



BUILDING AND INFRASTRUCTURE CONSUMPTION EMISSIONS

IN FOCUS

Table of contents

1. Why tackling construction emissions is critical	12
2. Reducing building and infrastructure construction emissions	16
2.1 The stakeholders and how they can trigger change	18
2.2 Quantifiable actions to reduce consumption	25
2.3 Emission reduction potential	34
3. Associated benefits	36
3.1 Social benefits	38
3.2 Economic benefits	41
3.3 Environmental benefits	45
4. Summary	46

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Acronyms

Abbreviation	Full term
ACE	Architecture, Construction, and Engineering
BECCS	Bioenergy Carbon Capture and Storage
CBE	Consumption-Based Emissions
CCS	Carbon Capture and Storage
D2020	Deadline 2020
EEIO	Environmentally Extended Input-Output Model
ETS	Emissions Trading Scheme
EU	European Union
EV	Electric Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale Greenhouse Gas Inventories
GTAP	Global Trade Analysis Project
LCA	Life Cycle Assessment
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
OECD	Organisation for Economic Co-operation and Development
NDCs	Nationally Determined Contribution
UN	United Nations

Key terms

Term	Description
Ambitious target	Target level of ambition for consumption interventions that is more 'ambitious' than the progressive target. It is based on a future vision of resource-efficient production and extensive changes in consumer choices. This level was typically informed by expert judgement rather than existing research.
Bioenergy carbon capture and storage	Carbon capture and storage (CCS) is a set of technologies that can keep CO ₂ from entering into the atmosphere, typically from sources with concentrated and high CO ₂ emissions such as power plants or industrial processes. Bioenergy with CCS (BECCS) is a potential greenhouse gas mitigation technology which removes CO ₂ from the atmosphere by combining bio-energy (energy from biomass) use with geological capture and storage.
Buildings and infrastructure	Consumption category encompassing full supply chain emissions from the construction of new buildings and infrastructure such as bridges and dams. This includes works associated with refurbishment, retrofit, demolition etc. It excludes operational emissions during a building's lifetime. The methodology for determining a city's consumption emissions is based on downscaling expenditure at a national level to the associated urban population on a pro-rata basis. This means the impact of national building and infrastructure projects were scaled down proportionally to the cities' populations. This is based on the assumption that new construction benefits the national population irrespective of where people live.
Circular economy	A circular economy is an alternative to a traditional linear economy where materials are made, used, and then disposed of. In a circular economy resources are kept in use for as long as possible to extract the maximum value from them. Products and materials are recovered and regenerated at the end of each service life.
City residents	Residents living within the city, i.e. excluding visitors.
Consumption-based emissions	Consumption-based GHG accounting is an alternative to the production-based approach to measuring city GHG emissions. This focuses on the consumption of goods and services (such as food, clothing, electronic equipment, etc.) by residents of a city, and GHG emissions are reported by consumption category rather than GHG emission source category. For the purposes of this report, the PAS 2070 methodology was adopted.

Consumption categories	Categories of products and services covered by consumption-based emissions. These are aggregated categories based on the EEIO model categories.
Consumption intervention	A change in production or consumption that in most cases leads to a direct reduction in consumption-based emissions. <i>e.g. reduce vehicle ownership</i>
Deadline 2020	Deadline 2020 is a routemap for achieving the Paris Agreement, which outlines the pace, scale and prioritisation of actions needed by C40 member cities to reduce their production-based emissions over the next five years and beyond. The report was delivered through collaboration between Arup and C40 in 2016.
Environmentally Extended Input-Output Model (EEIO)	This model provides environmental indices associated with financial flows. For the purposes of this report, the Environmentally Extended Input-Output Model was used to analyse spending from households and government, and business capital expenditure, based on financial flow data from national and regional economic accounts. It estimates GHG emissions using average GHG emission factors depending on where the goods and services consumed in a city are produced.
Global Trade Analysis Project	The Global Trade Analysis Project (GTAP) is one of several multi-regional input-output models available and was chosen for producing the C40 cities consumption-based emissions inventories due to its global reach.
Global Protocol for Community-scale Greenhouse Gas Inventories	The World Resources Institute, C40 Cities Climate Leadership Group and ICLEI – Local Governments for Sustainability (ICLEI) have partnered to create a GHG Protocol standard for cities known as Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). This protocol establishes a methodology for city GHG emissions reporting based on the production-based emissions accounting framework.
GHG budget	The quantity of greenhouse gas emissions that can be emitted in total over a set period of time defined by the probability of avoiding a specific global average temperature increase.
Nationally Determined Contribution	A commitment made by each signatory country to the Paris Agreement outlining the climate action it will take to contribute to the agreement's aims.
On-site (emissions)	Emissions occurring on the site of a specific industry e.g. emissions from on-site agricultural facilities.

Planetary boundary	Defines the environmental limits within which humanity can safely operate according to earth system science, the study of material and energy flows. Nine planetary boundaries have been identified: stratospheric ozone depletion, biodiversity loss, chemical pollution, climate change, ocean acidification, freshwater cycle, land system change, Nitrogen and Phosphorus flow, and atmospheric aerosol loading. Each boundary has an associated quantifiable limit. Staying within the boundary provides a safe operating space for humanity within which it is possible to continue to thrive in a long-term perspective.
Production-based emissions	A method of measuring emissions that accounts for direct emissions, and emissions from energy consumption within a territorial boundary. This methodology was developed by the Intergovernmental Panel on Climate Change for national emissions reporting. Note the term production-based and production emissions are used interchangeably within this report.
Progressive target	Target level of ambition for consumption interventions determined through research on currently available technologies and evidence of feasibility for progressive changes in consumer choices (e.g. historic evidence of consumer habit change or alignment with other consumer priorities such as health).
Rest of Nation	Source emissions of a city's consumption-based emissions that occur within that city's host nation.
Rest of World	Source emissions of a city's consumption-based emissions that occur outside that city and its host nation's borders. Note this does not exclude the emissions occurring within one of the C40 cities where these relate to a different city.
Supply chain	The sequence of processes involved in the production and distribution of a commodity. For example part of the global concrete supply chain would include a quarry, a storage facility, and the grinding facility.
Urban stakeholders	Persons or groups who are involved in the supply chain and that are impacted by the outcome, such as policymakers (all levels of government), building occupiers (tenants, owners), civil society (NGOs, trade networks, community groups, media) and the private sector (architects, construction and engineering firms, materials and machine manufacturers, property investors, developers).

Key findings

Emissions from building and infrastructure construction are expected to form the single largest category of consumption-based emissions for C40 cities between 2017 and 2050, producing 21% of consumption emissions. As this period is critical for reducing greenhouse gas (GHG) emissions in line with keeping global temperature rise to within 1.5°C above pre-industrial averages, serious action is needed in this area.

EMISSIONS SOURCES

60% of consumption emissions from building and infrastructure construction in C40 cities are associated with the **production and delivery of building materials** at

various stages of the supply chain. Minerals, dominated by cement, account for **32%** of all emissions from material consumption. Metals such as steel account for **15%**.

INTERVENTIONS

The report identifies interventions to reduce consumption emissions from buildings and infrastructure. These include enhancing building utilisation, reducing material use, and reducing the embodied carbon of the chosen materials. If they reach all the most ambitious targets for these consumption-related interventions, cities can achieve a **44% reduction in buildings- and infrastructure-related emissions between 2017 and 2050.**

- **Implementing efficiency in material design** Designers and building codes often require more material than is structurally necessary, creating material redundancy. Eliminating this waste at the design stage has the largest savings potential and could **cut GHG emissions by 18%** between 2017 and 2050.
- **Enhancing existing building utilisation** Buildings are underutilised and often discarded far before they have reached the end of their useful life. If cities optimise the use of existing structures, consequently reducing the need for new buildings, they could potentially cut **GHG emissions by 11%** between 2017 and 2050.

- **Switching high-emission materials to sustainable timber where appropriate**

Timber construction is a viable solution where there is availability of local, sustainably managed forests that follow internationally recognised standards. Provided that potential rebound effects are avoided, switching to timber usage could cut **GHG emissions by 6%** between 2017 and 2050.

- **Using lower-carbon cement** Concrete is one of the most carbon-intensive construction materials as the production of its cement component requires extreme heat and releases a great deal of CO₂. Reducing the need for cement in concrete by using lower-carbon alternatives could potentially cut **GHG emissions by 6%** between 2017 and 2050.

