City consumption
The new opportunity for climate action

green alliance...

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By Caterina Brandmayr, Dustin Benton and Emily Coats

Green Alliance
Green Alliance is a charity and independent think tank focused on ambitious leadership for the environment. We have a track record of over 35 years, working with the most influential leaders from the NGO, business, and political communities. Our work generates new thinking and dialogue, and has increased political action and support for environmental solutions in the UK.

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Executive summary

"Looking at emissions through the lens of what cities buy opens up new opportunities for climate leadership. Focusing on consumption potentially doubles the impact of city policy."

Cities account for over half of the world's population and over 80 per cent of global GDP. They have been at the forefront of global climate action and are amongst the first to feel its effects: seventy per cent of the C40 network of global megacities are already dealing with the effects of climate change.

So far, city climate policies have primarily focused on action within their borders. Cities are geographically small, but their economic power is large: the products bought by city residents are often produced by global supply chains, and looking at emissions through the lens of what cities buy opens up new opportunities for climate leadership.

Focusing on consumption potentially doubles the impact of city policy. New data for 79 city members of C40 reveals that about two thirds of their consumption emissions, or 2.2 $GtCO_2e$, are from imported goods and services. This is roughly the same as the emissions produced within their borders.

Cities have the ability to address these emissions. Their powers in local economic development, urban planning, regulation, procurement and transport, amongst other areas, could be used to lower emissions beyond city boundaries. Cities can specify low carbon materials and processes in the goods they buy, drive innovation in low carbon goods and services, and increase demand for lower carbon products. About 80 per cent of C40 cities' consumption-based emissions are within the control of cities able to exert a high degree of influence over them.

Some cities have already started to act: Paris is cutting its meat procurement by 20 per cent by 2020 and Stockholm is working with developers to reduce the emissions embodied in construction, even though these emissions are produced beyond their borders. But so far, cities have acted mainly in isolation.

Our analysis shows that cities working together to lower emissions in global supply chains can be much more effective than acting alone. We have shown that seemingly unrelated cities have similar patterns of consumption-based emissions: for example, Stockholm has consumption patterns more like Tokyo than its neighbour Oslo. These similarities can form the basis of joint action designed to influence global supply chains. Collaboration could take several forms:

Joining forces within a nation. Cities can act together to influence national policies on low carbon manufacturing. For instance, those in major car manufacturing countries could support closed loop recycling in the automotive sector. On a global scale, better material recycling has the potential to cut cumulative emissions from vehicles to 2050 by four to six $GtCO_2e$, which would be equal to shutting down all of Germany's lignite coal plants.

Decarbonising global supply chains. By working together, 18 European and Latin American cities could use their innovation institutions and procurement power to commercialise low carbon beef production. By adopting healthier diets alongside low carbon beef, emissions from beef consumption in cities would fall by over 60 per cent.

“Action by cities will be a major part of the solution to climate change.”

Partnering for sustainable development. As cities become wealthier, their emissions rise, but some wealthy cities have emissions that are 40 per cent lower than others. Collaboration across C40 cities could help developing cities to grow their GDP while locking in low carbon consumption and supply chains.

Our report also takes a closer look at three cities: London, Copenhagen and Toronto. Each of them could use their procurement and planning powers to drive demand for low carbon buildings. Using tried and tested methods in construction, like reducing the amount material used and using lower carbon materials, can cut embodied emissions by ten to twenty per cent at no additional cost. If cities require new buildings to be designed with lower embodied emissions in mind, savings of nearly 80 per cent are possible at similar costs to conventional buildings.

By simply addressing the supply chain emissions of a single high emissions food, eg dairy in Copenhagen and beef in Toronto, these cities could cut their total food consumption emissions by between three and seven per cent. Encouraging citizens to change their diets, supported by procurement and engagement with the hospitality sector, could cut food emissions by between 19 and 34 per cent.

Overall, by focusing on emissions arising from consumption, C40 cities now have the opportunity to double their emissions saving potential. Using their powers could give them control of emissions totalling more than those produced by the whole of India and just under those of the EU. This report shows that action by cities will be a major part of the solution to climate change, and identifies how they can help to keep global temperature rise below 1.5 degrees.

Introduction

"As large importers of goods and services from domestic and international markets, the actions of cities can drive the decarbonisation of supply chains far beyond their jurisdiction."

Cities account for over half of the world's population and more than 80 per cent of global GDP.[1] The production and consumption that happens in cities requires large amounts of resources, accounting for over 60 per cent of global energy use, 70 per cent of waste and 70 per cent of greenhouse gas emissions.[2] Cities are also ultimately the places that make policy a reality, responsible for implementing over 70 per cent of climate change mitigation and 90 per cent of adaptation measures. They are already demonstrating strong climate action.[3] This will be essential to achieving the commitments made by national governments under the 2015 Paris Agreement.

So far, cities have largely followed nation states in addressing greenhouse gas emissions generated within their boundaries. But, because they are geographically small and economically large, and are often the final consumers of goods and services produced along global supply chains, new methods of assessing city emissions arising from consumption open up a much wider range of opportunities for climate leadership. As large importers of goods and services from domestic and international markets, the actions of cities can drive the decarbonisation of supply chains far beyond their jurisdiction.

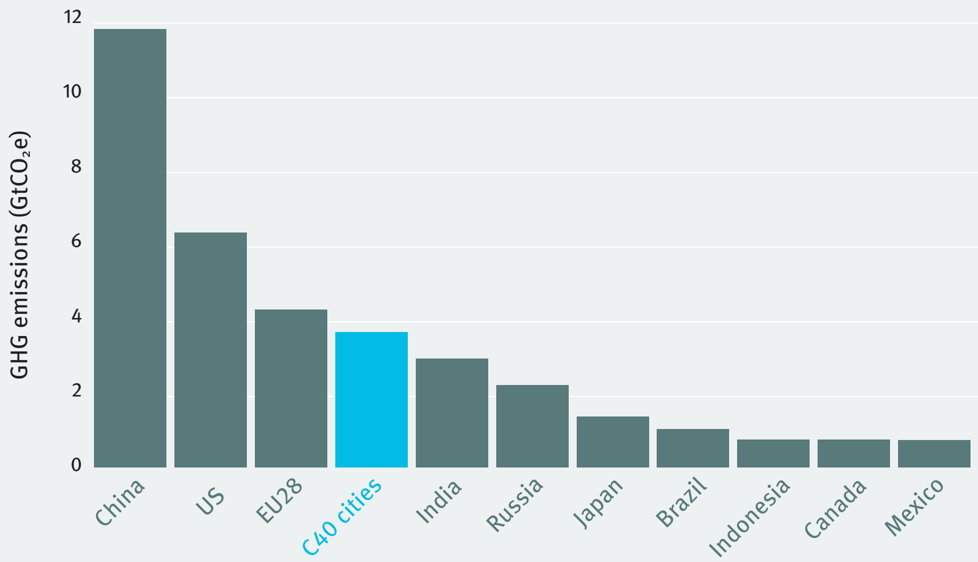
Few national governments have considered consumption-based approaches to curb emissions beyond their borders, despite the fact that emissions associated with internationally traded products are increasing and currently account for about 20-25 per cent of global CO_2 emissions.[4]

C40 cities' consumption-based emissions alone account for seven per cent of global emissions.[5] This is more than India's national emissions. If C40 cities were a country, they would be the fourth largest source of global emissions, behind China, the US and the EU28.[6]

C40 cities have already taken significant steps to reduce the emissions within their boundaries. Given their scale, if they worked together, they could also be global leaders in cutting consumption-based emissions.

C40 cities are major players in addressing climate change

Consumption-based emissions of C40 cities compared to the territorial footprint of main global emitting countries.[7]



Why should cities tackle consumption-based emissions?

Greenhouse gas (GHG) emissions accounting has traditionally focused on emissions from energy use within a city, either through direct combustion (defined as scope 1 emissions, see page six) or from the consumption of grid-supplied electricity, heating and cooling (scope 2 emissions), as well as emissions from the treatment of waste, aligning with IPCC and OECD guidelines for national economies. Together, these are known as sector-based emissions, and include emissions derived directly from socioeconomic activity within a city. For instance, emissions generated by a car manufacturer within city boundaries will be included, despite some of the cars they produce being sold elsewhere. For the 79 C40 cities considered in this study, sector-based emissions are estimated to be 2.2 $GtCO_2e$.[8] However, this type of accounting overlooks a substantial and increasing share of a city's GHG footprint arising from consumption and, more importantly, it does not reveal the real extent of their ability to curb global emissions.

Consumption-based emissions are allocated to the final consumer, rather than the producer, and account for the full range of emissions involved in providing a good or service consumed by city residents, including those generated outside city boundaries (known as scope 3 emissions). For example, consumption-based emissions from a smartphone sold in London will include emissions associated with the material extraction, manufacturing and transport which will have arisen outside the city and, possibly, outside the UK.

“If their climate policies addressed consumption-based emissions, C40 cities could potentially have up to twice the impact on global emissions”

Analysis of consumption-based emissions for 79 cities, carried out by C40, the University of Leeds, the University of New South Wales and Arup, and used as the basis for this report, reveals that, of the 3.5 $GtCO_2e$ created by consumption, two thirds arise outside of the city, and would, therefore, not be covered by traditional emissions reduction policies.[9]

This means that, if their climate policies addressed consumption-based emissions, C40 cities could potentially have up to twice the impact on global emissions than if they continued to act only on their sector-based emissions.[10]

Classifying emissions

Assessment of city emissions discussed in this report distinguishes between sector-based emissions and consumption-based emissions. These are defined as follows:

Sector-based emissions include emissions from energy use within the city boundary, through direct combustion or from the consumption of grid-supplied electricity, heating and cooling, as well as emissions from the treatment of waste.

Consumption-based emissions include all emissions involved in producing a good or service consumed by residents of a city; these are emissions from raw material extraction, manufacturing, distribution and retail (inside and outside the city, as long as they arise from consumption by the city’s residents), as well as emissions from household energy use within a city.

While these terms define ways to assess a city’s emissions, greenhouse gas emissions are also commonly classified as scope 1, 2 or 3 depending on their source and location:

Scope 1 emissions originate within city boundaries, arising from direct combustion, waste generated and disposed within the city, in-boundary transportation, as well as in-boundary land use, industrial processes and product use.

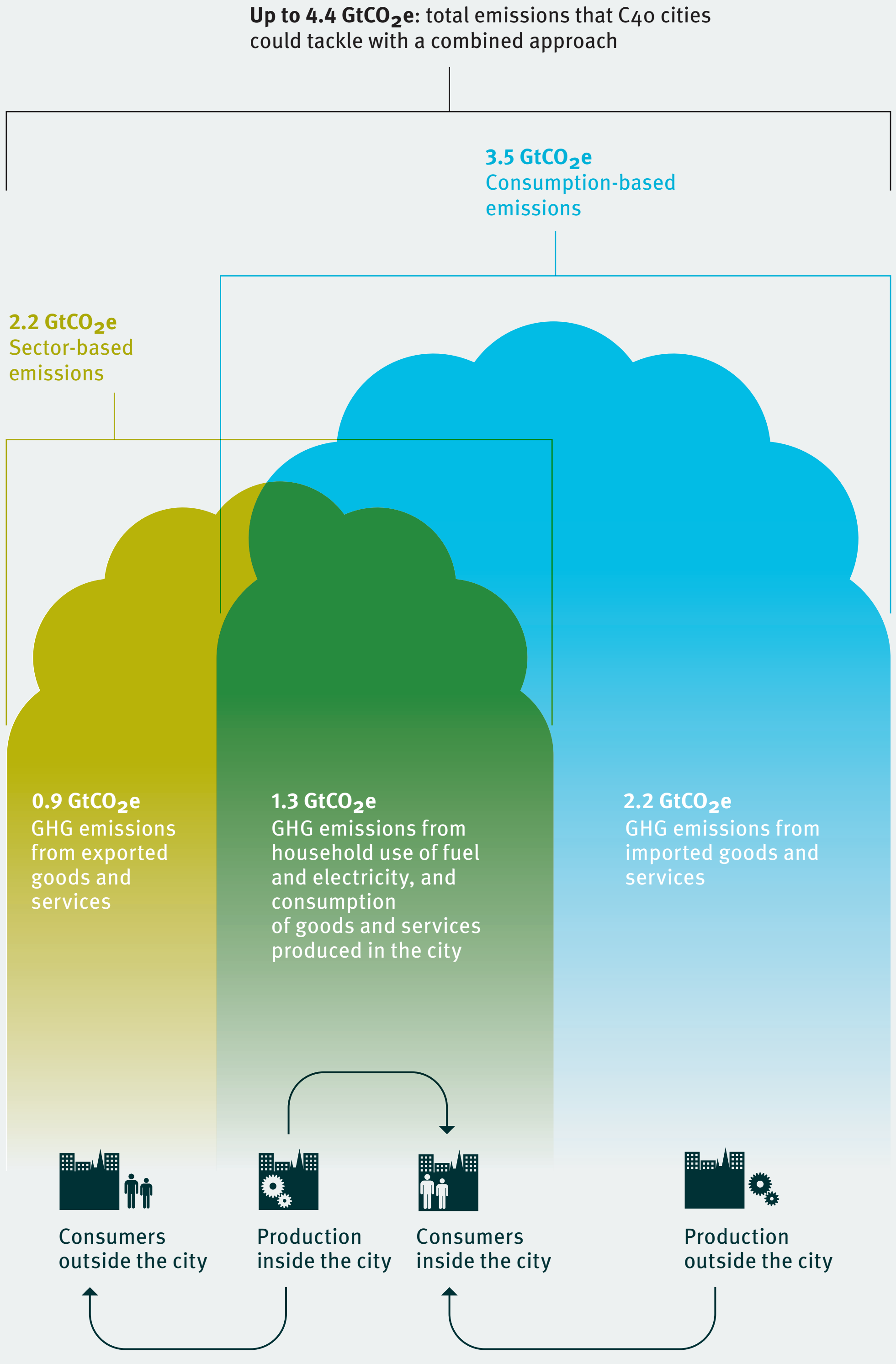
Scope 2 refers to emissions from grid-supplied energy, ie electricity, heating and cooling

Scope 3 emissions are generated outside the city boundaries, as a result of out-of-boundary transportation, waste generated inside the city but disposed outside, as well as other indirect emissions, eg from land use, transport and industrial processes needed to produce goods and services.

Sector-based emissions of C40 cities are mainly scope 1 and scope 2 emissions and the majority of consumption-based emissions are scope 3 emissions.

