies only focus upon the achievement of short term or interim carbon reduction goals, there is a risk that insufficient action will be taken out to mid-century and that infrastructure and technologies that are incompatible with the long term objective will be locked in. Given this timeline it is imperative that the construction industry urgently engage with efforts to depict a net zero emissions future for the UK, as decisions taken by the industry over the coming decades will fundamentally determine the viability of such an objective. This will require setting a target trajectory for the built environment that is consistent with current climate science, global and national ambitions.

Through a review of current company carbon reduction targets, and comparison with a range of sectoral carbon reduction trajectories, this paper has highlighted that current targets set by major UK construction firms are generally insufficient to deliver national carbon reduction goals. The largest firms are typically setting modest short term reduction targets, and only a minority have sought to align their targets with international commitments. Recent initiatives have encouraged a small but growing number of construction firms to develop such targets, leading to calls for the development of sectoral targets and pathways from which commensurate company targets can be developed. Developing a credible common sectoral decarbonisation trajectory for the UK built environment will require the adaptation of current alignment approaches to address the range of unique challenges set out in Section 3. Any failure to properly attend to these details in the selection of a methodology and development of a target trajectory will have significant consequences. As demonstrated by the example trajectories presented in Section 4, the implications of these seemingly minor changes are profound, necessitating radically different mitigation responses and resulting in substantially different cumulative emissions totals. It is therefore important that the industry must engage in an open and informed debate to determine an appropriate approach that recognizes these challenges.

This study was limited to a brief review of targets from the largest firms, and was only sufficient to provide a general indication of progress. A more comprehensive review of all company carbon targets, and perhaps their regular compilation in a public forum, would be a welcome extension of this work. The focus upon the UK industry was a further limiting factor. Future studies to determine target trajectories for other major construction markets would complement this work. A more in depth analytical study of the Science Based Targets adopted thus far by firms in other sectors would also be a welcome addition to the literature.

As the UK industry prepares to convene roundtable discussions on the development of a common trajectory, let us conclude by recapping the pertinent features that must be included. Such a trajectory must deliver both the 80% emissions reduction by 2050 set out in the Climate Change Act and the longer term objective of net zero emissions shortly thereafter implied by the Paris Agreement. It must consider the projected level of industry output and deliver reductions in absolute emissions not just carbon intensity. It must include commitments on Scope 3 emissions and some consideration of future carbon storage. However, it must also recognise that complete mitigation of all Scope 1, 2 and 3 emissions from construction, operation and maintenance of the built environment this century is not feasible, and that, within any net zero emissions scenario, a portion of the UK's remaining national carbon budget must be allocated accordingly. Therefore, in developing the trajectory, the industry must engage in an active attempt to depict the long term role of a sustainable construction industry in a net zero UK. Critically, it must encourage the requisite step changes in practice rather than a sequence of short term incremental improvements. It must garner widespread support within the industry and be accompanied by an action plan which instils confidence that it can be delivered. Finally, beyond its initial publication, the trajectory must be maintained and reported against, ideally by a suitably well-resourced and independent body. If such a trajectory can be developed, it will set a powerful precedent for other nations and industries seeking to deliver upon the Paris Agreement.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.enbuild.2018.01.023.

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