- **Reusing building materials and components** Recycling and reusing building components has immense potential in the long term, and reducing virgin steel use now could potentially cut **GHG emissions by 3%** between 2017 and 2050.

The report identifies that on-site emissions also need to be addressed to realise net-zero emissions targets. A key part of this involves addressing emissions from construction vehicles. However, the report does not cite any quantified potential emission reductions in this area, due to a lack of data available.

ENGAGING STAKEHOLDERS

The construction sector is made up of a wide range of stakeholders, each of whom has

an impact on choices made in material use and building use. It is essential to establish stakeholders' roles and the opportunities they have to trigger change, so that all parties can work together to achieve interventions with measurable outcomes.

This report identifies three key stakeholder groups: policymakers, civil society and the private sector.

These stakeholders need to commit to key initial actions. The report identifies these as:

- Commitment to roadmaps and strategies;
- Guidance on standards and development of accessible tools;
- Commitment to radical transparency;
- Leadership as pioneering influencers; and
- Establishment of mandatory construction emission reporting and targets.

BENEFITS

In addition to significant GHG reductions, these interventions have wide-ranging social, economic and environmental benefits that overlap with broader societal concerns. For example, the suggested interventions would reduce air and noise pollution locally, providing health benefits for citizens and the environment. They would also spark change within the growing construction economy, providing opportunities for new jobs and skills. Increasing the use of existing buildings could free up money that would otherwise have been invested in new buildings. Emphasising these cross-cutting benefits can help build a strong case for taking climate action.

Introduction

C40, Arup and the University of Leeds have collaborated on research and analysis to better understand consumption-based emissions in cities, to explore their scale and to consider what cities can do to reduce them.

Consumption-based emissions are accounted for using a different methodology than the usual production-based GPC framework which considers what a city emits directly within its territorial boundary. Instead, this report considers the emissions associated with all the products and services city residents consume, only excluding what a city exports without consuming.

The research set out a series of future scenarios to show how consumption-based emissions in C40 cities may evolve if no action is taken, if limited action is taken and if ambitious action is taken. It also evaluated previously untapped opportunities for emissions reduction across six key consumption categories:

- Food;
- Buildings and infrastructure;
- Private transport;
- Aviation;
- Clothing and textiles; and
- Electronics and household appliances.

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- ***Private transport;***
- ***Aviation;***
- ***Clothing and textiles;***
- ***Electronics and household appliances.***

The study explored the potential of interventions to mitigate climate change in these key consumption categories and the role of relevant stakeholders as well as the wider benefits of taking climate action. The overall results are presented in the project's headline report *The Future of Urban Consumption in a 1.5°C World* (2019).

The purpose of this "In Focus" report is to further detail the opportunities to reduce building- and infrastructure-related consumption emissions across the C40 cities and ultimately highlights what cities can do to reduce these emissions by 2030.

Consumption emissions in building and infrastructure construction refers to all emissions associated with the sourcing, production, transport, use and disposal of materials and the emissions on construction sites themselves.

Construction emissions from buildings and infrastructure are anticipated to increase by 37% by 2050, even if national governments deliver on their nationally determined contributions (NDCs) to meet the goals of the Paris Agreement. C40 cities have already made commitments to

deliver reductions in the operational emissions of their buildings through their Deadline 2020 commitments. Analysts estimated that this would lower the increase in annual emissions to 29% by 2050. Yet it is not sufficient to reduce emissions in line with a 1.5°C trajectory and thus further C40 city action on consumption emissions is necessary.

Limitations of the modelling approach meant that it was not possible to apply regional intervention targets. For the purposes of this report, supply chain interventions are applied as global averages.

This report confirms that urgent action is needed from all actors – governments, businesses, cities, civil society and residents. It is a call to mayors and urban policymakers to reflect on how their city development plans can help reduce buildings- and infrastructure-related emissions while delivering multiple benefits for residents. While mayors can play an important role as leaders and convenors in this effort, there must be collaboration across all sectors of society in order to achieve a better and more sustainable future.

The method, evidence base and limitations of this research are published in the Method Report.

We invite all stakeholders – including city administrations, NGOs, civil society, business and private citizens – to read and review the Method Report and to provide comments and recommendations for improvement, as well as links to other relevant work and data.

All documents associated with this research project can be found online at:

<https://www.c40.org/consumption>

1 Why tackling construction emissions is critical

By 2050, the global urban population will have increased by 2.5 billion people. The world will build a city of more than 1.5 million people every week until 2050 (UN DESA, 2018).

By 2060, the total floor area of buildings will double, with most of this new construction expected to occur in Asia and Africa (Architecture 2030, 2019). Between 2005 and 2025 it is estimated that enough floor space will be constructed in China to cover New York City ten times over: 40 billion square metres, in five million buildings (McKinsey Global Institute, 2009).

In 2017, emissions associated with the construction of buildings and infrastructure in C40 cities were estimated to account for 11% of the total consumption-based emissions across C40 cities.¹

Figure 1 shows the breakdown of projected cumulative buildings- and infrastructure-related emissions between 2017 and 2050, assuming that countries deliver on their NDCs as set out in the Paris Agreement and that C40 cities deliver on their Deadline 2020 commitments.² Adjacent to this, the key materials column shows how these emissions are associated with different material groups used in construction.

The data in Figure 1 shows that a significant contribution to buildings- and infrastructure-related emissions comes from electricity generation and fossil fuel extraction by the supply chain. Other major sources are the direct on-site emissions during minerals and metals production. These industries often have high energy requirements and are also responsible for large, direct, on-site emissions due to the chemical processes that occur in manufacture, for example in cement kilns and steel blast furnaces.

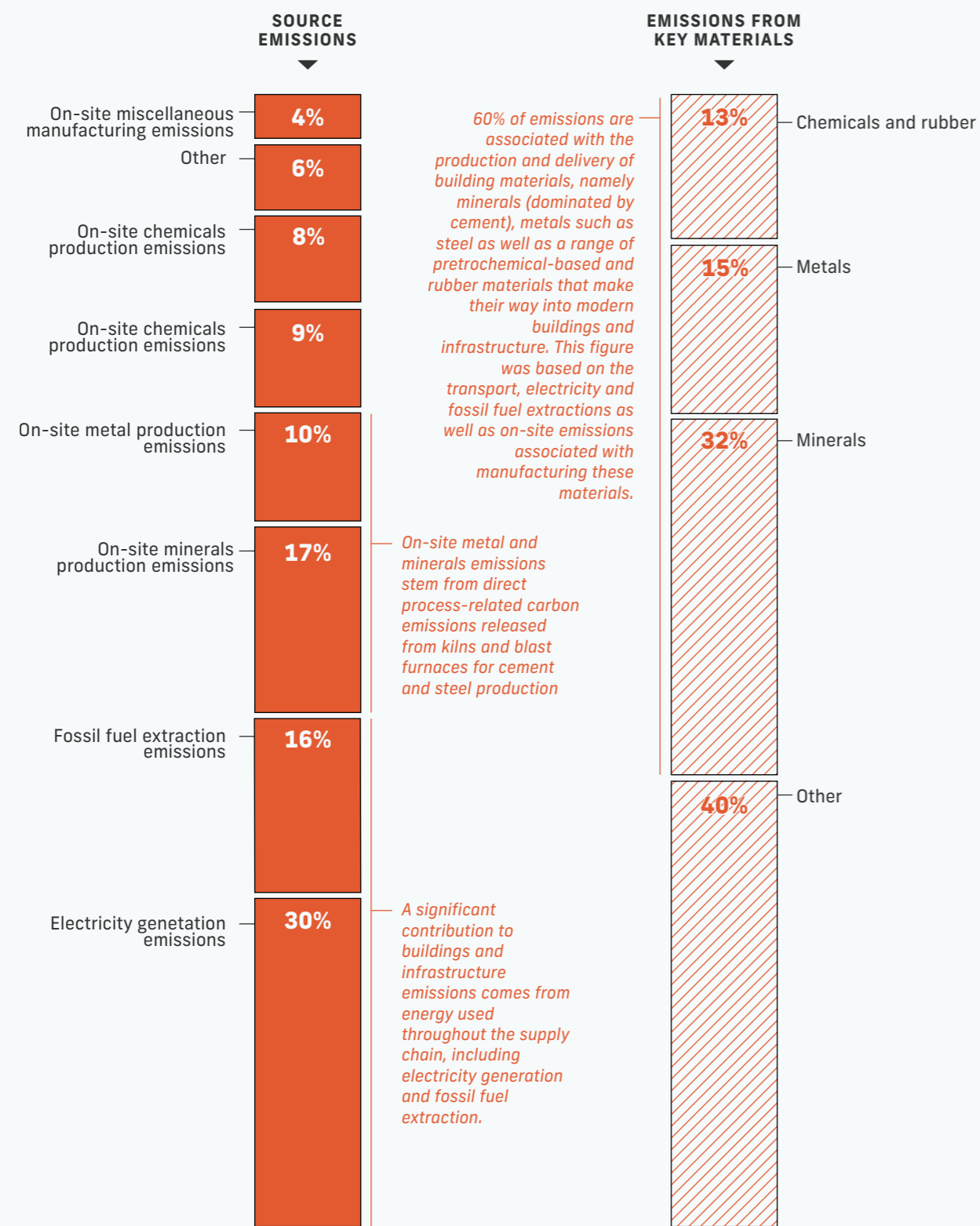
The key materials breakdown³ highlights that 60% of the industry's emissions are associated with the production and delivery of building materials, namely minerals (dominated by cement), metals such as steel, and a range of petrochemical-based and rubber materials.