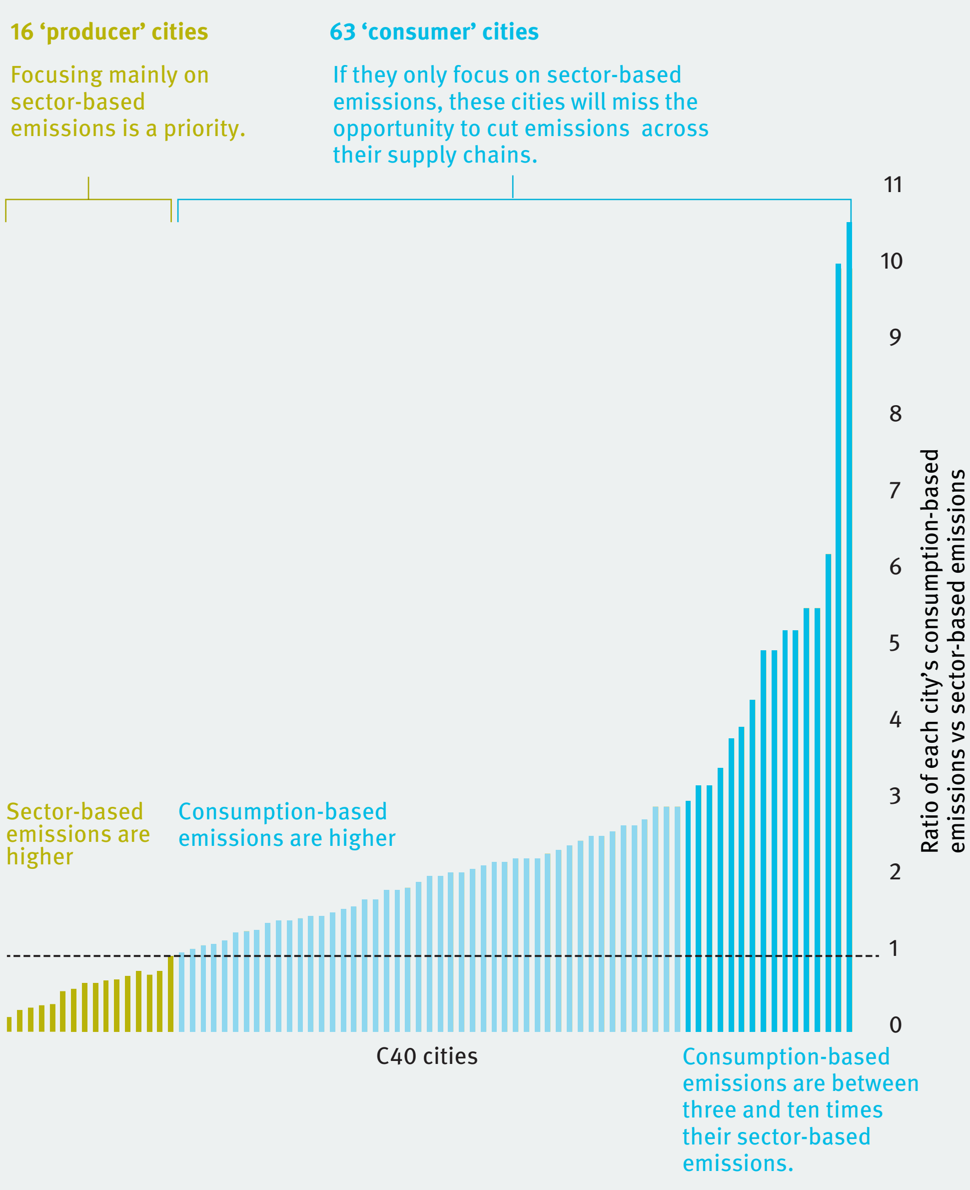
Most consumption-based emissions arise outside city borders and are not included in their sector-based emissions accounts

Emissions from 79 cities in the C40 network



Underlying these headline figures is a great deal of diversity. For 63 C40 cities consumption-based emissions are greater than their sector-based emissions. These are known as 'consumer' cities. Whereas 'producer' cities have more sector-based emissions. 'Consumer' cities, in particular, would benefit from considering a consumption-based approach, given that most of their emissions are linked to consumption. Forty cities, ie more than half of the C40 cities in this analysis, have consumption-based emissions over double their sector-based emissions, and 20 per cent of them have consumption-based emissions between three and ten times their sector-based emissions. So working to cut these emissions should be a priority.

For most C40 cities, consumption-based emissions are greater than sector-based emissions



"Cities have relevant powers across all areas where their consumption-based emissions arise."

Overcoming the barriers to action

Action by cities to cut consumption-based emissions has been limited by a number of challenges. This analysis looks at how to address them.[11]

First, there is a knowledge gap. City policy makers are often unaware of the full extent of upstream emissions, and often only have patchy data available to them. The consumption-based emissions data gathered by C40, used in this report, provides an overview and enables the comparison of consumption-based emissions for 79 cities across the world. Note that, except for London, Copenhagen and Toronto, data for individual cities discussed in this report has been anonymised. Further data gathering would enable a more granular analysis of consumption-based sources.[12]

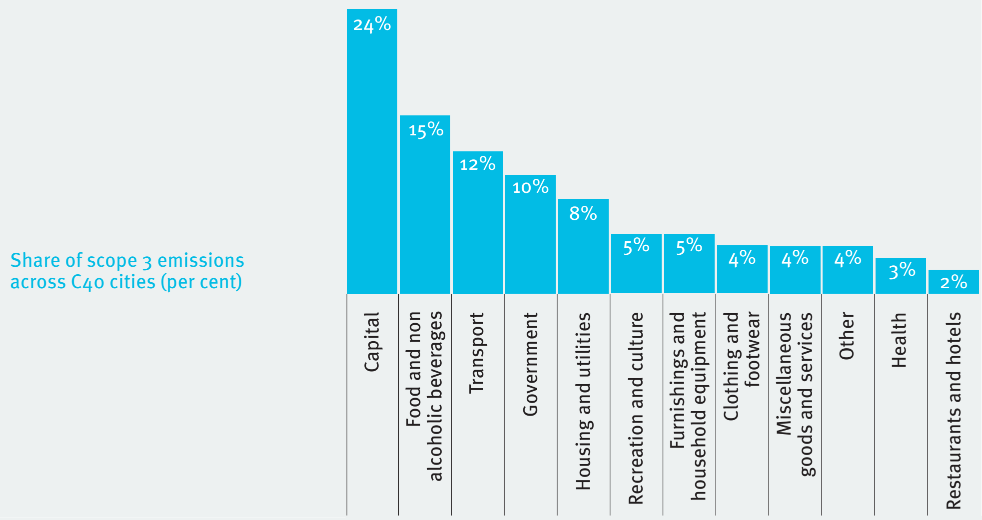
Second, there is a powers challenge: city decision makers may feel they have limited power over emissions which occur beyond their boundaries. Building on the previous analysis by C40, our report shows that cities do, in fact, have relevant powers and could address a large share of their emissions by using them judiciously.

Finally, the sources of consumption-based emissions are complex, covering multiple sectors and product categories and involving global supply chains. We have identified ways in which cities with similar consumption-based emissions profiles could work together across countries to decarbonise supply chains that might otherwise seem beyond their reach.

The power to act

Cities have powers across local economic development, public and private buildings, urban planning and transport.[13] These are already used to address sector-based emissions (ie mainly scope 1 and scope 2 emissions). Our assessment, summarised below, shows that these powers could also be used to address consumption-based emissions beyond city boundaries (scope 3 emissions). It shows that cities have relevant powers across all areas where consumption-based emissions arise beyond city borders. Importantly, for those sectors responsible for the majority of these emissions, such as infrastructure, buildings and machinery (included under 'capital'), food, transport and government services, there are often multiple powers available.

Cities have the power to reduce consumption-based emissions arising beyond their boundaries[14]



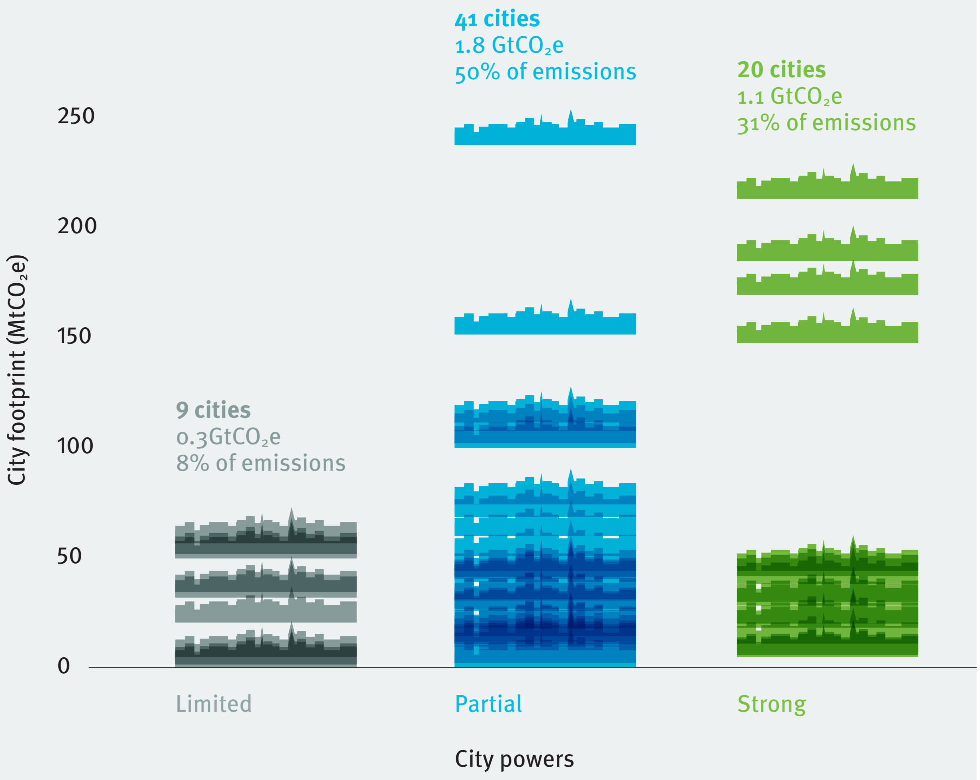
City powers to address scope 3 consumption-based emissions, by area

	Capital	Food and non alcoholic beverages	Transport	Government	Housing and utilities	Recreation and culture	Furnishings and household equipment	Clothing and footwear	Miscellaneous goods and services	Other	Health	Restaurants and hotels
Finance and economy	■	■	■	■	■	■	■	■	■	■	■	■
Urban land use	■	■	■	■	■	■				■	■	■
Waste	■	■		■	■							■
Food and agriculture	■	■									■	■
City roads	■		■			■					■	
Public transport	■		■	■								
Private transport	■		■									
Other transport	■		■			■				■		
Energy supply	■			■	■							
Public buildings	■			■	■							
Private buildings	■				■							
Water	■				■							
ICT	■											

The strength and combination of powers depends on the degree to which powers have been devolved to a city. Our assessment of the top emitting consumption sectors, based on analysis of C40 city powers, shows there are 20 cities in the C40 network, including four of the top ten emitters, which have strong powers.[15] These cities alone are responsible for over 30 per cent of the overall consumption-based emissions from C40 cities. A further 41 cities with partial powers are responsible for half of the total. This means about 80 per cent of consumption-based emissions come from C40 cities that are able to exercise a high degree of influence over them.

Cities with high consumption-based emissions also have the power to act

Individual city consumption-based emissions footprints vs their ability to influence their top five emitting sectors[16]



How cities can use their powers

Cities' powers allow them to address supply chain emissions through a combination of push measures, such as supporting innovation, financing and brokering, to encourage manufacturers and producers to opt for low carbon materials and processes, and pull measures, which create demand for lower carbon products, through regulation, procurement and engagement with local businesses and communities. These measures are already being implemented by cities to cut their sector-based emissions, as highlighted in the following section, and could be adapted to address consumption-based emissions, including scope 3 emissions.

“Toronto is developing a skilled workforce to support energy efficient buildings.”

Push measures

Linking up finance. Cities can support businesses to provide low carbon products and services by increasing access to finance. Financial institutions are unlikely to seek out high risk activities alone, but intervention from cities can encourage the finance sector to engage. This could include matching investors with businesses seeking finance by supporting or creating a finance finding institution. The London Waste and Recycling Board (LWARB) is an example of such a mechanism.[17]

Brokering innovation partnerships. Cities can broker collaboration between innovation institutions and relevant supply chain actors to support low carbon products and processes. For example, Stockholm has involved the Royal Institute of Technology, alongside real estate and infrastructure companies, to develop novel technologies and methodologies for the city’s new eco-districts, enabling a more efficient management of waste and water, as well as greater uptake of low carbon transport.[18] Innovation will be essential to cut emissions from food, eg from beef and rice production (the examples on pages 21 and 27), and transport, such as by improving metal and composite material recycling for car manufacturing. Cities could work with their academic institutions in supporting businesses to identify and commercialise lower carbon alternatives.

Direct funding. While finding finance and brokering collaboration can support projects relatively close to commercialisation, direct city-led financing can be deployed for more ambitious, path-breaking projects. For example, The Atmospheric Fund is already using its capital to derisk low carbon innovation and has supported projects with a total of 185Mt in GHG savings potential, nearly equivalent to Canada’s total emissions from the oil and gas sector in 2015.[19] Across C40, 22 cities can influence the operations of municipal credit agencies or banks and 11 directly own or operate these institutions and could provide funding opportunities for projects to help reduce consumption-based emissions. Direct funding can also be coupled with forward commitment contracts, to help derisk innovations by providing a critical mass of buyers, eg public agencies or the private sector, that commit to buying a product if it is developed to a specification. Similar pre-commercial procurement schemes have already been used for the Super Efficiency Refrigerator Program in the US and by the Swedish innovation agency VINNOVA to support near-market technologies, including appliances, public transport and heating systems.[20]

Skills development. Cities may control budgets for skills development, and can ensure provision better matches local business needs and economic opportunities arising from low carbon products and services. For example, as part of its decarbonisation roadmap, Toronto is developing a skilled workforce to support energy efficient buildings. Similar programmes could address consumption-based emissions, by providing training in low carbon materials and techniques, and how to use these in construction projects.[21]

Solving co-ordination problems. Cities can facilitate collaboration within and across supply chains by providing visibility over resources needed to curb consumption-based emissions. For example, one of the challenges for the construction sector is poor information about the availability of reusable materials

"Paris has established urban logistics areas for the delivery of goods into the city via rail and water, to reduce freight by air and road."

within existing building stock. Cities could, for example, set up a registry for suppliers of reusable steel. This could sit alongside a requirement for buildings to have a pre-demolition audit of which materials could be salvaged. Further carbon savings could be achieved by brokering collaboration across sectors, to identify opportunities for reuse between asset heavy industries such as mining and oil and gas, and the construction sector.[22]

Technical expertise. Limited information and poor awareness of inefficiencies are often behind lack of action by businesses. Cities can, therefore, provide technical insight into ways for businesses to minimise their consumption-based emissions. For example, London is working with restaurants and the hospitality industry to cut food waste, providing assistance on portion sizes and the use of surplus food. Importantly, this not only cuts emissions but also helps businesses save money.[23]

Infrastructure development. Cities can use their planning powers to ensure the provision of infrastructure to support low carbon business activities, such as transport and storage infrastructure. For example, Paris has established urban logistics areas for the delivery of goods into the city via rail and water, to reduce freight by air and road. Nineteen other C40 cities own or can influence the operations of intercity rail and freight systems and could implement similar policies. Likewise, cities can use their powers over digital infrastructure (ICT) to support the development of lower carbon products and business models built on digital connectivity. Finally, urban planning powers can be used to support the decarbonisation of important housing energy and infrastructure services. For example, low carbon heating options such as heat pumps, hydrogen or district heat networks require large scale infrastructure adjustments best addressed at the city level.

Pull measures

Demand side interventions can be used to influence consumption. These can be seen both as a way of reducing consumption and as a way to encourage the use of alternatives with a lower carbon footprint.

Regulation and standards. Already widely implemented to reduce direct emissions within a city, regulations and standards can create demand for low carbon, resource efficient products and innovation, and could be applied across most consumption sectors. For example, California has introduced standards to increase the share of recycled content in waste bags and newsprint, while a 25 per cent recycled content will be required for PET bottles in the Netherlands.[24] Cities with a large land ownership can also directly promote low carbon buildings and infrastructure. For example, Stockholm and other major Swedish cities teamed up to prioritise wood-based construction products for land owned by the city as a way of reducing the embodied emissions in buildings. This sent a powerful signal to the construction sector: as a result, the Swedish cement industry and major construction companies are developing an action plan for climate neutral concrete to make sure they can compete in a low carbon market.[25] Standards usually need to be co-ordinated across cities, so industry can comply with a single set of rules, rather than different sets of potentially conflicting standards. We outline on page 31 how this could be done with regards to electronic equipment and machinery.

“Oslo, Rotterdam and Copenhagen are working together on innovative procurement plans for zero emission urban delivery of goods and services to the public sector”

Public procurement. Cities control large budgets and can use these to purchase products and services with a lower overall carbon footprint. Public procurement guidelines can be applied across a range of sectors, including buildings, electronic equipment, food and sectors where public authorities are the principle buyers, such as transport and waste management. For example, Paris is promoting the consumption of seasonal, locally sourced foods, and has committed to reducing its meat procurement by 20 per cent by 2020.[26] Oslo, Rotterdam and Copenhagen are working together on innovative procurement plans for zero emission urban delivery of goods and services to the public sector.[27]

Financial incentives. Financial interventions, such as imposing a carbon tax on meat or introducing road pricing for private vehicles, are very effective at influencing consumer choice and are widely used. Cities like Portland in the US modulate property tax to reward properties built to higher building standards; a number of cities, including London and Singapore, have introduced road pricing mechanisms; and Sweden and Denmark have discussed the introduction of a carbon tax on red meat.[28] Across the C40 network, 46 cities can set property or municipal taxes, 30 can set business taxes and 18 have powers over sales taxes or VAT. These could potentially be used to influence consumption patterns and waste treatment options, since reuse and recycling, as well as reduction of food waste, will also help lower emissions. However, financial interventions can be politically challenging to implement.