¹ The methodology for determining a city's buildings and infrastructure emissions is based on down-scaling expenditure at a national level to the associated urban population on a pro-rata basis. This is based on the assumption that new construction does benefit, and is likely used by the national population irrespective of where they live. For example, Parisians might use bridges across the whole of France.

² For further information on the scenarios, see the associated headline report: "The Future of Urban Consumption in a 1.5°C World".

³ This figure was derived by adding the proportion of transport, electricity and fossil-fuel extraction emissions involved in manufacturing these materials to their direct on-site emissions.

fig.1
Cumulative buildings and infrastructure-related emissions broken down by source and key material based on data from C40 cities consumption-based emissions.



Despite the assumption that NDCs will deliver industry improvements – such as increased efficiency of steel and cement production, the adoption of lower-carbon fuels, the substitution of cement clinker and the adoption of carbon capture and storage in material production – the emissions from the sector will still grow substantially. Buildings and infrastructure, therefore, is the largest of the six key consumption categories that were identified when accounting for cumulative emissions between 2017 and 2050.⁴ This makes focussed intervention in this area critical.

Analysts anticipate that emissions from the construction of buildings and infrastructure will increase by 37%

⁴ The NDC scenario was based on third-party modelling by the International Energy Agency published in the 2017 "Energy Technology Perspectives" report.

2

Reducing building and infrastructure construction emissions

Cities are centres of intensive construction demand, with high population densities and requirements for housing, workplaces and infrastructure.

When we rethink how buildings and infrastructure are constructed using a whole-life-cycle approach, we find significant opportunities to reduce consumption-based emissions.

A whole-life-cycle approach encompasses building and infrastructure construction from planning to deconstruction. It includes interaction with the entire value chain, including investors, developers, policymakers, communities, designers, engineers and material manufacturers. This makes collaboration a challenging yet critical aspect of any effective interventions.

The construction sector is fragmented and inherently complex. The following section seeks to better understand: who are the key stakeholders? What levers do they have at their disposal to trigger change? And how should they interact? All stakeholders must indeed intervene and collaborate prior to the planning and design stages to ensure that the targets of material and building-use change are technically and financially achievable.

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2.1

The stakeholders and how they can trigger change

Urgent action is needed from all actors – governments, the private sector, civil society and residents - in order to achieve a more sustainable future.

Governments have significant influence over choices that impact embodied carbon emissions in buildings and infrastructure. Improving legislation at national and/or city level is an important supporting factor – taxes, building codes, planning and specification requirements all influence the design and procurement choices made by other stakeholders. Government finance can support the industry to adapt to necessary changes, but most importantly there needs to be a long-term vision with appropriate regulatory changes defined, to enable the market and supply chain to develop effective solutions.

Additionally city mayors can play a significant role – not only through local public construction procurement and planning policies – but also through convening key industry players to form a coherent plan to reduce emissions from buildings and infrastructure. The convening power of mayors is especially relevant in the construction sector. The relationships between, and overlapping aims of, city governments,

developers and landowners can accelerate the implementation of interventions along the construction value chain.

The private sector is often most familiar with current innovations and has the greatest access to relevant data. This information puts private sector actors in a position to lead both by setting bold sustainability goals and by sharing their knowledge to guide other stakeholders. Private sector actors can also in their close relationships with clients highlight opportunities for low carbon choices the client may not have been aware of.

Civil society can play an important supporting role in providing guidance, facilitating innovative developments and providing independent scrutiny of industry progress. Culture and media may play an indirect role in influencing building designs. For example popular tv-shows or design magazines could promote less resource-intensive aesthetics such as biodegradable interior finishes, and the use of secondary materials.

Individuals are not included as a stakeholder group in this context, as they typically have little power to reduce consumption-based emissions in construction. But they are still an important factor for consideration, especially by government stakeholders. In some instances, building occupiers can highlight their preference for building materials that have no negative impacts on human or environmental health, and this can drive industry action. National, city and regional governments can focus on educating residents about the impact of construction to spur engagement and consumer-based action. Critically, all levels of government must engage with their residents with their embodied carbon work and ensure that sustainable buildings stay affordable and integrated in their social housing strategy.

Based on the observations above, the report thus clusters three groups of key stakeholders:

Government finance can support the industry to adapt to necessary changes, but most importantly there needs to be a long-term vision with appropriate regulatory changes defined, to enable the market and supply chain to develop effective solutions.

STAKEHOLDER CATEGORY		Examples
POLICYMAKERS		All levels of government and regulation
CIVIL SOCIETY		NGOs, trade networks, community groups, media
PRIVATE SECTOR	ACE	Architects, construction and engineering firms
	Manufacturers	Material and machine manufacturers
	Investors	Property investors and developers

Table 1 displays the levers and interactions identified for each stakeholder group. The aim is to create the communal goals, accessible tools,

transparency and market stimulation necessary to lower consumption-based emissions in the planning and design stages.

Tab.1

Stakeholders' levers and interactions

LEVERS	STAKE-HOLDERS	RATIONALE
Commitment to roadmaps and strategies	Civil society, policymakers, investors, ACE, manufacturers	<p>Initial interventions require an understanding across all stakeholders that they are all striving for the same goal. Commitments help focus energy and funding and, ultimately, delivery.</p> <p>Stakeholder interactions Policymakers typically have responsibility for developing official strategies for construction. However, these need to be developed with input from civil society and industry. Independent from government, industry clients can set their own procurement policies and reduction targets. Those most familiar with the relevant technologies such as the ACE community and manufactures, can provide details as to the pace and potential for technological advancement. Construction clients can drive innovation by updating their design briefs and tender requirements.</p> <p>Examples In 2019, Vancouver declared a climate emergency resulting in the development of a climate emergency response with six “Big Moves” set to define the city’s climate targets for the coming years. The moves included a focus on lower-carbon construction, with a set target of 40% embodied carbon reduction compared to the 2018 baseline by 2030. This move has spurred the market to consider locally viable low-carbon alternatives, such as timber (City of Vancouver, 2019). In the private sector Skanska UK, the UK division of multinational construction and development company Skanska Group, has committed to a net-zero carbon portfolio by 2045 without using carbon offsetting schemes. The company has explicitly stated that all their targets include the emissions from their whole supply chain, in addition to their direct emissions (Skanska UK, 2019).</p>

LEVERS	STAKE-HOLDERS	RATIONALE
Guidance on standards and development of accessible tools	Civil society	<p>The complexity of accounting for consumption-based emissions calls for standardised, impartial and verified emissions data. Civil society actors such as professional bodies, networks and other non-industry actors play an important role in creating accessible and equitable tools and guiding all other stakeholders in their application.</p> <p>Stakeholder interactions Cities can work with and fund third-sector organisations that support reducing embodied emissions of new buildings and improving building utilisation for new and existing buildings. City governments also have a role in endorsing the work of these organisations and raising their profile.</p> <p>Examples A number of key guidance documents and tools specific to embodied carbon are available. These include the RICS’ Professional Statement on “Whole life carbon assessment for the built environment” (RICS, 2017) and the UK Green Buildings Council’s “Practical how-to guide: Measuring embodied carbon on a project” (UK Green Building Council, 2014). Another way to lower embodied emissions in the construction supply chain is to adopt circular economy principles. NGOs such as the Ellen MacArthur Foundation (EMF) have played a pivotal role articulating what these principles mean when applied to construction and engaging the ACE community and policymakers on tangible actions they can take. For example, the Ellen MacArthur Foundation produced the Circular Economy in Cities: Project Guide on circular economy implementation for city leaders (Ellen MacArthur Foundation & Arup, 2019).</p>

LEVERS	STAKE-HOLDERS	RATIONALE
Commitment to radical transparency	Investors, ACE, manufacturers	<p>Empirical improvements to consumption emissions are only possible with accurate data and baseline measurements. For this reason, commitments to radical transparency are key. A variety of private actors can disclose their data. Together, supply chain data from construction clients, life cycle assessment (LCA) data from designers and Environmental Product Declarations from manufacturers can accelerate the effectiveness of low-emission design.</p> <p>Stakeholder interactions As the actors working most closely to implementing new solutions, ACE can play a role highlighting opportunities for low-carbon or material-efficient design to clients.</p> <p>Examples The Structural Engineers 2050 Commitment Initiative urges structural engineers and engineering firms to recognise their role in reducing GHG emissions and aims to help grow the database of material quantities in building projects to enable the transparent determination of an embodied carbon baseline (Carbon Leadership Forum, 2018).</p>

LEVERS	STAKE-HOLDERS	RATIONALE
Leadership as pioneering influencers	Policymakers, investors	<p>Established institutions, both public and private, can send a strong message to the industry by adopting procurement policies that reflect the prioritisation of lower-emission building and infrastructure construction. This move can serve to demonstrate innovative multi-stakeholder collaborations and highlight the viability and potential of new processes to the private sector.</p> <p>Stakeholder interactions Clients, including governments, can set specific visions around delivering a building that has minimal associated emissions. For example, for the construction of a new location in 2015 Marks & Spencer sought to create the chain's 'biggest and greenest store'. This goal resulting in the creation of a proprietary hemp and limecrete prefabricated walling solution now being used in other stores (Marks & Spencer, 2015). Developers, investors and those involved at scale with the procurement of construction services can set targets or requirements for an assessment of embodied emissions in their projects (Giesekam, et al., 2016). This will influence the relationship between designer and procurer in construction; neither can unilaterally deliver maximum emissions reductions; each depends on the other and together they can have a large and direct impact.</p> <p>Examples Cities have the potential to be pioneering influencers, both through flagship construction projects and flagship policies. For example, in Los Angeles, the mayor was able to convene other "Big 11" mayors to support a legislative package to help develop low-income and affordable housing (Mayor Eric Garcetti, City of Los Angeles, 2017). On a national scale, Rijkswaterstaat, the state infrastructure developer in the Netherlands, requires all projects submit a whole-of-life carbon assessment using their inhouse calculation tool (Rijkswaterstaat, 2019). The UK government, while building a new railway line, has set a target to implement a minimum 50% replacement of cement content in concrete with low-carbon alternatives – and has achieved up to 72% in some places (Crossrail Learning Legacy, 2019).</p>

LEVERS	STAKE-HOLDERS	RATIONALE
Establishment of mandatory construction emission reporting and targets	Policymakers	<p>Large-scale reduction in consumption emissions related to buildings and infrastructure can occur when this aim is incorporated into building and planning regulation – much the same way that the reduction of operational emissions is.</p> <p>Stakeholder interactions Legislative changes will necessitate changes in construction markets, but policymakers can provide funding to the private sector to adapt to these changes. The UK government provided sustained funding for enhancing BIM capability, required for integrated designs, through collaboration with the University of Cambridge in the “Centre for Digital Built Britain” (University of Cambridge, Centre for Digital Built Britain, 2019). Cities and national governments have very different powers and often operate at a different pace. For example, interacting within the broad category of policymakers, city mayors can lobby central government for a national legislation that incentivises low-embodied-carbon construction.</p> <p>Examples The Dutch national government rolled out the national standard for measuring embodied carbon, the MPG, in 2013. Initially planning applications just needed to include a calculation of the embodied carbon. In 2018 a maximum value was set for all new homes and offices over 100 m². This has supported nationwide discussion and work on embodied carbon. Dutch cities have used the national MPG as a baseline, and set targets far beyond the national requirements for their own projects (Rijksdiens voor Ondernemend Nederland, 2019).</p>

2.2

Quantifiable actions to reduce consumption

Due to the urgent need for action all stakeholders must be clear in their opportunities and responsibilities in driving key solutions. “The Future of Consumption in a 1.5°C World” research report explores a number of objectively effective, emissions-reducing interventions.

The six interventions identified are described in full in Table 2 and include actions to address the underutilisation of buildings, the reduction of material use, the reduction of embodied carbon, and the use of low emission construction vehicles. For example, concrete and steel are two of the most common building materials, but both entail very carbon-intensive manufacturing due to the chemical processes and the significant amounts of energy required. The report addressed this issue by considering switches to sustainable timber and low-carbon cement where possible.

The use of excess material within the construction industry is common. Net reductions in material consumption are both feasible and necessary to reduce emissions in production and, to a lesser extent, associated extraction, transport and demolition processes. For example, one study

One study found that in a sample of steel-framed buildings in the UK, beams were being used at less than their actual loading capacity by

50%

found that in a sample of steel-framed buildings in the UK, beams were being used at less than 50% of their actual loading capacity (Moynihan & Allwood, 2014).

This research also identified that a switch to low-emission or electric construction vehicles is a necessary action to meet the net-zero emissions targets. However, as materials are the main source of emissions these must be tackled as a priority.

Two target levels were considered for each of the six interventions. The first target level was based on the application of currently available technology coupled with progressive changes in consumer choice. The second target level is more ambitious and is based on the widespread application of technology that is currently in development and extensive changes in consumer choice. The interventions presented envision changes in household consumption patterns and trade flows and express these changes as percent changes.

Fully implemented, these interventions would support C40 cities in aligning with the 1.5°C target trajectory for consumption-based emissions from building and infrastructure. The purpose of the ambitious targets is to provide a set of reference points.

Please note one of the six interventions was not included in the model and its emission reduction potential was not quantified, this intervention is colour coded purple in the table.

This report also identified that a switch to low-emission or electric construction vehicles is a necessary action to meet the net-zero emissions targets.

Tab.2

Interventions to reduce consumption-based emissions from buildings and infrastructure

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Material efficiency	Reduction in steel and cement use of 20% and 32% respectively	Reduction in steel and cement use of 35% and 56% respectively	<p>Material efficiency is one of the most effective means to reduce emissions as it is applicable to the construction of both buildings and infrastructure. This means avoiding excessive structural material, often driven by over-specification by designers and building codes. This does not reduce the size of the structure, but reduces the amount of materials used to construct it. Optimising the procurement of materials as well as the design of building components can also reduce material use and on-site waste. For example by using modular components, which have standardized shapes and connections, or prefabricated components which are constructed in a factory before being assembled at the construction site.</p> <p>Ambitious potential The ambitious targets for material efficiency are based on the same strategies but assume higher levels of uptake and application.</p>

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Enhance building utilisation	10% reduction in demand for new buildings	20% reduction in demand for new buildings	<p>Buildings are underutilised and often discarded before they have reached the end of their useful life. Building utilisation can be increased by promoting refurbishment over new construction and encouraging the efficient use of existing space and infrastructure through flexible design. Flexible designs consider the potential future uses of a building by allowing the inside to be reconfigured for different functions. For example, apartments could be reconfigured for a growing family or shops could have the facilities to transform into office spaces. Changing work habits such as home working and coworking are also expected to increase building utilisation.</p> <p>Ambitious potential The ambitious target is based on a doubling of effort to improve building utilisation.</p>

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Material switching	75% of residential and 50% of commercial buildings constructed with sustainable timber	90% of residential and 70% of commercial buildings constructed with sustainable timber	<p>The use of sustainable timber as the primary building material is an emerging alternative to structural concrete and steel. Targets were estimated for buildings up to six storeys (based on UK building guidelines) though a limit of 12 to 18 stories is quickly becoming the norm in other nations (Designing Buildings Wiki, 2019)(Hilburg, Johnathan, 2018). Timber construction is a viable solution in specific contexts where local forests are sustainably managed following internationally recognised standards. Due to its potential to act as a carbon store, timber has high potential levels of carbon sequestration. Users must be mindful to avoid the potential rebound effects of using timber. For example, increased plantation wood supply might drive down the price of timber, increasing the demand. This demand might be so big it then puts pressure on natural forests that should not be used as building materials (Warman, Russell, 2018).</p> <p>Ambitious potential The ambitious targets for material switching would mean that almost all residential buildings are constructed from sustainable timber, alongside almost three-quarters of commercial buildings.</p>

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Low-carbon cement ⁵	50% of cement replaced with low-carbon alternatives	61% of cement replaced with low-carbon alternatives	<p>Concrete is one of the most carbon-intensive construction materials as one of its main ingredients is cement. The production of cement requires extreme heat, and thus energy. Cement also releases a great deal of CO₂ as part of its production process when its main ingredient, limestone, is heated. The progressive target was based on the emissions reduction potential when replacing a portion of the most common type of cement, Portland cement, with alternative materials such as ground-granulated blastfurnace slag and blends of Portland cement, limestone and calcined clay.</p> <p>Ambitious potential The ambitious target of 61% reduced carbon intensity assumes greater adoption of low-carbon clinker substitutes for Portland cement clinker.</p>

⁵ The model only considers low carbon cement by way of replacing Portland cement. Newer alternate technologies such as Carbon Capture Storage are not included in the model.