Behaviour change. Finally, cities can make low carbon choices the default. For example, Copenhagen decided to reduce private car travel in the 1970s by making integrated, pleasant public transport available and by reducing space for private car parking in favour of cycling (the city has nearly 370 km of dedicated cycle lanes).[29] This was a result of public opinion research which showed that the relative ease of navigating multiple shops on a high street was central to whether someone decided to use a bike or a car. These interventions did not ban cars, but they led to 33 per cent of all trips being made by bike, using city powers in urban land use planning and public transport.[30] Similarly, Berlin has a strategy to move from vehicle ownership to a sharing model, which has helped it to maintain the lowest motorisation rate in Germany. To achieve this, electric vehicle (EV) fleets are integrated with public transport, enabling residents to comfortably use EVs, bikes and public transport.[31]

Finally, alongside direct powers and resources, city leaders can use their role to set the vision for the nature of a city’s built environment, drawing attention to local challenges at a national level or energising local action on emissions beyond the city boundaries through community engagement. And they can use consumption-based emissions as a reason to ask national governments to give them additional powers, as the Mayor of London, Sadiq Khan, has done to address the air pollution from machinery used on construction sites.[32]

Working together

“City decision makers could usefully team up across the world to influence emissions that would normally be far beyond their reach.”

As we have discussed, cities, as big drivers of consumption, could be powerful actors in curbing supply chain emissions. Jointly, they could have twice as much impact in cutting global GHG emissions if they aligned their priorities and acted together, harnessing their respective powers.

The recent creation of a comparable set of consumption-based emissions data across 79 C40 cities has made it possible, for the first time, to explore how this might be achieved.[33] We have used this data to identify common features in overall consumption-based emission profiles for cities.

Despite variations in geography, wealth and other factors which influence emissions, our assessment reveals more similarities between cities across the world than might be expected. We have identified seven broad city clusters based on similarities in emissions profiles (see page 18). For example, Stockholm, Tokyo and Vancouver all fall into a ‘Big state’ cities cluster, Durban, Auckland and Santiago are all in the ‘Driving dominates’ cluster, and Madrid, Melbourne and Portland come together under ‘Living comfortably’. The spread of geographies in each cluster suggests that city decision makers could usefully team up across the world to influence emissions that would normally be far beyond their reach.

City clusters

Living comfortably: wealthy cities, mainly in North America, Europe and Australia, with a large share of emissions from private housing

Builders: large Asian cities, with highest emissions from investment in durable goods such as infrastructure and machinery, driven by urbanisation and large scale economic growth

Government led: wealthy cities, mainly in Canada and Europe, with high emissions from investment in durable goods, housing, and a high proportion of emissions from government services

Food and transport: large cities in the low to middle income range, mainly in Southeast Asia and Latin America, with a large share of emissions from food and transport

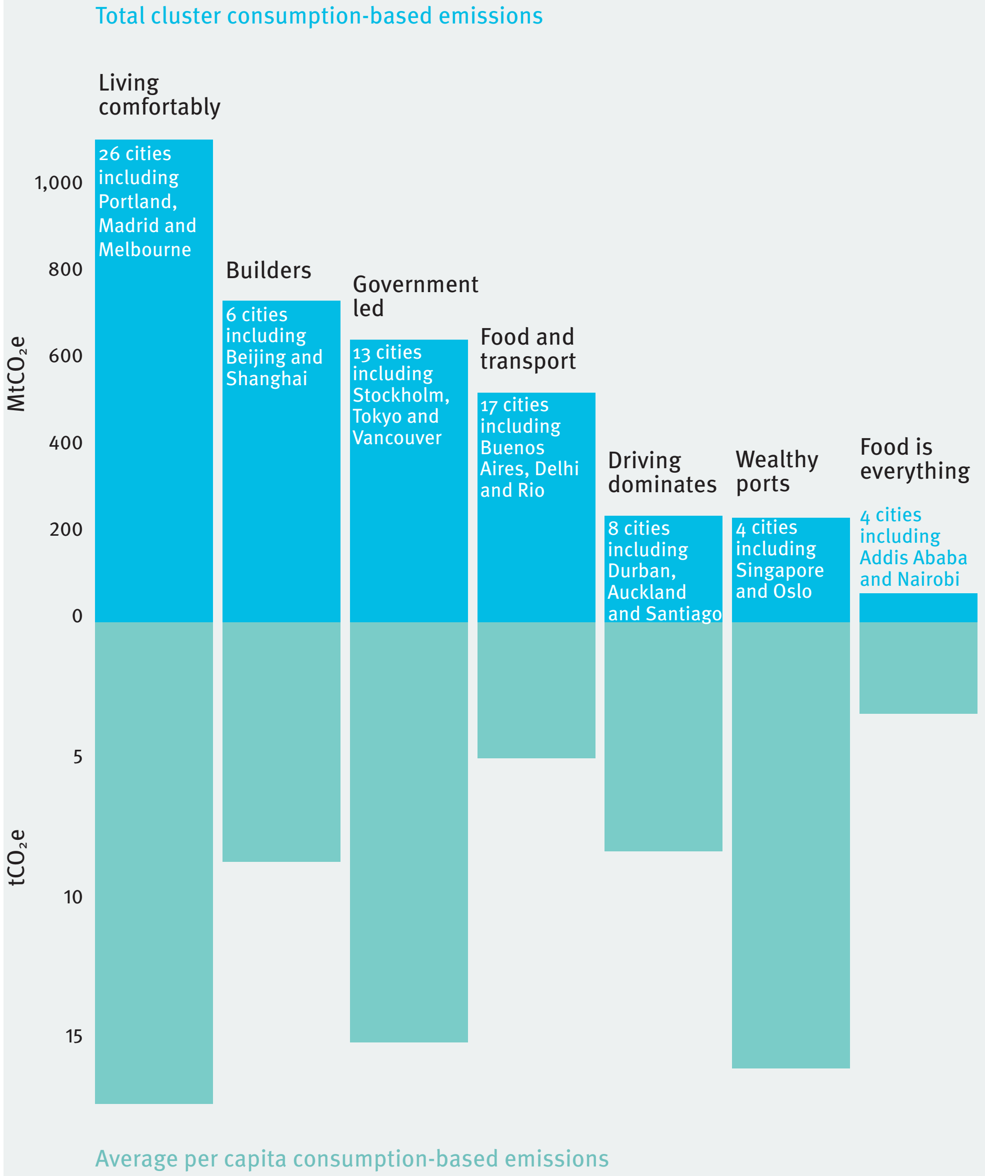
Driving dominates: mainly southern hemisphere, low to middle income cities, with high direct emissions from residential transport

Wealthy ports: high income coastal cities, with high emissions from shipping

Food is everything: low income, mainly African cities, where emissions related to food are dominant

“In terms of consumption-based emissions, for example, Stockholm is more like Tokyo than its closer neighbour Oslo.”

Similar consumption profiles can enable clusters of cities to work together[34]



Our cluster analysis reveals areas of co-ordinated strategic action that could be explored within the C40 network. Focusing particularly on the city clusters with the highest average per capita and total consumption-based emissions, we have identified the following opportunities for intervention:

'Government led': public procurement This would direct state spending towards low carbon products and services, helping to establish supply chains for products with reduced embodied carbon. Public sector spending represents a substantial share of total city spending (global figures estimate the public sector represents 15-20 per cent of GDP) and there are existing examples of low carbon procurement in ICT, vehicles, buildings and infrastructure, all areas with large consumption-based emissions. By building on existing initiatives, such as EU Green Public Procurement and circular procurement guidelines, C40 cities could identify opportunities to reduce the consumption-based emissions associated with these sectors. Furthermore, given the potential role of public procurement in supporting innovation, C40 cities could co-ordinate action to promote novel low carbon products. Some C40 cities have already joined forces to buy low carbon buses, helping drive down costs and create economies of scale for a new technology. For example, London has already seen a price reduction of more than 10 per cent for its electric buses. This type of action could be replicated in other areas to cut consumption-based emissions.[35]

'Living comfortably': low carbon urban development This would encourage the decarbonisation of services related to housing and utilities, particularly heat and power, and inform low carbon urban planning for cities in this cluster. While efforts to decarbonise the power sector are already underway within the C40 network, this group of cities (many of which are US cities affected by urban sprawl) could build on ongoing work by the C40 Land Use Planning and Low Carbon Districts Networks to further minimise housing energy consumption through denser and more compact development.[36] City and district scale planning can also facilitate the decarbonisation of heat through large scale deployment of low carbon options, such as district heat networks, and enable the development of low carbon neighbourhoods, such as the eco-districts in Portland and Stockholm, where energy use and waste management are optimised.[37] Cities in this cluster could also identify opportunities to use smart technology to optimise energy and water use. This is already been pioneered by Copenhagen, where real time monitoring in municipal buildings has helped save 6,500 MWh of heat, 1,345 MWh of electricity and 30 million litres of groundwater in 2016, and is forecast to save about $6 million per year, once fully implemented, with a payback time of six years.[38]

'Builders': resource efficient industry and infrastructure This would support low carbon development in growing Asian cities. These cities have a large carbon footprint from machinery and construction. Product standards and circular business models, implemented through the electronics buyers club we discuss on page 31, could help cut emissions from machinery through resource efficiency. But, given the strong economic role of Chinese cities in this cluster (15 per cent of China's GDP) and their large manufacturing base (four of them are among the largest cities in China for manufacturing), a joint manufacturing support programme could have more impact. [39] This would provide technical expertise and

“Joint city action, through partnerships that span countries, provides new opportunities previously considered out of a local decision maker’s reach.”

drive the adoption of low carbon products and processes, which would help businesses become more productive through efficient use of resources. A similar programme could focus on low carbon steel production and the whole life carbon assessment of infrastructure projects.[40] Given the potential capital savings, prioritising low carbon infrastructure could be advocated as a strategy to build business resilience and competitiveness.[41] This would support sustainable infrastructure delivery across other regions, given that China finances and develops more infrastructure in developing countries than all the OECD countries combined.[42]

‘Wealthy ports’: support low carbon shipping This would encourage decarbonisation across the whole shipping industry. The cities in this group are in Europe and Asia. A clean air port partnership, discussed on page 34, could encourage fuel shift, design and operational improvements to cut emissions. Given that this partnership would include three of the world’s top ten busiest ports, it could also support wider uptake in the industry and in neighbouring harbour cities.

Putting joint action into practice

Tackling consumption-based emissions has the potential to bring cities across the world closer together. High level mapping of emissions hotspots could form the basis of joint political endeavour, but analysis of specific sectors and products, such as a smartphone sold in London or a beef steak served at a restaurant in San Francisco, can demonstrate the opportunity to link emissions reduction strategies across supply chains and multiple cities. Although addressing the emissions embodied in traded goods and services is complex, joint city action, through partnerships that span countries, provides new opportunities previously considered out of a local decision maker’s reach.

Our analysis has identified a number of areas where cities could join forces to address their consumption-based emissions. In the next section, we look in more detail at how groups of cities could influence their supply chains, working together within a state or across national borders, or influencing supranational entities.

Demonstrating the potential for joint action

Teaming up within a state

Some consumption sectors have emissions that arise outside cities but within the same country. In this case, the geographical proximity, shared regulatory regimes, and similar politics can facilitate collaboration between cities. For example, a joint innovation partnership on rice production in India, which we explore below, may be useful for cities wanting to lower carbon emissions, tackle air pollution from stubble burning and support local economies relying on rice production. Alternatively, cities within the same country could use their economic and soft powers to influence national policies for low carbon production, as highlighted in the example of low carbon vehicles on page 24.

Tackling common priorities

Indian innovation to boost low methane rice production

Five Indian cities have high emissions associated with rice consumption, accounting for about 23 per cent of their emissions from food consumption and about five per cent of their total emissions. Together, these amount to 9.2 $MtCO_2e$ (roughly equivalent to the yearly GHG emissions from all cars registered in Bengaluru, Kolkata and Jaipur combined).[43]

Given that these emissions are largely national and arise mainly from rice paddies (responsible for over 80 per cent of rice production emissions, and about one per cent of global GHG emissions), Indian cities could set up a partnership to implement the following measures: [44,45]

Change rice paddy water management

The duration of flooding of rice paddies influences the growth of methane producing bacteria. Better water management practices can lower methane emissions. For example, draining a paddy mid-season can reduce emissions produced by 40 per cent, multiple draining can cut it by 48 per cent and alternative wetting and drying reduces emissions by 90 per cent.[46] There is also a set of practices for growing rice called System of Rice Intensification (SRI) which has been shown to reduce GHG emissions by 66-73 per cent.[47] This method is being used in parts of India, but it involves many rules and few rice farmers follow all the SRI practices.[48] Better water management also increases rice yield and conserves water which are important co-benefits for farmers.[49]

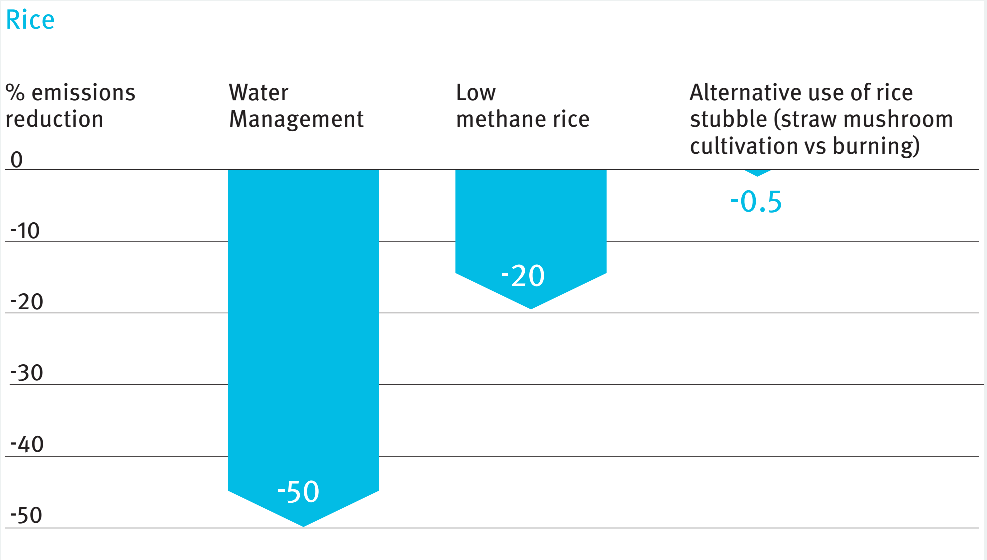
Low methane varieties of rice

Some rice varieties have been linked to lower methane emissions. For example, researchers in China, the US and Sweden have developed a form of rice called SUSIBA2 which can cut methane emissions by up to 90 per cent at certain stages of production.[50] Short duration rice varieties are also available, cutting methane emissions by about a quarter as a result of faster growth (110-130 days to mature compared to 160-200 days for traditional rice varieties) and limiting the number of days where crops need to be flooded.[51] Finally, opting for high yield rice varieties could support production without increasing emissions from land use change, as it would reduce the amount of land used for rice production.

Collect (or shred) stubble rather than burning it

Burning rice stubble is a widely practiced method of removing field residues since it is cheap and easy, but it increases the carbon footprint of rice production as well as being a source of air pollution.[52] It could be avoided by using mulching machines to shred the rice straw and return it to the field, which also increases soil productivity. Alternatively, paddy straw can be collected for power generation or for use as substrate for mushroom cultivation, while the use of short duration rice strains, discussed above, could give farmers more time to remove the straw rather than burning it.[53]

Potential emissions reductions [54]



An innovation partnership could support low carbon rice production in the following ways:

Hosting an innovation programme for the commercialisation of low methane rice strains A number of Indian institutions already study rice genetics and production practices, including the Indian Agricultural Research Institute and the Indian Institute of Rice Research. Cities could help to fund research into low methane varieties, work with farmers in their rural hinterlands and support commercialisation of low methane producing varieties through advanced forward procurement.

Supporting the uptake of alternative water management This can be done through a series of demonstration projects to raise awareness of different water management systems, and by procuring rice from farmers who follow such practices.

Supporting rice stubble collection for various applications Cities could initiate a collection system for crop residues at aggregation centres, providing economies of scale, and use public and corporate procurement to reward farmers that opt for alternative uses of crop residues (rather than burning them). Furthermore, the innovation programme into low methane rice strains could support the development and uptake of short duration rice varieties to facilitate straw removal from the fields.

Emissions associated with rice consumption in C40 cities are similarly high in neighbouring countries, including Bangladesh and Vietnam, where they account for nearly half of their food related emissions. Commercialising low methane varieties and practices in India could provide a model for other C40 cities in the region to cut their emissions.