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Reuse of building components	11% reduction in virgin metal and petrochemical-based materials	22% reduction in virgin metal and petrochemical-based materials	<p>The reuse of building components can potentially have a large impact on consumption emissions. A handful of cities, regions, and countries are pursuing the application of circular economy principles to their construction sector for this reason. For example, Amsterdam commissioned a study called PUMA: Prospecting the Urban Mines of Amsterdam to determine the available metals in the city's current building stock to better plan for their future uses (Circle Economy, Copper 8 & Gemeente Amsteram, 2017). In most cases the reuse of building components is an intervention that requires some preparation. The design of a building needs to be modular and reversible to be easily deconstructed for reuse. There also needs to be an established market for the deconstructed building components.</p>

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Reuse of building components (cont.)	11% reduction in virgin metal and petrochemical-based materials	22% reduction in virgin metal and petrochemical-based materials	<p>The widespread reuse of building components is thus largely a long-term strategy. Nonetheless, in the short term (i.e. within the applied study period to 2050), construction companies could reuse at least a quarter of structural steel through improved coordination between the demolition and construction phases. A key limitation, however, is that reusable building materials are unlikely to meet the demand for new construction – at least until the population stabilises.</p> <p>Ambitious potential The ambitious target of 22% reduction in use of virgin steel and petrochemicals in construction is only feasible if there is an increased source of reusable components.</p>

INTERVENTION OPTION	PROGRESSIVE TARGET	AMBITIOUS TARGET	RATIONALE
Use of low - or zero - emission construction machinery	Fossil-free construction machinery	Use of electric machinery only	<p>It is estimated that emissions from construction sites represented 5–10% of total production-based emissions in cities (DNV GL Energy, 2019). These emissions are local and thus have a greater impact on air and noise pollution in the city. For example, it has been estimated that 14.5% of PM_{2.5} matter in London is due to local construction sites (Bellona, 2019). Moving towards low- or zero-emission construction energy through the inclusion of electric vehicles and biofuels is an option to address localised emissions at construction sites.</p> <p>Ambitious potential While the benefits of this intervention are undisputed, the data to quantify all of them is currently not available and researchers have identified this as a knowledge gap in the field.</p>

When applying these interventions, it is important to remember their potential limitations. Due to data availability some assumptions skew towards western European experiences and may not be relevant to all regions. For example, the use of timber might not be viable for every

city and every climatic condition. In addition, most lower-carbon cement alternatives are produced from the waste products of the fossil fuel industry and will become less relevant over time as the world moves towards renewable forms of energy production.

2.3

Emission reduction potential

If C40 cities adopt a whole-life-cycle approach to construction and apply the planning and design interventions identified in the previous section, in line with the progressive targets, the emissions from buildings and infrastructure could be cut by 29% by 2050.

Adoption of the ambitious targets would enable a further 15% reduction of emissions, totalling a 44% reduction in cumulative buildings- and infrastructure-related emissions. Figure 2 illustrates the breakdown between five of the interventions. The use of low- and zero-emission construction machinery is not included as an intervention in this model, due to the data gap that meant researchers could not quantify its benefits.

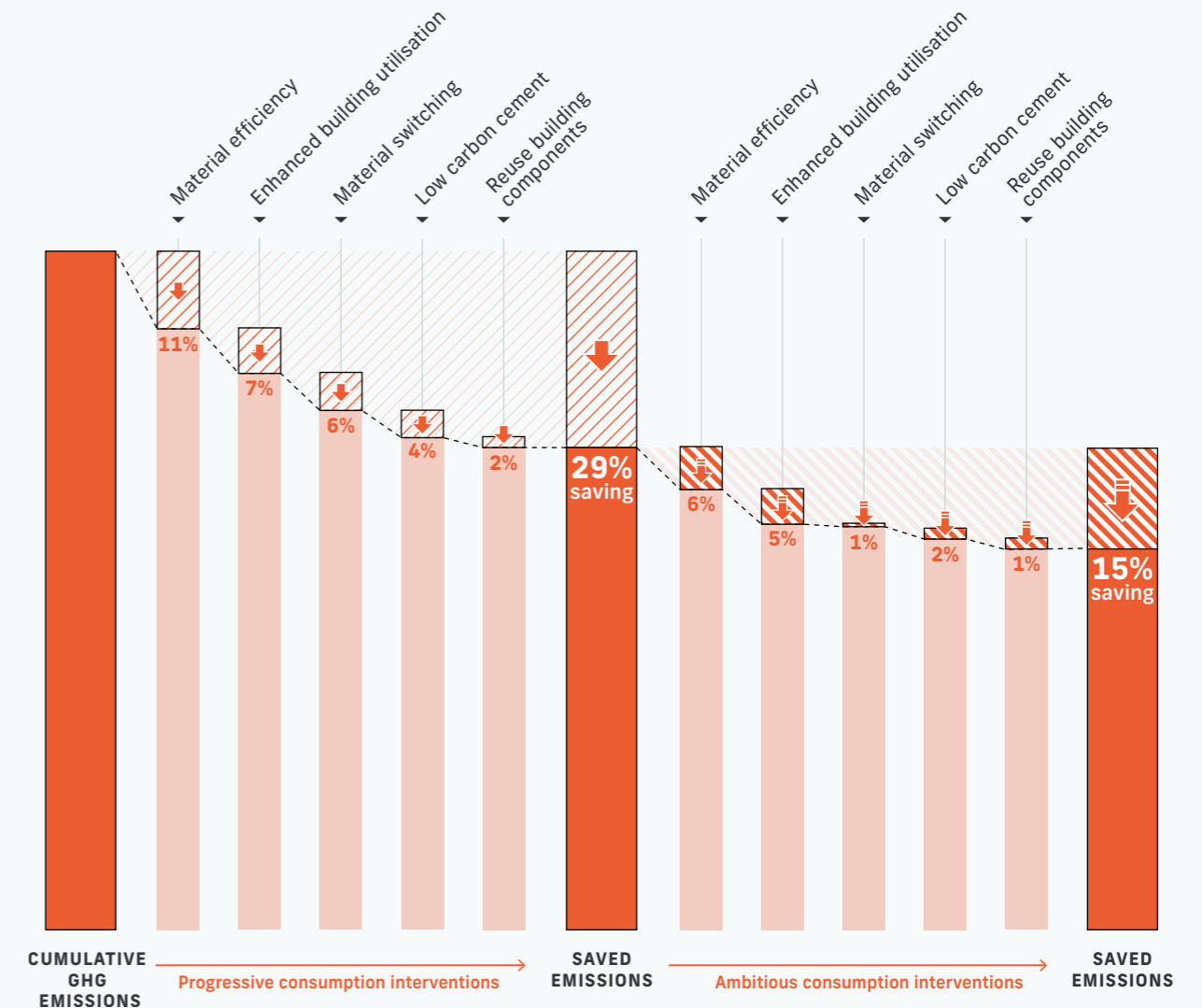
Material efficiency stands out as having the highest potential emission reduction impact, offering savings of 18% in cumulative emissions between 2017 and 2050. Enhancing building utilisation, material switching and low-carbon cement all offer significant savings at 11%, 6% and 6% respectively. While the potential savings associated with reuse of building components is smaller than the rest, at 3% it still represents important savings.

Material efficiency stands out as having the highest potential emission reduction impact, offering savings of

18%

fig.2

Potential buildings and infrastructure emissions savings, broken down by intervention options and level of target ambition.



3 Associated benefits

Climate change is often seen as competing with a range of other pressing issues, such as lack of affordable housing, poverty, unemployment, and poor health.

Responding to the climate crisis can have wider benefits that help address these other areas of concern. And highlighting these benefits helps build a strong case for adopting the recommended interventions.

In addition to the significant potential for mitigating GHG emissions, clean construction interventions have additional social, economic and environmental benefits, and the 2019 report identified a number of these (see Box 1 and the following sections). If C40 cities deliver consumption interventions in line with ambitious targets, the benefits would be greater still.

In the report, it was possible to quantify some of the benefits associated with the interventions, but most were not quantifiable due to limited data availability. The report identifies these missing data points as knowledge gaps. The benefits that are quantified are based on data from 27 of the 94 C40 cities, again due to limited data availability. City-specific data on planned developments was not available,

so benefits were modelled on hypothetical 500-unit residential developments and office developments with capacity for 2,000 employees. The results are illustrative examples only, as the total number of developments and their scale will vary between cities.

The accompanying Method Report contains full details of the methodology and data sources used to estimate the benefits discussed in this section.

In addition to the significant potential for mitigating GHG emissions, clean construction interventions have additional social, economic and environmental benefits.

3.1

Social benefits

Construction is a major contributor to congestion, air pollution and noise pollution, which can all negatively impact city dwellers' health – both physical and mental.

The World Health Organisation has identified air pollution as one of the leading causes of premature death (World Health Organisation, 2018). This is echoed by the European Environment Agency, who found that exposure to air and noise pollution annually caused 500,000 and 10,000 premature deaths respectively in European counties (DNV GL Energy, 2019). In London, construction and construction machinery are estimated to generate 12% of the NO_x emissions and 15% of particle matter (PM₁₀) (Mayor of London, 2015).

Implementing the aforementioned interventions can help alleviate some of these impacts. Reducing new building demand, increasing material efficiency through lean design and prefabrication, and switching to lighter materials such as timber, can all reduce the number of lorry deliveries required for a building site. This in turn lightens congestion and lessens both air and noise pollution.

If builders replace high-density materials such as cement and steel with low-density timber, for example, it will require fewer deliveries to a building site. Since timber is 1/5th the density of concrete and 1/17th the density of steel, lorries can transport big individual timber components as opposed to taking many trips carrying small, but heavy, cement and steel elements that need to be assembled at the construction site. When setting the progressive target for the material switching intervention, the analysis estimated that on a new-build 500-unit residential development and a new-build office for 2,000 employees, switching to timber would translate to approximately 550 and 250 avoided deliveries respectively. Figures 4 and 5 set out the results of this analysis.

Switching to zero-emission construction vehicles is another option for reducing dangerous local emissions and noise, and improving air quality and noise pollution from the site itself (DNV GL Energy, 2019).

fig.3

Reduction in deliveries due to material switching, for example residential development of 500 units.

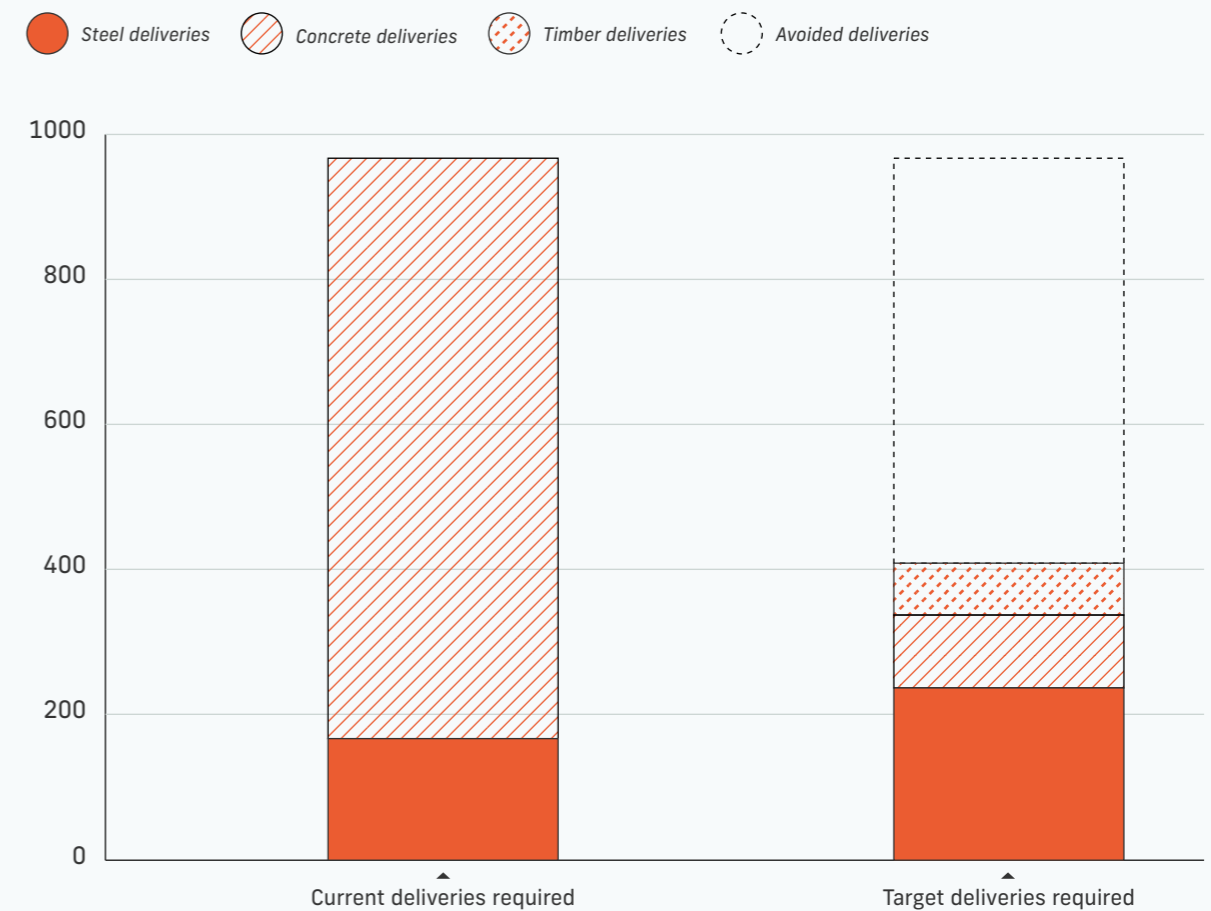
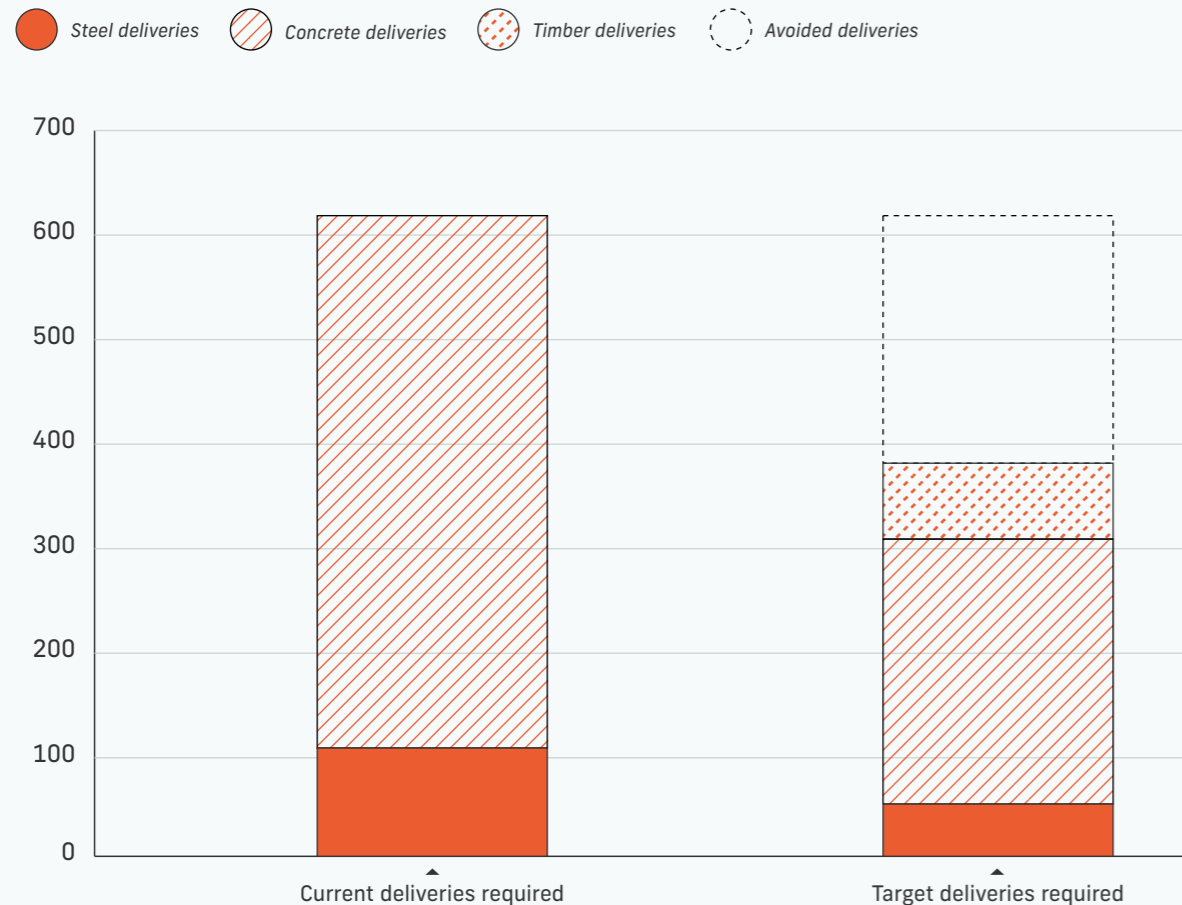