Using collective power to influence a state

An urban alliance for clean cars

Within the transport sector, high emissions from the production and maintenance of motor vehicles are shared by a cluster of cities in leading economies, including cities in Europe, the US, China, South Korea and Japan. These add up to 26 $MtCO_2e$ across these five regions with the majority of emissions generated nationally. Use of motor vehicles is also responsible for a large share of direct emission within cities, with 88 $MtCO_2e$ (which is more than Austria's territorial emissions) arising from private transport.[55]

Decarbonising transport is one of the main areas where cities have been active: nearly 20 per cent of city initiatives in the C40 network focus on transport.[56] A number of cities have also set ambitious targets for banning diesel and petrol vehicles: for example Copenhagen is planning to ban diesel cars by 2019, and Paris will ban both diesel and petrol cars by 2030, ten years ahead of the rest of France.[57]

As vehicles become more efficient, and with the move to electrification, the balance of emissions impact is shifting from energy in use to embodied energy: a typical diesel vehicle's embodied emissions are eight per cent of its lifecycle emissions, compared to an average of 33 per cent of an electric vehicle's (EV's) much lower overall carbon footprint in Europe.[58] Cities could continue to lead on cutting emissions from vehicles by integrating policy to reduce embodied carbon with existing measures to reduce transport emissions.

Reducing weight and using recycled materials

Lighter cars are more fuel efficient: a ten per cent weight reduction results in three to seven per cent lower fuel consumption. Although lightweight materials, like aluminium, high strength steel and carbon fibre composites are more carbon intensive to manufacture, this is still the right trade-off to cut overall emissions: swapping conventional steel for aluminium or high strength steel saves 5-8 kg CO_2e per kg replaced over the lifetime of a vehicle.[59,60] Using recycled materials to make lightweight car parts can significantly improve this saving.

"Emissions cut through vehicle recycling alone would be equal to shutting down all of Germany's lignite coal plants."

For example, in the UK, Jaguar Land Rover switched from steel to a recycled aluminium alloy, which is cheaper and requires less energy to make compared to virgin aluminium. As a result, it reduced its material costs by 25 to 30 per cent and cut its dependence on virgin aluminium from 90 to 50 per cent as well as making its vehicles lighter.[61]

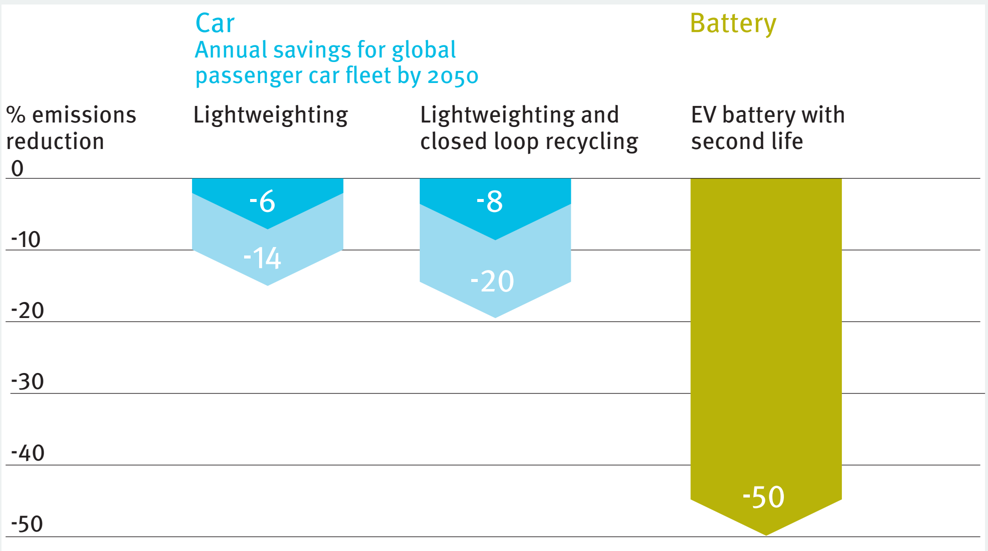
Cars are the second most imported good globally, so cutting their production footprint could have far reaching effects.[62] The global impact of lightweighting would reduce cumulative emissions by 9-18 $GtCO_2e$ by 2050 under optimal conditions. Closed loop metal recycling could reduce these emissions by a further 4-6 $GtCO_2e$.[63] On average, these emissions savings each year would be roughly two thirds of all the emissions generated by global aviation in 2017, and emissions cut through closed loop vehicle recycling alone would be equal to shutting down all of Germany's lignite coal plants.[64]

Electrification of transport with a second life for EV batteries

EVs have a lower lifecycle carbon footprint than conventional cars and can additionally help cities tackle air pollution.[65] However, their production footprint tends to be higher than fossil fuelled vehicles, with batteries accounting for up to 24 per cent of their total carbon footprint.[66] As cities electrify transport, they can reduce its carbon footprint by ensuring that EV batteries are repurposed for a second life.

EV batteries are usually replaced roughly every eight years, but discarded batteries retain about 80 per cent of their original capacity. These used batteries can be repurposed for stationary electricity storage, as is already done by BMW in their 2MW power storage facility in Hamburg which is made up of more than 100 EV batteries.[67] Relying on used EV batteries could cut overall battery emissions by up to 50 per cent.[68] And while costs of repurposing are currently around US$100, economies of scale, achievable through joint city action, could halve this cost, providing a competitive alternative to using new batteries for power storage.[69]

Overview of potential emissions reductions[70]



Cities could cut the embodied emissions of cars in the following two ways:

Influencing industrial policy The automotive industry is often a national flagship industry, and one that countries have generally been willing to support through their industrial policies. Cities in industrial clusters with a strong automotive manufacturing base, such as Guangzhou and Shanghai in China, Chicago in the US or Yokohama in Japan, can use the economic and political weight of local industries to influence national industrial policy.[71,72,73] Cities could encourage national governments to support a strategic programme for closed loop recycling in the automotive sector, which would help car manufacturers to reduce their material costs, improve resilience by limiting dependence on virgin materials and cut the emissions associated with vehicle production. Interventions could include establishing the reverse logistics required for harvesting metals at a vehicle's end of life, as well as supporting materials science innovation to improve recyclability and ensure that secondary materials have the same qualities as virgin materials, particularly for novel materials such as carbon fibre composites.[74]

Local procurement can be used to support industrial policy for resource efficient car manufacturing. All 12 US cities with high emissions from motor vehicles own or operate a municipal fleet; 11 of them can set and enforce policies for taxis; and five can set and enforce policies for private vehicles. Similarly, nine out of the ten EU cities with high emissions from the production and maintenance of motor vehicles own, partially own or operate a municipal fleet; four can set and enforce policy regulations for private vehicles; and seven can set and enforce policy or regulations for taxis.

In the UK, local authority vehicle fleets are, collectively, nearly twice the size of central government's vehicle fleet.[75] This means that, C40 cities could support manufacturers' investment in material innovation through local procurement and transport policies. Similarly, cities could increase demand for recycled or closed loop recyclable content (ie materials that could be recycled for use in the same application) by targeting corporate fleets with modulated business fees, preferential parking permits and modulated duties for end of life disposal.

Repurposing batteries for decentralised energy infrastructure Dense urban infrastructure makes the reinforcement of local power grids expensive. Batteries can help to reduce the need for grid reinforcement. Cities could use their influence to stimulate the market for repurposed EV batteries. They could use them for stationary electricity storage to balance energy use in city rail and underground transport infrastructure; use their planning powers to facilitate the use of repurposed batteries to support the electricity grid; and include an option to buy second life batteries in agreements with car hire schemes, like Zipcar or DriveNow. These actions would reduce the need for costly and disruptive electricity grid upgrades, increase the viability of decentralised energy and decrease energy costs for city owned rail and underground services.

Working across borders

Supply chains often stretch across borders. These global production processes, and the dispersed nature of markets that drive demand for goods, can make isolated efforts to improve energy and resource use difficult.

Again, collaboration between cities could unlock opportunities to influence production processes and cut emissions that would otherwise be out of reach of individual cities. This could be done through a targeted approach that supports specific actors along supply chains to cut their emissions, as in our example below of a transatlantic beef partnership. Or the purchasing power of the C40 cities could be used to aggregate demand and motivate change along global supply chains, as proposed in the electronics' buyers club (see the example on page 31).

Working together along international supply chains

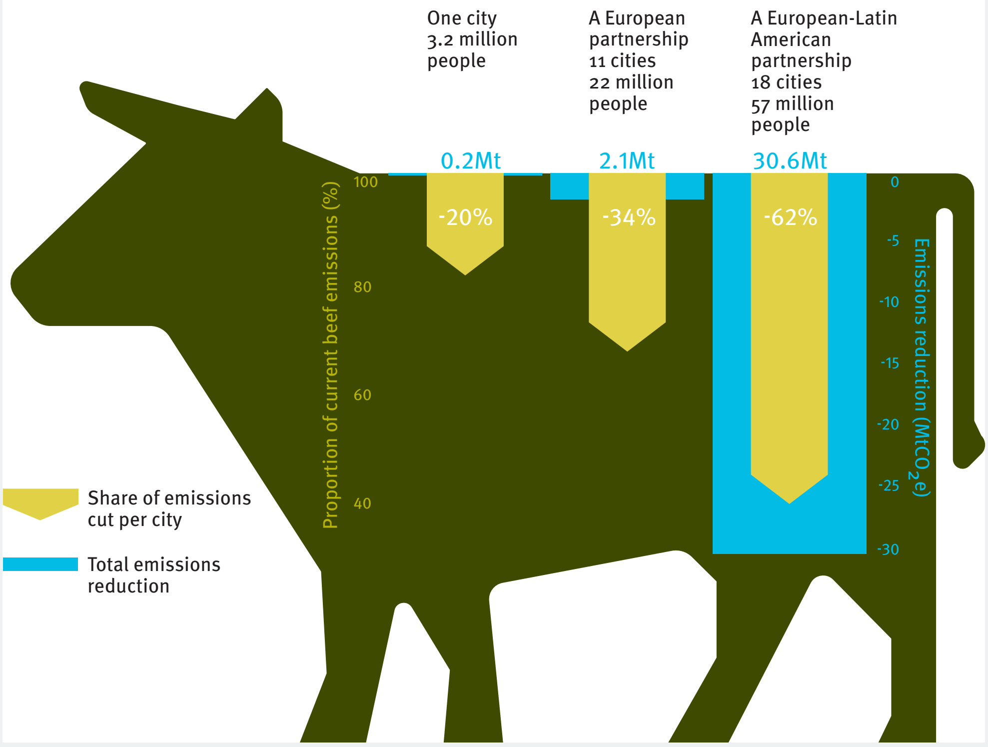
A transatlantic beef partnership

A cluster of 11 European cities have high consumption-based emissions from food, with beef being one of the top sources of emissions. These emissions arise mainly nationally, but, overall, about a quarter are imported. On the other side of the Atlantic, about half of the food consumption related emissions of seven Latin American cities arise from nationally sourced beef. Because the European cities import beef (between 11 and 68 per cent of their embodied beef emissions are from imports) and over 50 per cent of beef imported into Europe is from the countries of the seven Latin American cities, C40 cities have the opportunity to work together to reduce emissions.[76]

By establishing a European-Latin American partnership these cities could together address emissions across the whole supply chain. For these 18 cities, the combined emissions from beef consumption add up to 49 $MtCO_2e$, equivalent to the emissions from 11 coal fired power plants.[77] They represent 2.1 per cent of the overall consumption based emissions for the 11 European cities and 17.1 per cent for Latin American ones, enough to merit serious consideration by policy makers.

Furthermore, working right across the supply chain allows pursuit of both demand side options, like reducing beef consumption, and supply side options, like changing the emissions intensity of the production process. Taken together, the measures we have evaluated could potentially cut emissions by up to 31 $MtCO_2e$ across the 18 cities (as shown on the graphic below).[78] Because beef production emissions make up around 9.5 per cent of global emissions, spreading an approach first pioneered in C40 cities to other places around the world could make a significant impact on mitigating climate change.[79]

Cities working together can cut over 60 per cent of their beef emissions



The options we evaluated:

Feeding seaweed to cattle

About half of beef emissions arise from the digestive processes of cattle, also known as enteric fermentation.[80] Better feeds can cut methane emissions.[81] For example, recent research has shown that, if seaweed made up just two per cent of cattle feed, it could reduce the amount of methane produced by interfering with the microbial enzymes responsible for methane production in the stomach. Initial studies show that feeding seaweed to livestock reduces methane production by over 80 per cent.[82] Furthermore, it may offer the advantage that the mitigation effect appears a few days after the dietary shift.

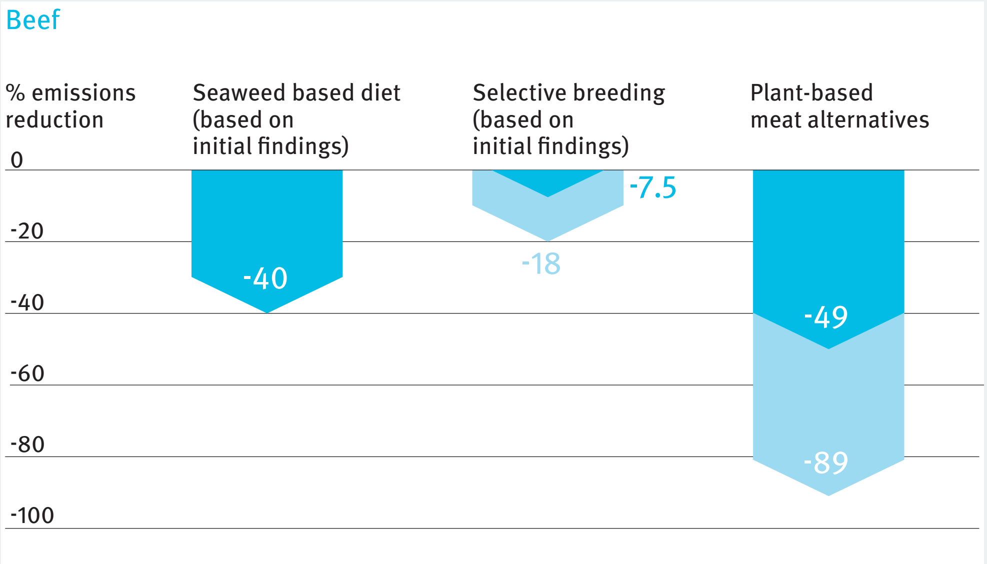
Breeding low emissions cattle

Selective breeding could also be used to reduce the amount of methane cows produce. Test facilities at Givendale farm in Yorkshire, England, are breeding cattle for net feed efficiency by selecting cows that have the best food to weight conversion rate. Initial results have seen the most efficient cattle in the herd producing around 15 per cent less methane than the least efficient cattle.[83] Scientists in Scotland have also been able to link cattle genetics to the rumen microbial community, estimating that about 80 per cent of the variation in cattle methane emissions could be explained by genetics, which dictates the balance of microbial species in the gut. Expanding on this research could lead to the wider use of low emission cattle in farming.[84]

Replacing beef with plant-based meat

Cities can reduce their meat consumption by encouraging the use of lower carbon plant-based meat substitutes. Several approaches could be taken. On the established end of potential interventions, Google's head offices have swapped 50 per cent of the meat in their burgers for mushrooms. An alternative approach is to develop 'meat-free meat'. For example, Impossible Foods in the US has created a burger which has the same texture as meat, that even 'bleeds', but is composed of plant proteins and produces 87 per cent fewer greenhouse gas emissions in its production than a typical beef burger, whilst also cutting water use and land requirements.[85] In addition to environmental benefits, these measures also have health benefits associated with lower red meat consumption.

Overview of potential emissions reductions:[86]



The challenge is how to encourage the use of these interventions. We propose a joint European-Latin American partnership, which could do the following:

Establish an innovation partnership between universities and producers
Measures like cutting methane production through selective breeding and new feeds are still in the research phase. Cities could foster and fund collaboration between academic institutions and farmers to commercialise these innovative low carbon farming options. This could be modelled along the lines of the Scottish Interface Food and Drink partnership, which brings together businesses wanting to innovate as part of a common interest group and matches their needs with academic institutions.[87] C40 cities could tap into local academic centres such as the University of São Paulo, one of the top universities for agricultural science. And they could encourage cattle farmers in urban hinterlands to introduce low carbon farming measures that have proved to be viable.