fig.4

Reduction in deliveries due to material switching, for example office development for 2,000 employees.



3.2

Economic benefits

Reducing consumption emissions from construction – to levels where cities meet their 1.5°C warming emission targets – will initiate changes in the current supply chain and economic structure of the construction industry.

This shift will require new processes and innovations, which will demand new skills and can generate new jobs – another example of climate actions benefitting other areas of societal concern. As the economic structure transforms, the industry must pay attention to training and re-skilling the existing workforce to ensure a just transition.

While the potential for economic growth is accepted, there is not enough data to quantify this benefit, and researchers have identified it as a knowledge gap in this field of study.

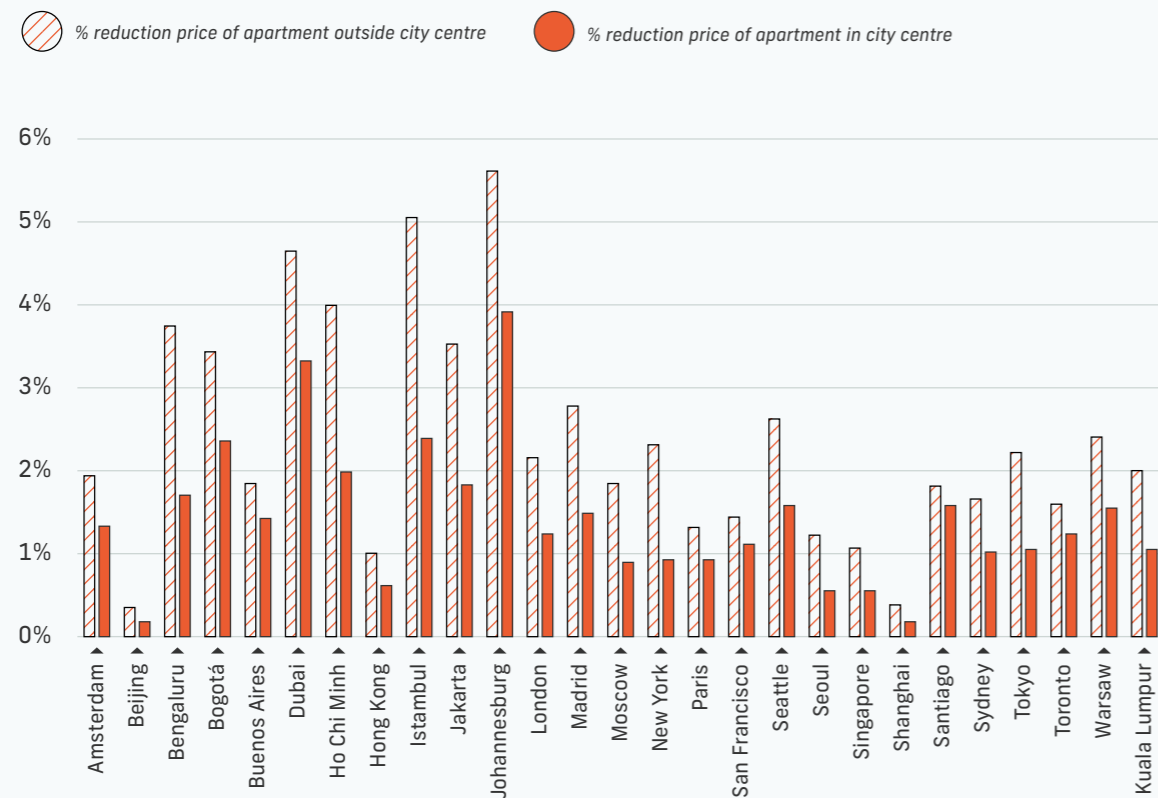
Applying the interventions on material efficiency and enhanced building utilisation could have more direct, and quantifiable, economic benefits for cities. For example, reducing the amount of materials used on a project could see an average of a 6% reduction in construction costs in cities.⁶

This holds when assuming at least a quarter of the original construction costs were due to steel and cement. The potential cost saving could be passed on to consumers – local residents and businesses – should local housing policies and construction labour markets be incentivised or regulated accordingly.

Figure 5 shows, for different cities, the potential reduction of apartment prices that result from material efficiency driving lower construction costs. Depending on the city, the drop in material spending translated to a reduction in apartment prices of between 0.2% and 5.6%. As expected, the percentage price decrease is greater for less-dense, less-developed cities and smaller in very dense cities with high land value. In very dense cities the percentage reduction might be more pronounced outside the city centre, where land values tends to be lower.

⁶ Material costs and labour costs vary significantly across cities, while emerging digital technologies are disrupting the relationship between them. This saving is calculated considering material savings only.

fig.5
Potential reduction in apartment prices in C40 cities as a result of reduced construction costs due to material efficiency⁷



Further economic benefits exist in other intervention options. Enhancing building utilisation, by using buildings that would otherwise have been demolished, or increasing the functions of existing buildings, has the potential to free up money that would otherwise have spent on new developments. This report estimates that per 100,000 m², C40 cities could save up to \$36 million in construction costs for residential developments and up to \$54 million in construction costs for commercial developments.^{8,9}

⁷ This is a potential saving, and whether it is realised and passed on to the house buyer will depend on local housing policies and construction labour markets incentives or regulations.

⁸ Based on average construction cost per m² for "low-rise medium standard apartments" and for "central business district offices" in various cities. These do not include the cost of land.

⁹ These estimates do not account for additional costs for refurbishment of existing assets to enhance utilisation, as these depend on a number of variables including the conditions of the original building, the level of changes required (in terms of layouts, systems and structure), the required fit-out specifications, etc.

Figures 6 and 7 show the estimated savings for a new-build 500-unit residential development, and a new-build office for 2,000 employees across different cities. As expected, cities with high property prices such as London, Hong Kong and San Francisco show the greatest

savings from avoiding new construction. However, to realise the benefits of enhanced building utilisation, the cost savings have to be consciously redirected into sustainable projects or initiatives, such as energy retrofits.

fig.6
Construction-cost savings in a selection of C40 cities, due to enhanced building utilisation of 500-unit residential development

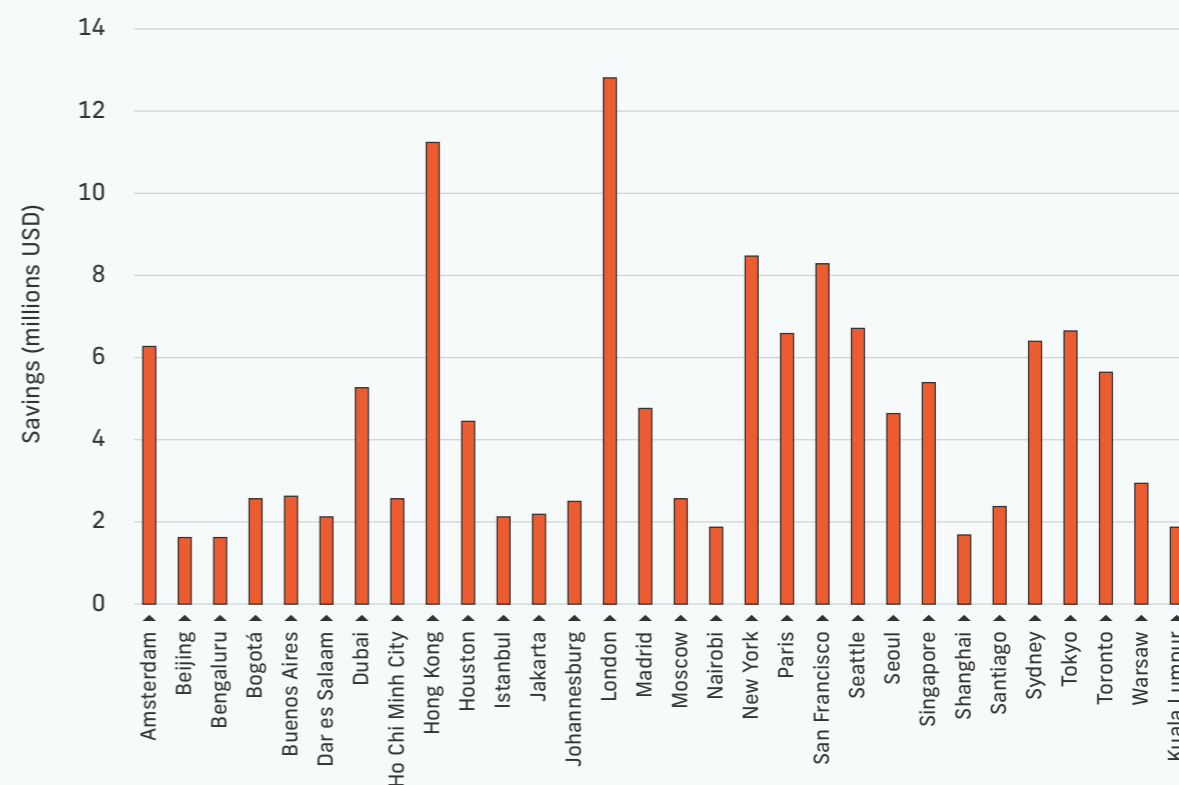
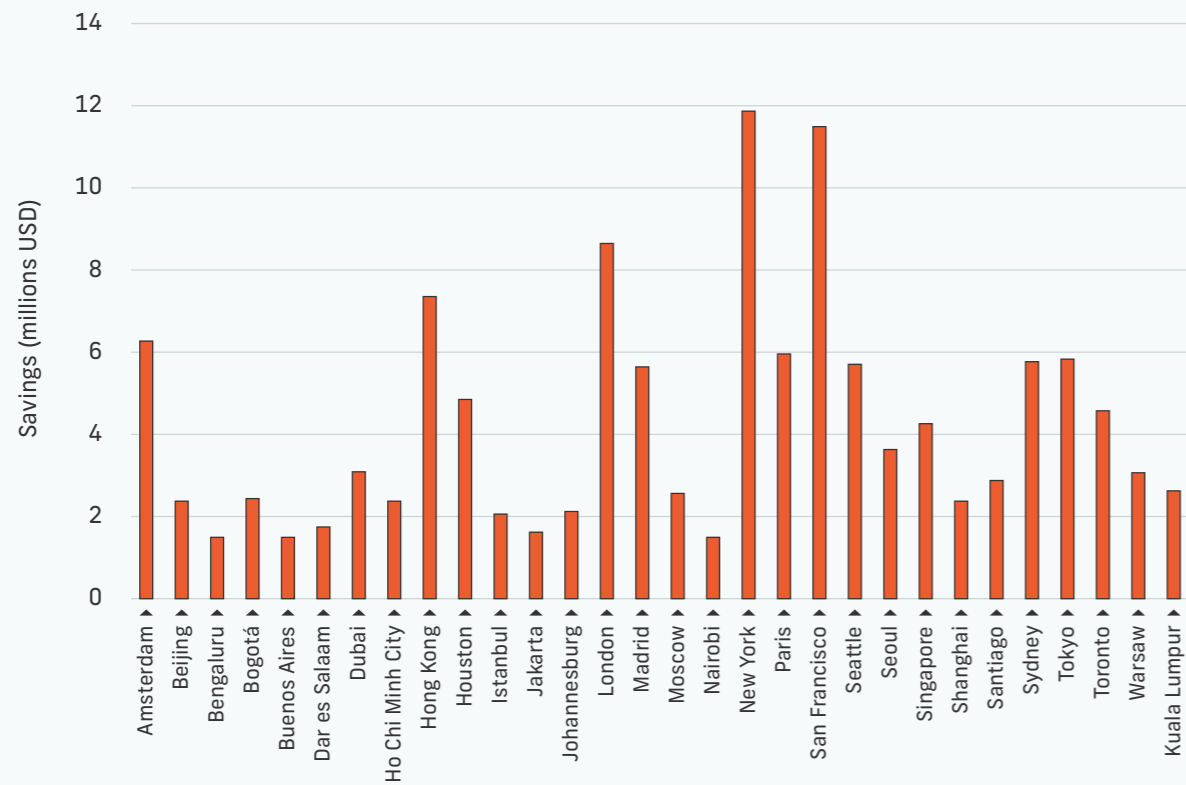


fig.7

Construction-cost savings in a selection of C40 cities, due to enhanced building utilisation of office development for 2,000 employees



3.3

Environmental benefits

On top of reducing GHG emissions, the adoption of lower consumption emissions initiatives offers other positive environmental impacts.

Urban vegetation has been shown to be seriously impacted by air pollution, both in global south and global north cities (J.N.B. Bell et al., 2011). As stated previously, reducing the demand for new buildings, increasing material efficiency through design, and material switching to lighter materials such as timber can all reduce the number of lorry deliveries to a building site. This lightens congestion and lessens air and noise pollution around the city. Air and noise pollution are often very localised, and levels of air pollution can vary strongly from one street to the next. The introduction of electric construction vehicles can seriously reduce the noise and air pollution locally around construction sites.

Implementing material switching to timber can also improve local ecosystems and biodiversity. This is because the sustainably and ecologically managed forests that would be created to supply timber materials can both serve to restore local ecosystems and as a carbon sink.

Reducing the demand for new buildings can lead to more open space, and a greater chance to develop green space within cities. Rethinking the use of buildings can facilitate the introduction of new initiatives, such as urban gardening and urban farming, which both benefit local ecosystems.

4 Summary

Buildings and infrastructure construction is one of the largest contributing categories to the consumption-based emissions of C40 cities, representing 11% of total consumption emissions in 2017. It will grow to be the largest category between 2017 and 2050.

The global trends towards population increases, rising average incomes and living standards mean that without concerted effort, global emissions will continue to rise. Even if national governments deliver on their NDCs and city governments honour their Deadline 2020 commitments, projections still indicate that the emissions from buildings and infrastructure construction will increase by 29% by 2050. This emissions increase does not align with a 1.5°C trajectory.

This report adds to the body of evidence illustrating the need for coordinated stakeholder action and quantifiable interventions. It identifies policymakers, civil society and the private sector as the main groups of stakeholders, each with their own responsibilities and opportunities to shape political will and industry preparedness for the shift towards low-emission construction.

The quantifiable interventions presented in the report centre on reducing new building need, reducing the demand for materials and reducing the emissions associated with chosen construction materials. The successful delivery of these interventions will not only reduce emissions but will bring social, economic and additional environmental benefits, such as improved citizen and environmental health, reduced congestion and more spatial and monetary resources to invest in other environmental projects.

If C40 cities change the way they plan, design and construct building and infrastructure in line with the identified interventions to their maximum potential, the category's cumulative emissions could be cut by 44% by 2050.

BUILDINGS AND INFRASTRUCTURE CATEGORY INTERVENTIONS

- material efficiency
- enhance building utilisation
- material switching
- low-carbon cement
- reuse building components

GHG EMISSION REDUCTION POTENTIAL

44%

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