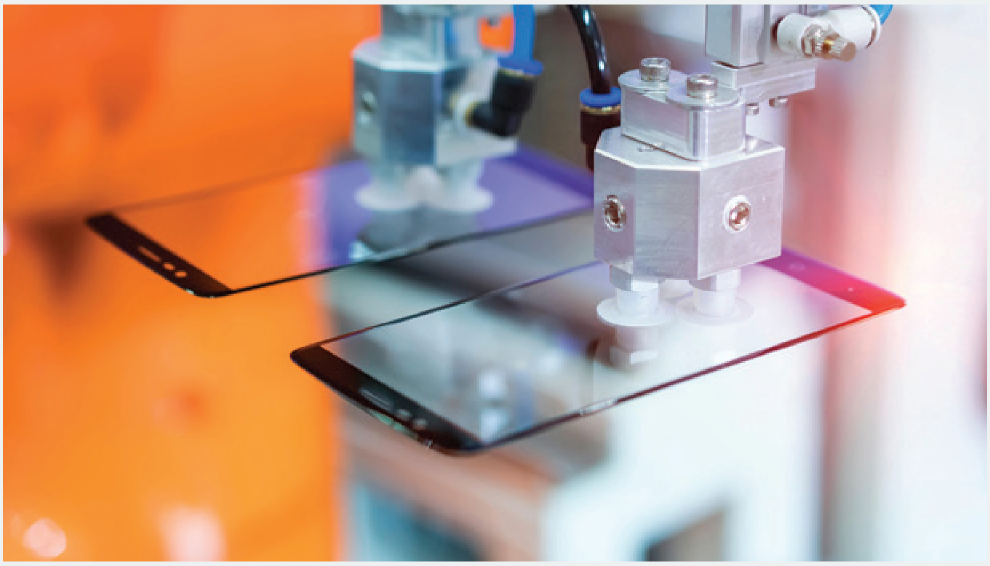
Leverage public procurement Buying low emissions beef and reducing meat consumption in municipal canteens would stimulate the demand for low carbon foodstuffs. Paris is already doing this: it plans to reduce meat served by municipal and departmental catering services by 20 per cent by 2020 via its Sustainable Food Plan.[88] Cities could work with C40's Food Systems Network to identify opportunities to use their procurement power to cut meat related emissions.[89] Furthermore, forward procurement is a proven tool for bringing innovative products to market, and could be used to establish novel practices in low carbon beef production.

Brokering corporate action By liaising with local businesses and institutions, city authorities could agree a commitment to support low carbon beef or plant-based meat alternatives. Engagement efforts could focus on large corporate employers, encouraging them to provide low carbon meals for their employees, as well as retailers and corporate caterers, both of which are well placed to drive change along their supply chains towards low carbon alternatives.

Three of the 11 European cities and two of the seven Latin American cities with high emissions from beef production have stronger powers than others to address emissions from food, including the ability to set business taxes and shape policies on local economic development. Leadership from those cities would help to inspire the other cities with partial powers to join in. This highlights how collaboration might strengthen city powers beyond what local decision makers might perceive as achievable within their existing remit. It could also lead some city leaders to seek greater powers.

Cities using their combined economic power

An electronics buyers' club



Cities in the US, Brazil and Japan all have a high share of emissions associated with electronic equipment due to investment in durable goods, ie capital. They also, along with other cities in China, India, South Africa, Nigeria and Europe, have a high share of emissions from machinery and electrical equipment.

In total, 46 cities across these regions are responsible for a total of 130 $MtCO_2e$ from electronic equipment and machinery (comparable to the UK's entire transport emissions in 2017), with 68 per cent of these emissions generated nationally.[90] The metro areas of the 12 US cities included in this group account for over 38 per cent of GDP of US metro areas.[91] The six Chinese cities assessed rank among the top 11 in the country for GDP and together account for 15 per cent of China's GDP.[92] Collectively, this gives them considerable economic power.

Supply chain emissions are significant in the electronics and machinery sector. Manufacturing accounts for 75 per cent of an average smartphone's and 67 per cent for a laptop's GHG footprint, and embodied emissions have been rising over the years. Embodied emissions are concentrated in integrated circuit boards and screens, components that are challenging to reuse. Therefore, extending a product's lifespan is the best option to reduce its carbon footprint.[93] For machinery, the GHG footprint is currently dominated by emissions during use, but rising energy efficiency standards have been shifting the bulk of emissions toward manufacturing.[94]

To reduce emissions, cities could extend the life of electronics and machinery in the following ways:

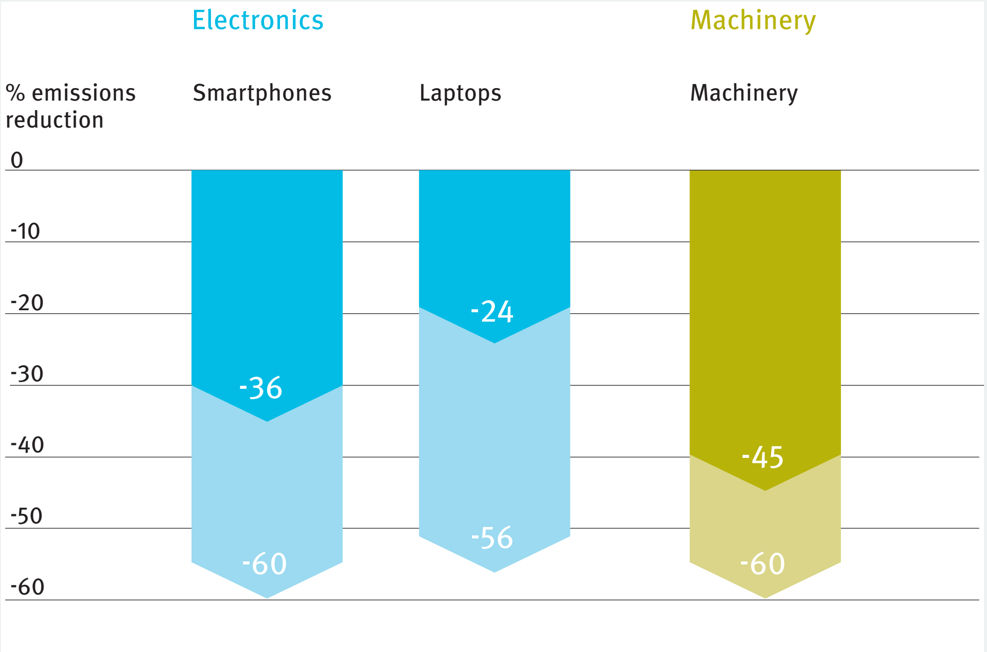
Raising product standards

Existing standards, such as EU ecodesign, EnergyStar and EPEAT, are limited to energy efficiency in use.[95] The group of 46 cities we have identified could work with standards bodies to expand these to include resource efficiency, for example by requiring products to satisfy durability or repairability requirements, and then only buying products that meet the highest standards.[96] Longer lasting products would not only cut emissions, but also give consumers products that have a higher resale value. Action in this area could build on early ecodesign preparatory studies by the European Union or private initiatives, such as the repair start up iFixit's repairability ratings.[97]

Expanding circular economy business models

Service based business models help to extend product lifetimes through shared use, repair and remanufacturing. Examples of where they can be applied range from lighting to elevators, to non-domestic ICT. They tend to be more common in the business to business context, suggesting they could be effective at reducing emissions from private and public investment in durable goods such as electronics and machinery. Remanufacturing, in particular, suits machinery, and there are existing applications for medical equipment, office printers and heavy duty machinery.[98]

Overview of potential emissions reductions[99]



To raise product standards, cities could pursue two strategies. First, they could jointly lobby national governments or supranational institutions, such as the EU, to expand them. Alternatively, they could develop their own, shared standards based on existing ratings, such as those provided by iFixit, and use them in their procurement while working with local businesses to apply them. The example of

EPEAT's adoption by municipalities in the US shows that this approach is effective. For instance, when San Francisco announced it would no longer buy Apple computers, which failed to meet EPEAT standards, hundreds of companies and government contractors followed suit, prompting Apple to re-enter the certification scheme to reduce the environmental impact of its products.[100]

Product standards support service based business models. But, to go further, cities can shape the market in four ways:

Introduce financial incentives This could be done through tax breaks on product repairs; while current examples of these measures are generally implemented at the national level, eg in Sweden and Belgium, cities could use their powers to introduce similar financial incentives at the local level. For this, 22 of the 46 cities in this group have powers to set business taxes; while 17 can set sales or VAT taxes.

Facilitate access to finance Support could be given to businesses that opt for service based models, either through government led financing or by linking up with private investors. Businesses adopting a circular economy approach require different financial arrangements to account for upfront capital costs and pay back from customers over the lifetime of the product. The London Waste and Recycling Board supports local small and medium-sized enterprises engaged in circular economy activity through direct investment combined with private sector finance.[101]

Establish and support cleantech innovation hubs These hubs would enable the development and commercialisation of low carbon products, business models and services related to electronics and machinery. For example, the Scottish Institute for Remanufacture focuses on developing technology and processes for greater product remanufacturing, repair and reuse, including a recent project to increase electronic waste collection and reuse.[102] Similar initiatives could be integrated in existing innovation hubs, such as Copenhagen's cleantech cluster or Cape Town's Green Cape cluster.[103]

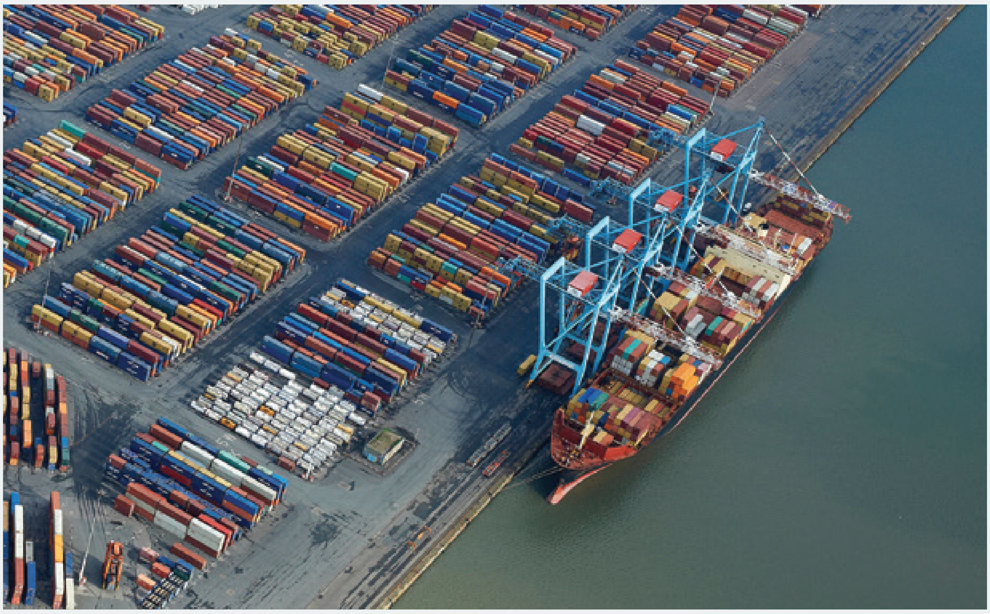
Require information Details about the availability of spare parts could be required for municipal contracts, as is done in France under the French Consumption Law.[104]

Importantly, driving greater resource efficiency of electronics and machinery will spread benefits more widely for consumer products, making them more durable and available through more circular business models. This will help to cut embodied emissions from household consumption across a city.

Influencing a supranational entity

Cities can jointly lead the way on cutting emissions from sectors where tackling them has been challenging, such as aviation and shipping. In doing so, they can nudge supranational organisations to be more ambitious.

A port partnership for clean air



A group of four harbour cities in Northern Europe as well as four Southeast and East Asian cities have high emissions from water transport: 41.7 $MtCO_2e$ overall. They could establish regional partnerships to focus on emissions from shipping. Action across a set of large harbours in Europe and Asia can provide greater incentive to use alternative fuel and instigate design and operational improvements to cut emissions.[105]

The shipping industry is currently responsible for about 2.5 per cent of global GHG emissions, and emissions are forecast to increase between 50 and 250 per cent by 2050.[106] Cities within C40 could use their harbours, three of which are in the top ten busiest ports globally, to decarbonise an industry which has so far been difficult to engage and has only recently agreed to a target for reducing its emissions.[107,108] A significant share of emissions from shipping arises during the time ships spend in harbours and emissions from ships at berth are to up to ten times more than those of a harbour's own operations.[109] The main areas where cities can lead on this agenda include:

Requiring onshore power supply

Most ships are powered by highly polluting diesel or heavy fuel oil. The engines on the ship are also used while it is at berth loading or offloading. Onshore power supply (OPS), which requires an installation on board as well as harbour infrastructure, allows ships to connect to the grid and shut off their engines when in port. This cuts CO_2 emissions at berth by up to 50 per cent, while reducing noise, vibration and engine wear and tear.[110] It also dramatically cuts air pollution: a mid-size cruise ship in port produces as much air pollution as 688 idling heavy goods vehicles.[111] Exact emission reduction potential depends on the source of electricity.

Some ports across the globe are already working to provide the required infrastructure for OPS and are introducing incentives for ship owners to use it.[112] In Spain, port fees are reduced for those ships equipped for OPS, while Sweden and Germany have reduced the electricity tax of OPS under the EU Directive on taxation of energy products and electricity (2003/96/EC).[113] There are similar initiatives in Los Angeles, Rotterdam and Vancouver.

A port partnership across C40 cities could support deployment of onshore power in port cities that have not yet implemented it, providing a joint incentive for ship owners and operators to invest in onshore OPS solutions.

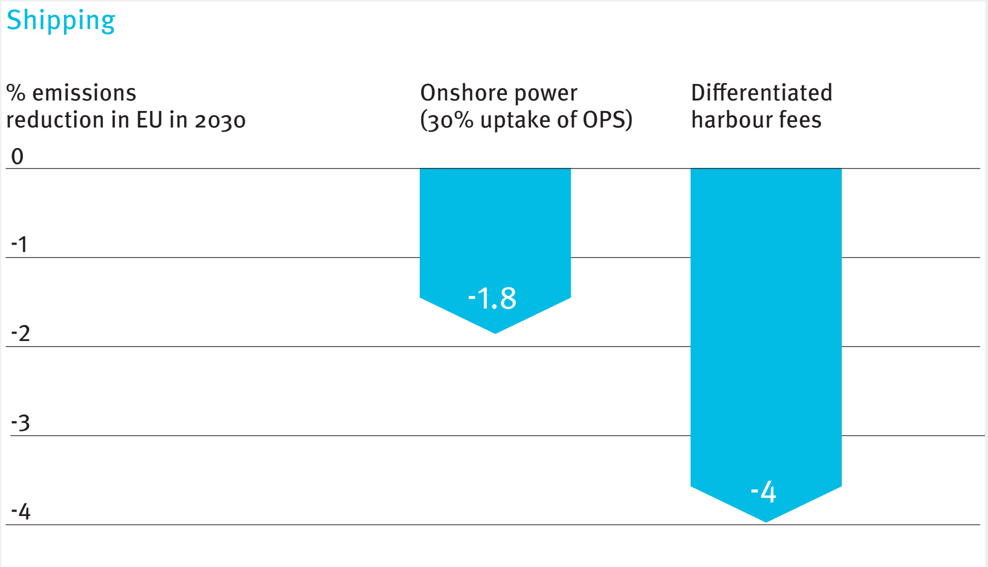
Differentiated harbour fees

Differentiated charging can be used to influence the fuel efficiency and use of low carbon alternative fuels of ships, and could potentially also be based on GHG emissions monitored during operations.

Conservative estimates from one European study suggest that a 20 per cent discount on port dues could cut emissions from shipping to and from EU ports by nearly four per cent in 2030.[114] This was based on 50 per cent higher efficiency than the Energy Efficiency Design Index requirements set by the International Maritime Organisation until 2025 (an improvement that has already been achieved by a number of ships).

Currently only a few European ports apply environmental charges, but these are not aligned and none gauge shipping emissions with sufficient precision. A port partnership could use a new European Union requirement for companies to monitor and report CO_2 emissions from ships over 5,000 gross tonnes (loading and unloading, cargo and passenger) in place since January 2018. This would provide precise information on emissions, enabling cities to align their charging schemes according to emissions.[115]

Overview of potential emissions reductions:[116]



To be most effective, OPS and environmental charging cannot be applied by ports individually. Action should instead be co-ordinated across a set of large harbours in European and Asian regions.[117] Two of the four northern European harbour cities in C40 own or operate their port. This collaboration could provide an incentive for the two other cities to seek further powers to set more ambitious policies. At present, these cities can only set a vision and influence policy. Similarly, two out of four Asian ports either can set and enforce policies, or own or operate their port. These could encourage the two other harbour cities in the region to engage harbour authorities or demand an expansion of their powers.

Cutting aviation emissions

Aviation is responsible for around two per cent of global CO_2 emissions. Projections show its impact will increase by 200 to 360 per cent by 2050.[118] Similar to shipping, the industry has been slow to reduce its footprint, despite having agreed an emissions deal in 2016.[119] Over 74 $MtCO_2e$ a year arise from C40 cities, with 27 cities accounting for 80 per cent of these emissions. C40 cities could jointly address air transport emissions in the following ways:

Promote alternative modes of transport

Cities could follow the example of Paris, where the city's employees are not allowed to travel by plane within the country. This could be replaced by rail travel, which competes with aviation on travel time for distances up to 1,000 km, or by videoconferencing.[120] C40 cities could also launch a private sector engagement programme similar to WWF's One in Five Challenge, which encourages businesses to reduce air travel and has seen participants cut their domestic flights by 38 per cent over four years.[121]

Mayors could use their planning powers, as well as their soft powers, to advocate greater low carbon transport connections, like high speed rail, to link their cities with neighbouring regions. This could include improved integration of airports with the wider rail network. The majority of top emitting cities own, or can influence the policies related to, intercity rail and freight systems.

Alongside transport infrastructure development, cities could encourage low carbon tourism to and from the city. For example, Paris has established a tourism board partnership encouraging the use of trains for tourists from other cities within rail travel distance from the capital.[122]

Reduce air transport emissions

Cities can also engage airline companies and airport operators to reduce their carbon footprint, using the powers they have over local airports, given that 16 cities own or can influence their operations and 29 can influence related policies and regulations (17 of these are among the top 27 cities responsible for 80 per cent of aviation emission across the C40 network). For example, cities that can set (or influence) local airport fees, could modulate them according to the fuel efficiency of airline companies. There is about 50 per cent difference in fuel efficiency between the best and worst performing airlines.[123] Introducing a modulated fee could encourage underperforming airlines to improve their efficiency.

“For middle income cities, citizens in the highest emitting city produce nearly three times as much CO_2e per capita compared to the lowest.”

Shaping city development

As cities become wealthier, they can work together to limit the rise in emissions that is generally observed with increasing GDP. Building on lessons across the C40 network, developing cities may use strategic urban planning as well as the development of low carbon supply chains to keep their emissions low.

Locking in low carbon consumption from the start

Jus Vun / Millennium Images, UK

Data on consumption-based emissions across C40 cities shows that, in general, emissions increase as GDP grows. This is in line with other findings that show a strong linear rise in emissions from services and manufactured products as GDP increases.[124]

However, there is wide variation in emissions between cities with similar levels of per capita GDP: for example, for middle income cities (around $50,000 per capita), citizens in the highest emitting city produce nearly three times as much CO_2e per capita compared to the lowest.

Some of these factors may arise due to geography or from consumption patterns: the total number of products purchased, for example. But collective action decisions, often taken or influenced by city administrations, on product standards, materials, the carbon intensity of supply chains and infrastructure, will shape the overall consumption-based emissions of a city.

“Efficiency of production is the second strongest factor explaining the difference in footprint between cities.”

In fact, further analysis of C40’s data reveals that, after total expenditure, efficiency of production is the second strongest factor explaining the difference in footprint between cities.[125] Furthermore, analysis of sector specific consumption across wealthier and lower income cities reveals that sectors like transport and housing have particularly high emissions disparities between cities of similar wealth, suggesting they are dependent on the wider development of city infrastructure.

So, as cities become wealthier, there may be opportunities to limit the rise in emissions, either by changing consumption patterns, eg through strategic urban planning, facilitating the greater use of public transport or promoting rail rather than air transport, as well as by promoting efficiency along production supply chains to cut emissions associated with specific goods.

For example, as developing cities start to upgrade their transport infrastructure and housing stock, they could advocate for national policies, or use their local economic development powers, to support local (or at least domestic) low carbon steel production rather than be tied to inefficient, carbon intensive steel mills, which could lock in high embodied emissions for decades.[126]

A strategic partnership between C40 cities could identify interventions that would enable cities to grow their GDP while minimising the rise in consumption-based emissions. This could include supporting long term strategic planning for low carbon infrastructure through the C40 Land Use Planning and Transit Oriented Development Networks, and integrating low carbon production into strategic supply chains from the start.[127]

Low income countries have already leapfrogged landline phones straight to mobile phones, and many developing cities are already showing ambitious action to fast track deployment of mass transit. A similar jump could be achieved on consumption-based emissions, but will require early action to avoid growth locking in carbon intensive consumption.[128]

Spotlight on London, Copenhagen and Toronto

We have highlighted the different ways in which cities could join forces to cut consumption-based emissions. But how does action happen at the individual city level? How can a city lock in low carbon consumption, either through voluntary measures or policy? Here, we show some of the measures that London, Copenhagen and Toronto are implementing and consider further action they could take.

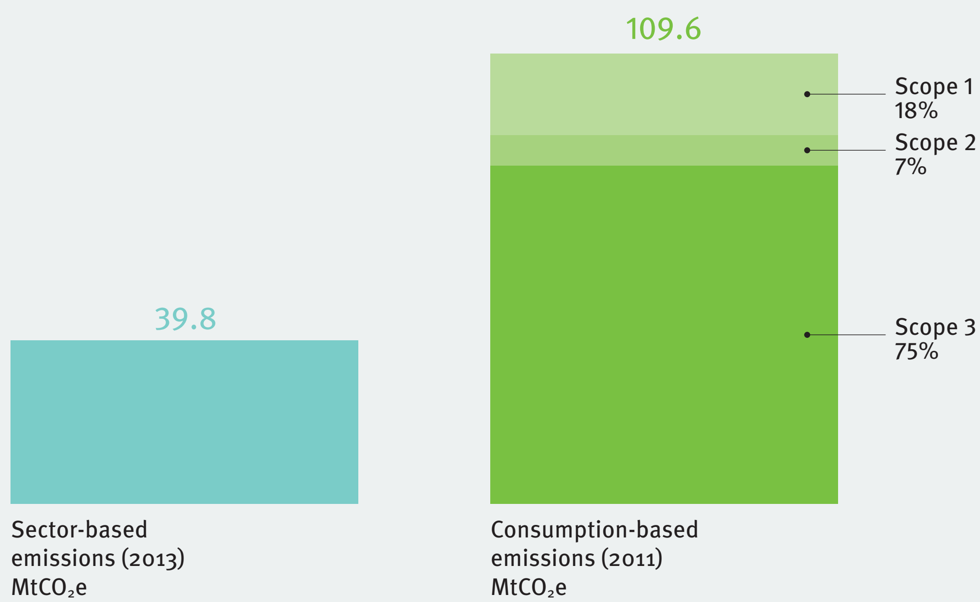
London

Consumption profile

Similar to most other C40 cities, London is a 'consumer' city. Its consumption-based emissions are nearly three times the city's sector-based emissions, and most of them arise outside the city boundaries.[129]

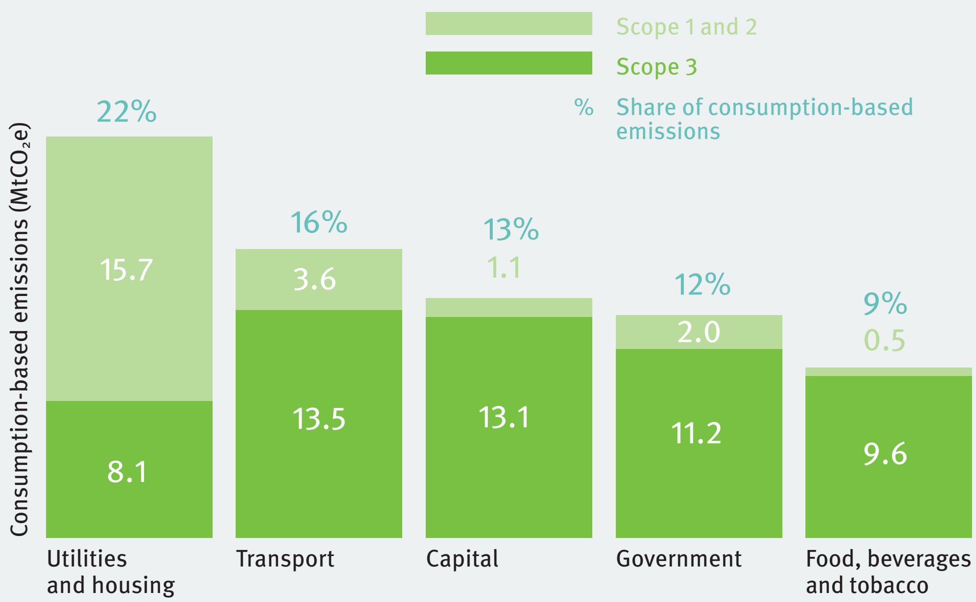
London's emissions

Sector-based vs consumption-based emissions, divided by scope



The highest share of consumption-based emissions in London arise from the following categories: utilities and housing, transport, capital, government and food. While utilities and housing is responsible for the largest share of emissions (22 per cent of London's consumption-based footprint), about two thirds are scope 1 and scope 2 emissions, therefore they are already addressed through existing climate action to tackle the city's sector based emissions. Scope 3 emissions, ie emissions generated outside the city, account for most of the consumption-based footprint of the other sectors, particularly transport and capital (including construction).

London's top emitting consumption sectors and their share of the city's consumption-based footprint



Existing climate action

London has already taken ambitious action to tackle its sector-based emissions. The mayor's Environment Strategy sets out a roadmap to become a zero carbon city by 2050, focusing on cutting direct emissions from housing, energy and transport.

London has also started tackling consumption-based emissions. The city aims to reduce food waste by 20 per cent by 2025 and its FoodSave initiative is already helping businesses to design out waste through food waste audits.[130] Other efforts to become a zero waste city, such as cutting single use packaging and boosting recycling could also contribute to further reducing consumption-based emissions by making better use of resources.

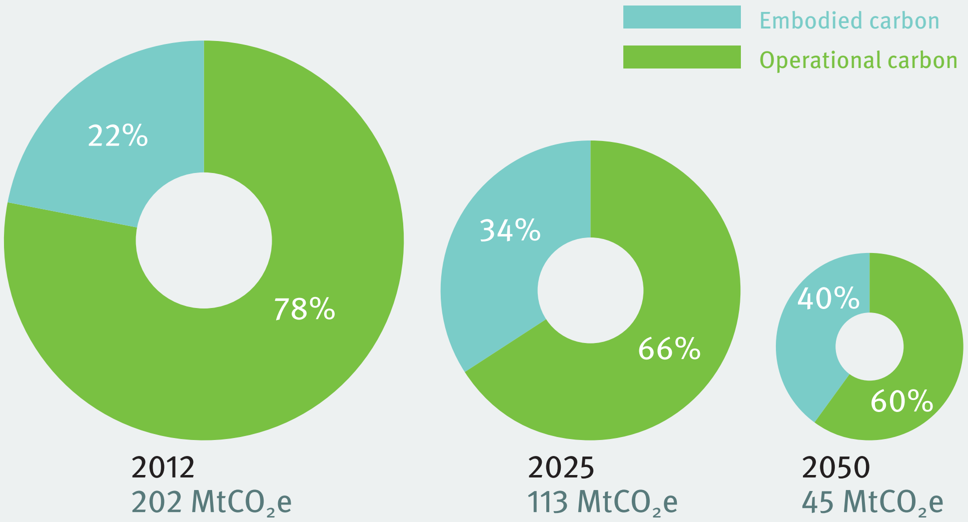
Finally, London has led the way in understanding its emissions. Together with the British Standards Institute, it produced the first UK standard on scope 3 emissions at city level, and has committed to reporting them to provide an understanding of its wider carbon footprint.

Future opportunity: low carbon construction for better air quality and housing

Like many C40 cities, London has a high share of consumption-based emissions linked to construction. For new buildings, embodied emissions (ie emissions arising from material extraction, transport and construction on site) are usually over a quarter of the whole life carbon emissions of a building.[131] For other forms of infrastructure, embodied emissions are typically a much higher proportion of the total carbon footprint. Overall, in London, embodied emissions from construction account for 4.96 $MtCO_2e$ per year, equivalent to 4.5 per cent of its consumption-based emissions and about a third of consumption-based emissions from capital investment. Construction's embodied emissions are set to grow as a share of London's total footprint as energy efficiency reduces operational emissions. Forecasts for the UK show that, by 2050, embodied carbon will account for 40 per cent of overall emissions from the built environment.[132]

As operational emissions fall, a building's embodied carbon becomes more significant

Total annual built environment emissions for the UK[133]



London can reduce these embodied emissions using tried and tested low carbon building methods in construction, like reducing the amount material used and using lower carbon materials, including recycled or reused materials, which can generally result in ten to 20 per cent reductions in embodied carbon with no additional costs.[134] Depending on the project, greater embodied emissions savings can be also achieved. For example, the Enterprise Centre at the University of East Anglia in Norwich, UK, has nearly 80 per cent lower footprint of a typical university building, thanks to the use of low carbon materials, and its cost was comparable to that of a conventional building.[135]

Addressing embodied carbon in construction can also result in reductions in scope 1 and 2 emissions, which London is seeking to cut. For example, improving design to create lighter buildings reduces the need for substructure, minimising the use of concrete and associated embodied carbon, as well as reducing the need for excavation and heavy machinery on site. This would support the mayor's efforts to cut emissions from non-road mobile machinery (NRMM) and contribute to better air quality. Similarly, lightweight structures would typically require fewer site deliveries, which would further reduce impacts on air quality and minimise congestion and scope 1 transport emissions.[136,137]

What has London done so far?

Transport for London (TfL) started using whole life carbon management to cut embodied carbon in its infrastructure projects in its Camden Station Capacity Upgrade, which set a whole life carbon reduction target of 40 per cent. This pushed

“The final design yielded a 27 per cent reduction in whole life carbon against the original concept baseline and reduced lorry movements for construction by ten per cent.”

TfL and its supply chain to question every aspect of project design, based on how specific choices would affect carbon. The final design yielded a 27 per cent reduction in whole life carbon against the original concept baseline, equivalent to 11.8 ktCO_2e, and reduced lorry movements for construction by ten per cent. One way this was achieved was by reducing the number of tunnels from six to just two larger ones, which reduced the need for excavation and concrete, and by bringing sections up to the surface to allow natural ventilation rather than requiring cooling. This approach also led to a substantial saving in capital expenditure, contributing to an overall final cost reduction for the project of 18 per cent.[138]

Similar successes have been reported by other infrastructure companies in the UK, including Anglian Water, who have successfully reduced the embodied emissions across their portfolio by 54 per cent in six years whilst making an average 20 per cent saving in capital costs. Across the UK, this approach to infrastructure could save 4 MtCO_2e in capital carbon and 20 MtCO_2e operational carbon per year by 2050.[139]

How could London make low carbon construction the norm?

1. Drive demand for low carbon construction via public procurement
London has already committed to monitoring scope 3 emissions as part of its Environment Strategy.[140] It could go further by addressing embodied carbon in procurement undertaken by the Greater London Authority (GLA).

In its latest draft of the London Plan, the GLA has put forward a proposal which requires projects referable to the Mayor to conduct a whole life carbon assessment and show actions to reduce lifecycle emissions.[141] Building on this, the GLA could liaise with TfL and the construction industry (through bodies such as the Royal Institute of Chartered Surveyors or the UK Green Building Council, who have both put forward recommendations on whole life carbon assessment) on how to include requirements in their tender documents to address the whole supply chain.[142,143]

The GLA could also support local authorities in London to use whole life carbon management tools in their project delivery.[144] Various local authorities, including Westminster City Council, Hammersmith and Fulham, and Camden have been interested in embodied carbon.[145] The GLA could develop a common protocol for local authorities to address embodied carbon, based on work already begun by the UK Green Building Council. Given the interest, co-ordinating local authorities and the industry should be sufficient to establishing a standardised protocol for setting carbon management requirements in local procurement.[146]

2. Provide financial incentives for developers opting for low carbon
The GLA could encourage developers to reduce embodied carbon via several means. One option would be to let developers use embodied carbon savings in their carbon offsetting schemes. In London, all buildings must meet a minimum carbon standard, or else developers have to either pay into a carbon offset fund or pay for an existing offsite carbon saving project. The existing carbon offsetting scheme focuses on reductions in operational carbon only, in line with the city’s current efforts to cut direct emissions. But future iterations of building emissions reduction targets could allow developers to include reductions in embodied carbon as a carbon offset option for new developments.[147]

3. Adapt existing regulation

Building on its commitment to zero carbon homes, London could require reporting and reductions in embodied emissions as part of the scheme, beyond projects referable to the mayor.[148] The Netherlands already requires assessments of commercial and residential buildings over 100 m^2, and is considering the introduction of targets in the next couple of years. In London, a need for a further 4.7-6.1 million square metres of office space between now and 2041 is forecast.[149] This will result in a total estimated 2.1-2.7 $MtCO_2e$ in embodied carbon (ie 91 to 118 $ktCO_2e$ a year).[150] New residential development is estimated to contribute about 800 $ktCO_2e$ every year until 2029.[151] Whole life carbon management with an average reduction in embodied carbon of 15 per cent per project (achievable with cost neutral interventions to improve design and prioritise low carbon materials) would reduce emissions from residential and commercial buildings by up to 138 $ktCO_2e$ per year, cutting London's annual overall construction footprint by 2.9 per cent.[152]

4. Support off-site construction through procurement and access to finance

The UK's industrial strategy identifies off-site construction as a way of improving the productivity and quality of construction. Moving part of the construction process to a controlled factory environment minimises the need for the transport of materials to and from the construction site, and helps to minimise the waste generated which, in the case of on-site construction, can account for up to 15 per cent of a building's embodied carbon.[153] Furthermore, it is particularly suitable for the use of low carbon materials, including timber frame and cross laminated timber.[154]

This construction approach is particularly suitable for London, given it is planning to build 65,000 additional homes per year up to 2029.[155] Off-site construction can create well insulated buildings and pre-assembly of construction components within a controlled environment also cuts transport to site and the need for on-site non-road mobile machinery, which is responsible for eight to 15 per cent of London's air pollution as well as noise and congestion.[156,157] Estimates of transport related emission reductions suggest savings of 20 per cent compared to on-site construction, some of which would be scope 1 emissions.[158]

Y:Cube, YMCA, Mitcham (Image courtesy of Rogers Stirk Harbour + Partners)

These benefits are already evident from existing examples of off-site construction in London. Y:Cube, a project by YMCA London, has delivered a set of affordable flats with 35 per cent lower embodied carbon. The level of insulation and airtightness has cut electricity and heating bills to £10 per month, compared to the UK average of £93.[159] And the design and assembly is such that the flats can be moved and re-installed multiple times, allowing for a more versatile use of materials and components.[160]

Another example is Dalston Works, one of the world's largest cross laminated timber buildings. Developed in partnership with the London Borough of Hackney, the building has embodied carbon levels which are about half that of a concrete building structure of the same size. Moreover, thanks to off-site manufacturing of building components, deliveries to the site were cut by 80 per cent compared to traditional construction methods, which reduced lorry movements, improving London's air quality and noise levels, and cutting direct emissions within the city.[161]

Dalston Works (Image courtesy of Daniel Shearing Photography)

Given the potential benefits of off-site construction and the need to secure a minimum volume of buildings to justify setting up an off-site construction factory, the GLA could support it by brokering demand across London boroughs and through public procurement.

The GLA could also identify funding models more in line with off-site construction requirements. Typically, off-site builders need a greater proportion of finance at the early stages of construction compared to traditional construction methods. The London Waste and Recycling Board – which supports waste reduction – could explore options for early project financing.

Summary

Building on its commitment to report scope 3 emissions, the successes of TfL and existing examples of its forward thinking practice in reducing embodied carbon, London could further its climate leadership by introducing policy drivers to cut embodied emissions in construction and lead by example within its own operations.

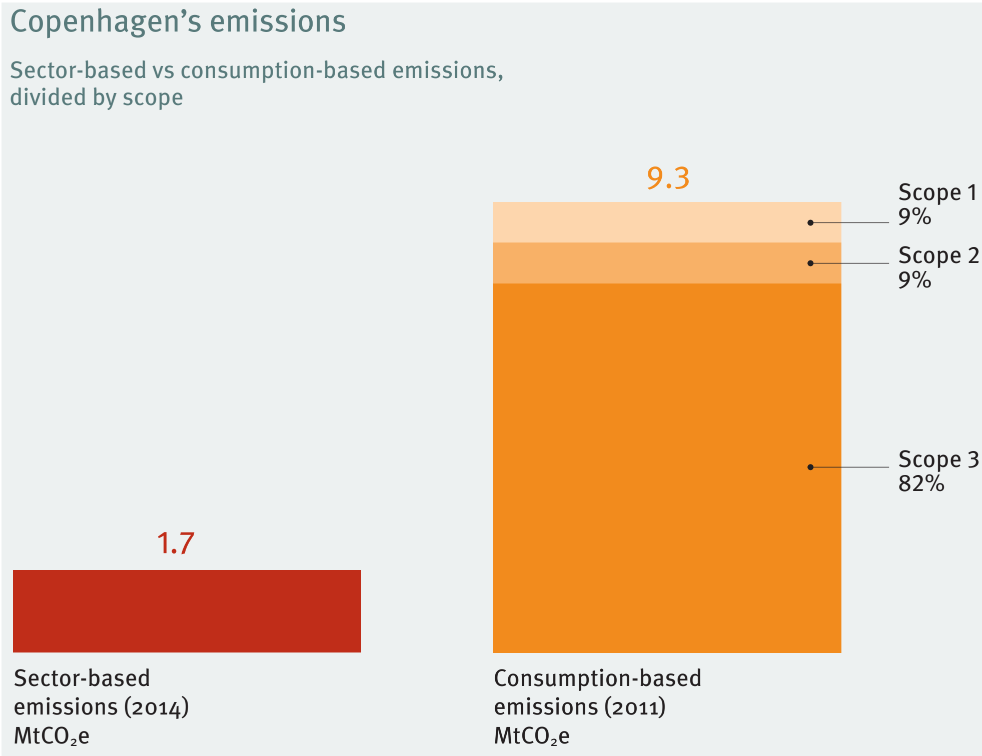
Our recommendations are summarised below.

Opportunity for action	
Consumption category	Construction
Consumption-based emissions (2011)	4.96 $MtCO_2e$
Share of London's consumption-based footprint	4.5%
Recommendations	
Push measures Support the construction sector in lowering embodied carbon	Provide financial incentives for developers opting for low carbon construction
	Support off-site construction through procurement and access to finance
Pull measures Create the demand for low carbon construction and reward leading practice	Drive demand for low carbon construction via public procurement
	Adapt existing regulation for embodied carbon saving
Potential impact	Ten to 20 per cent reductions in embodied carbon (achievable in new buildings at no additional cost), could cut emissions by 138 $ktCO_2e$ per year, equivalent to 2.9 per cent of London's overall construction consumption-based footprint. Examples of low carbon construction in London show potential embodied carbon reductions up to 50 per cent at similar cost to conventional buildings.[162]
Co-benefits	Potential reductions in scope 1 and 2 emissions and improved air quality, for instance through fewer deliveries to site, reduced need for non-road mobile machinery, improved insulation through advanced manufacturing off-site. Capital savings as a result of embodied carbon reductions in infrastructure delivery

Copenhagen

Consumption profile

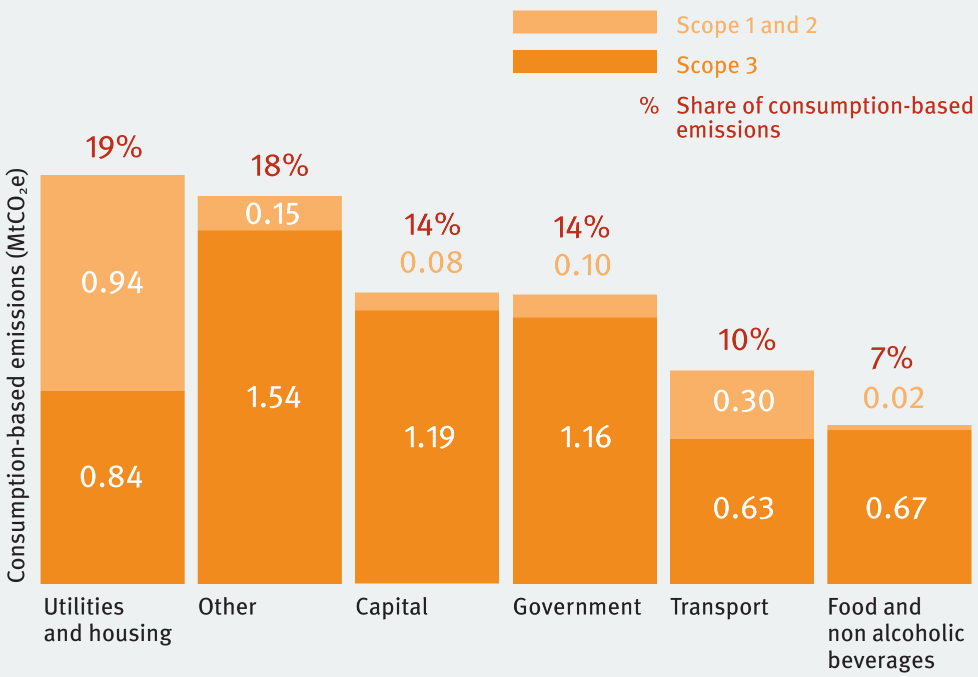
Like London and Toronto, Copenhagen is a 'consumer' city: consumption-based emissions are nearly five times its sector-based emissions, and over 80 per cent of them arise outside the city boundaries.[163]



Sectors responsible for the main consumption emissions include housing and utilities, other, capital, government, transport and food. Of these, scope 3 emissions constitute the largest proportion, except for utilities and housing.

“Copenhagen has shown strong leadership on climate action. It aims to be the first carbon neutral capital in the world by 2025.”

Copenhagen’s’s top emitting consumption sectors and their share of the city’s consumption-based footprint



Existing climate action

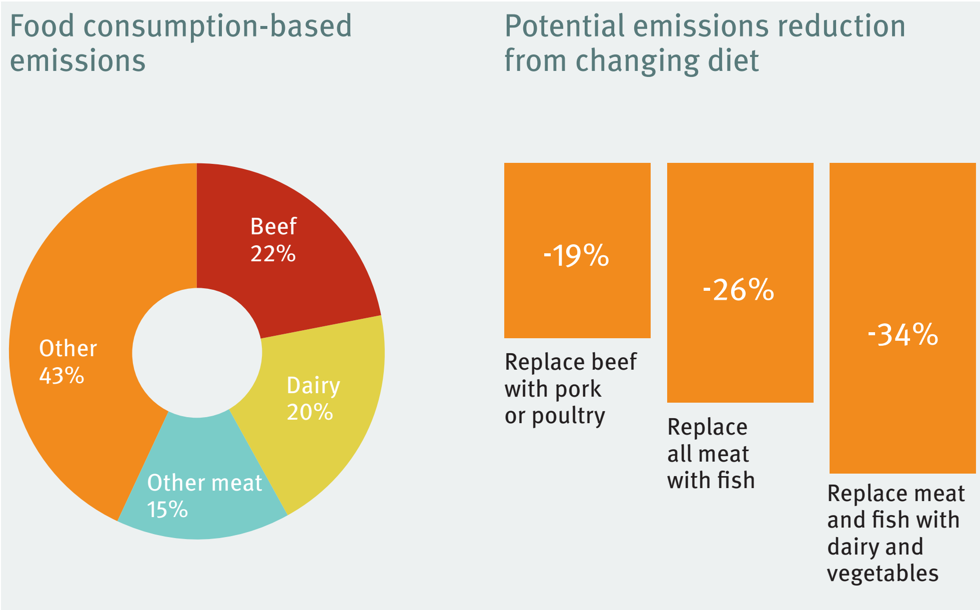
Copenhagen has shown strong leadership on climate action. It aims to be the first carbon neutral capital in the world by 2025. Among the areas addressed through its 2025 Climate Plan, there is strong emphasis on cutting transport emissions, with an ambitious target of 75 per cent of journeys to be done on foot, cycling and by public transport.[164] And, building on its extensive district heating system and wider efforts to decarbonise energy provision, the city is using its innovative, hi-tech sector to pioneer new systems for real time consumption monitoring and to inform strategic infrastructure upgrades.[165]

Here, we take a look at two areas where Copenhagen, having already committed to becoming carbon neutral, could build on the new evidence from C40 on consumption-based emissions and further its climate leadership by developing policies to reduce the carbon footprint from its top emitting sectors.

Future opportunity: from an organic food capital to a low carbon food capital

Sustainable food has a strong public following in Copenhagen. Food is also one of the largest single contributors to Copenhagen’s carbon footprint, accounting for 7.4 per cent (ie 690 $ktCO_2e$ per year) of the city’s consumption emissions, or about 3.3 $kgCO_2e$ per person per day.[166]

Beef and dairy account for more than 40 per cent of this footprint and, for a city working alone, the best strategy would be to shift away from beef towards lower carbon meat or vegetarian options. The following figures show what a shift in consumption would do to Copenhagen's per capita food footprint:[167]



What has Copenhagen done so far?

Copenhagen sees organic food as the best certification of environmental quality and animal welfare and has pursued a goal of 90 per cent organic public food since 2007. Today 88 per cent of publicly procured food is organic, more than anywhere else in Denmark.[168] To ensure carbon reduction as well as organic benefits, Copenhagen has designed its procurement policy to support a dietary shift that is primarily plant-based and reflects the Nordic seasons. In parallel it has also worked to improve food usage, for example encouraging the use of less well known cuts from animals, and to reduce food waste. Importantly, cutting food waste also contributes to reducing the footprint of food consumption, since it maximises the productive use of resources that went into producing those foods and avoids unnecessary demand for additional food.

Focusing on capacity building and education of kitchen staff, Copenhagen has also launched a programme where children get involved in the preparation of their school meals. This helps them to become familiar with a greater variety of plant-based foods and ways of preparing them, encouraging them to adopt a lower carbon lifestyle later in life.

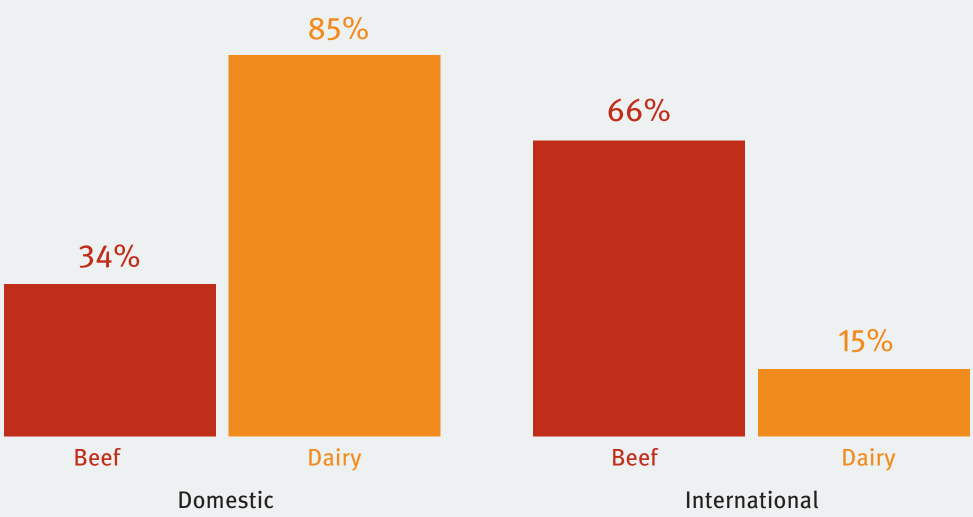
The city is also working with the EAT Foundation and the Stockholm Resilience Center on a framework to understand the Copenhagen food system and identify strategies to maximise both health and environmental outcomes.[169]

How can the city lead on cutting food related emissions further?

Analysis of the geographical origin of Copenhagen's emissions from food consumption suggests that both demand as well as supply side measures would provide opportunities for cutting greenhouse gas emissions further. Emissions from beef are largely international (two thirds arise outside Denmark), and could be addressed through efforts to promote a dietary shift within the city (or through joint action such as the transatlantic beef partnership suggested earlier in this report). The largely domestic nature of emissions from dairy consumption (nearly 80 per cent arise within Denmark) suggests there are greater opportunities for Copenhagen to decarbonise its local supply chains.

Importantly, while changing demand through procurement and engagement with the private sector could be a strategy for Copenhagen to reduce its own emissions, decarbonising its supply chains would also help to cut emissions across a wider set of cities, once again highlighting the leadership role of Copenhagen in driving climate action at a wider scale.

Origin of Copenhagen's consumption-based emissions for beef and dairy



1. Widen demand for low carbon food

Copenhagen's procurement covers almost 70,000 meals per day and has already been adapted to support a low meat diet at no extra cost. But, to engage the wider population in adopting a healthy, more plant-based diet, Copenhagen could pursue three approaches.

First, it could consolidate the city's current efforts to establish a coalition on sustainable food with public and private stakeholders, which host about 60 international congresses (and their guests) every year. These offer about 200,000 daily meals per year, and (assuming a similar carbon footprint as the city's average food consumption emissions and a similar reduction potential) emissions could be cut by 124 tCO_2 per year if beef was replaced with lower carbon meat options.[170] While this is a small reduction when compared to the overall city footprint, starting to engage the hospitality sector into adapting menus to be lower carbon could trigger a wider provision of low carbon meals across the sector, which comprises about 8.5 million guests nights per year. The partnership could also focus on reducing food waste, building on Copenhagen's success in reducing food waste in public canteens to an average of 16 g per meal (this compares to an average of about 3.5 kilo of household food waste a week, or 500 g a day).[171] To achieve this, the city could consider establishing a public-private partnership with the hospitality sector along the lines of London's FoodSave programme.[172]

Second, the city has a large number of high end Michelin star restaurants and strong leadership in food innovation. The mayor could launch a city wide challenge to develop low carbon menus that are both healthy and sustainable. This leadership could build on existing EU-funded work that the city is undertaking to support middle range restauranteurs and street food sellers in converting their production to become more sustainable.

Finally, Copenhagen could expand its Food Partnership with four other Danish municipalities, which commits them to developing action plans for a sustainable approach to food. Extending the partnership could include establishing a joint procurement for low carbon produce and developing low carbon logistics infrastructure to facilitate access to locally produced, seasonal food.

2. Support local low carbon food supply chains
Dairy is currently responsible for 20 per cent of Copenhagen's food emissions, and strategies to change meat consumption could increase dairy consumption, raising these emissions further. Because 85 per cent of these are domestic emissions, the city could focus on reducing the greenhouse gas footprint of local dairy production. The city could expand its Food Partnership to offer a joint forward commitment procurement to low carbon dairy produced in the areas around the five municipalities in the Food Partnership, building on broader collaborative efforts such as the transatlantic beef partnership, discussed on pages 27 to 30, which could fast forward the commercialisation of low carbon farming practices. Based on initial studies, an emissions reduction of 7.5 per cent, and up to as much as 40 per cent, could be achieved through selective breeding and the use of alternative feeds in cattle farming. If similar reductions were achieved in relation to Copenhagen's dairy consumption, the carbon footprint of the city's food could be cut from between one and seven per cent.[173]

Furthermore, Copenhagen could work to engage the dairy industry in reducing its emissions, building on existing efforts, such as dairy company Arla's commitment to cut its carbon footprint by 30 per cent by 2020.[174] For example, the city could advocate carbon footprinting audits to identify potential emission hotspots and benchmark carbon footprints across farms. There is evidence that on-farm energy use varies substantially, with some farms using around double the amount of electricity per cow than others. This suggests that reviewing farm activities to spot inefficient energy use could help lower the footprint and, potentially, contribute to cost savings.[175]

To make this work, the Danish government would ideally support these initiatives with R&D and EU agricultural support money, as low carbon dairy could raise the low carbon competitiveness of the Danish dairy industry, which currently accounts for 20 per cent of Danish agricultural exports, or about €1.8 billion annually.[176]

The city also has a political interest in strengthening its local food procurement as it supports local economic development. While sourcing local products does not necessarily mean cutting emissions, the city can ensure that a transition towards locally sourced food also leads to a reduction in its carbon footprint. This would require low carbon transport infrastructure, in collaboration with the Capital Region, to ensure that food deliveries do not contribute to a rise in transport emissions. For example, local logistics centres could help to minimise congestion and facilitate the implementation of larger scale, low carbon delivery into the city. Copenhagen could also liaise with Paris and learn from its experience in developing a low carbon logistics system for rail and water freight into the city. Finally, as the city establishes local food supply chains for restaurants and supermarkets, which would require adjustments in buying practices to cope with smaller scale local producers, it could start by identifying low carbon products and prioritise the take up of those.

Future opportunity: liaising with its neighbours to deliver low carbon buildings

While operational emissions from buildings are already being tackled through current policy to address sector-based emissions, Copenhagen has a growing interest in addressing embodied emissions from construction. These account for 8.6 per cent of the city's consumption-based carbon footprint, which is about a third larger than Copenhagen's road transport emissions by comparison.[177]

Ten to 20 per cent reductions in embodied carbon can be achieved at no additional cost through better design and the use of low carbon materials, including recycled or reused materials.[178] These interventions can also contribute to the city's efforts to cut scope 1 and 2 emissions. In fact, improving design to create lighter buildings reduces the need for substructure, minimising the use of concrete and associated embodied carbon, and reducing the need for excavation and heavy machinery on site (also contributing to better air quality). Similarly, lightweight structures would require fewer site deliveries, minimising congestion and transport emissions.[179]

What has Copenhagen done so far?

Copenhagen's *Sustainability in construction and civil works* 2016 guidelines include requirements for construction materials for projects commissioned or supported by the city. These go beyond existing legislation and include requirements about life cycle assessment for the City Development Department, assessment of reusable building components and materials recycling across all projects except housing renewal.[180]

Pilot projects have also started examining different options for reducing embodied carbon in construction. For example, the Realdania Foundation has supported research into how to cut embodied emissions for Danish residential construction, highlighting opportunities at different stages of a dwelling's lifetime and building local knowledge.[181]

How Copenhagen can drive reductions in embodied carbon

1. Create demand pull for low carbon buildings and infrastructure

Copenhagen is planning to expand its transport system, which is a chance to team up with London to share best practice on implementing whole life carbon assessment for infrastructure delivery and replicate the success of the Camden Station Capacity Upgrade (which has yielded a 27 per cent reduction in whole life carbon against the original project plan).[182] This would enable the city to establish the knowledge and engagement with the supply chain. It could mean minimising the embodied emissions of new development for the whole network, including Metro, S-train and bus networks.

The city could also make whole life carbon assessment mandatory via its procurement and planning policy, to ensure it becomes the norm for the private sector. For example, Sweden already requires large transport infrastructure projects, such as roads, rails and tunnels, to report their embodied carbon, and contractors can receive monetary incentives if they opt for low carbon materials.[183] Similar requirements could be introduced for local infrastructure development, highlighting how it helps to cut capital costs, as the examples of TfL and Anglian Water in London show (see page 47).

The Danish construction sector has developed a certification modelled on the guidelines for the German Sustainable Building Council system, which includes life cycle impacts and circular economy criteria for disassembly and material reuse.[184] This could be applied to housing as well as commercial buildings, where substantial emissions savings could be achieved. Copenhagen is expected to grow by nearly 110,000 inhabitants by 2025, requiring the construction of 6.8 million square metres of new city.[185] We estimate this will generate about 2.4 MtCO_2e in embodied emissions, but simple, cost neutral changes to buildings could cut this figure by ten to 20 per cent, reducing the city's construction footprint by six per cent per year.[186]

2. Engage the supply chain

Stockholm has been actively involved in addressing its embodied carbon and, given their similar climates, the same building design and material choices are likely to be transferable to Copenhagen.[187] The cities could partner to share best practice on the use of low carbon materials and construction practices. This partnership could support the Danish concrete industry in developing an action plan for carbon neutral concrete (emulating work already underway in Sweden) and engage industry in adapting the PAS 2080 certification (a British publicly available specification which is primarily about management of whole life carbon in infrastructure) to the Nordic context.[188, 189]

3. Enable a more circular construction sector

Finally, Copenhagen could extend the existing requirement for the assessment of reusable building components, currently applicable to projects commissioned by the city, to private or commercial developments.[190] To ensure this requirement can be met, the city could consider the following two sets of interventions.

It could facilitate a secondary market for the reuse of salvaged materials, by commissioning an eBay-style platform to link demolition and construction projects or by establishing an institution that can act as a broker, similar to the Scottish Material Brokerage Service.[191] Building on its pioneering work on the real time digital monitoring of energy and water consumption, Copenhagen could also start testing the use of material passports to support the reuse of construction components.[192] Material passports are already implemented by the Danish shipping company Maersk; however, although there are examples of applications in buildings, eg in the Netherlands, the use of this technology in construction is still in development.[193] Copenhagen could liaise with its cleantech cluster, CLEAN, on the development and commercialisation of novel material passport technologies to help identify components suitable for reuse, for example, by monitoring the condition of components after long term use.[194] And it could use its forward advance procurement to test some of these applications in new municipal developments.

To overcome any barriers to reuse, the city could also help the industry to identify cost effective measures for the performance testing of secondary components. A similar approach was taken by London's Olympic Delivery Authority to repurpose surplus gas pipelines as structural steel in the construction of the Olympic stadium in 2012.[195] Copenhagen could act as a broker between the construction industry and its cleantech cluster to identify and develop novel testing solutions where required.

Together, these measures could address the fact that existing material reuse is currently limited to low quality recycling of concrete waste and bricks, which saves less carbon than reuse.[196]

Summary

Already a global climate leader, Copenhagen now has the opportunity to build on its success and address the consumption-based emissions of its food and construction sectors.

Our key recommendations are summarised in the tables below.

Opportunity for action	
Consumption category	Food
Consumption-based emissions (2011)	0.7 $MtCO_2e$
Share of Copenhagen's consumption footprint	7.4%

Key recommendations	
Push measures Support the decarbonisation of local food supply chains	Support decarbonisation of domestic dairy supply chains through low carbon dairy farming
	Support local low carbon food production through procurement and low carbon logistics infrastructure
Pull measures Encourage a dietary shift towards lower meat consumption	Expand the sustainable food partnership with the hosts of Copenhagen's international congresses
	Engage the hospitality sector on the development of low carbon menus
	Expand low carbon food procurement across municipalities in the Food Partnership
Potential impact	Between 19 and 34 per cent reduction is achievable through dietary shift to low carbon meat or vegetarian diets Based on initial studies, 7.5 to 40 per cent emissions reduction is achievable through selective breeding and alternative feeds in cattle farming; if similar savings were achieved for domestic dairy, it could cut the city's overall food footprint by between one and seven per cent
Co-benefits	A plant-based, balanced diet is reported to have positive health implications[197] Decarbonisation of the domestic dairy industry could contribute to greater competitiveness through cost savings and climate leadership

Opportunity for action	
Consumption category	Construction
Consumption-based emissions (2011)	0.8 $MtCO_2e$
Share of Copenhagen's consumption footprint	8.6%
Key recommendations	
Push measures	Liaise with Stockholm and the Swedish construction sector to share best practice on low carbon materials and practice
Support the construction sector in lowering embodied carbon	Enable the circular use of construction materials through material passports and a platform to help identify opportunities for reuse
	Engage the industry in identifying cost effective measures for performance testing of materials for reuse
Pull measures	Drive demand for low carbon construction via public procurement
Create the demand for low carbon construction and reward leading practice	Extend requirements for whole life carbon assessment to infrastructure as well as new housing and commercial buildings
Potential impact	Ten to 20 per cent reduction in embodied carbon is achievable in new buildings at no additional cost. This corresponds to 51 $ktCO_2e$ yearly emissions savings for new developments, equivalent to six per cent of the city's overall construction footprint.
Co-benefits	This could lead to reductions in scope 1 and 2 emissions and improved air quality through fewer site deliveries and the reduced need for non-road mobile machinery. Capital savings from reduced embodied carbon in the delivery of infrastructure

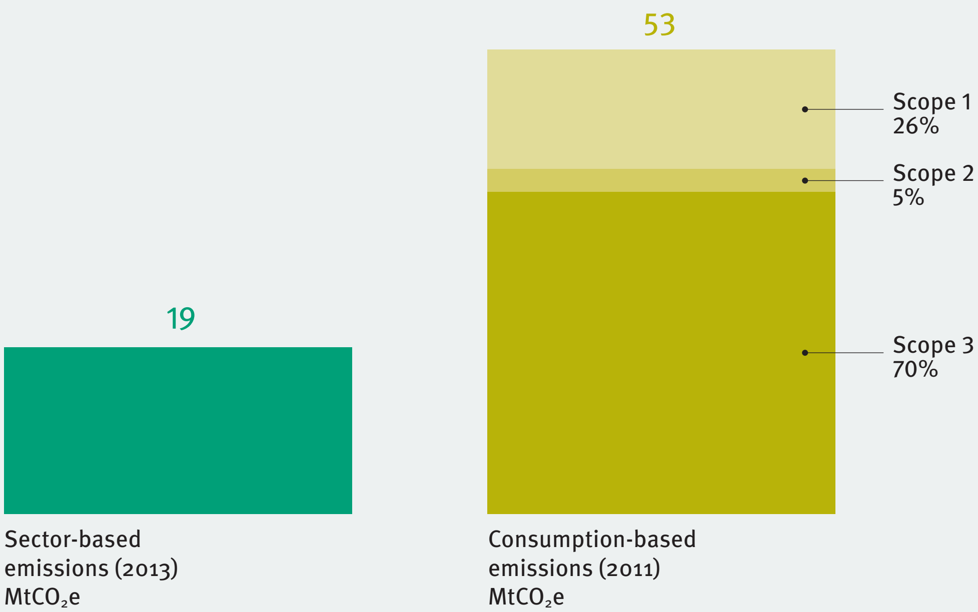
Toronto

Consumption profile

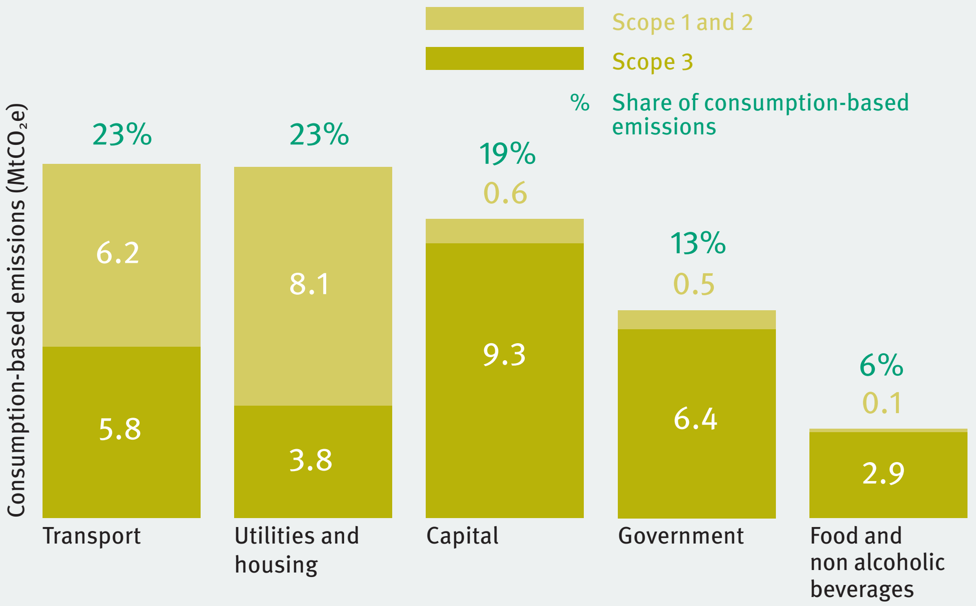
Like London and Copenhagen, Toronto is a 'consumer' city and, since about 70 per cent of its footprint is made up of scope 3 emissions, a consumption-based approach could highlight further opportunities for Toronto to drive decarbonisation outside its boundaries. Consumption-based emissions mainly arise from transport, housing, capital investment, government activities and food. Overall, these five sectors account for over 80 per cent of Toronto's consumption-based emissions footprint.[198]

Toronto's emissions

Sector-based vs consumption-based emissions, divided by scope



Toronto's top emitting consumption sectors and their share of the city's consumption-based footprint



Existing climate action

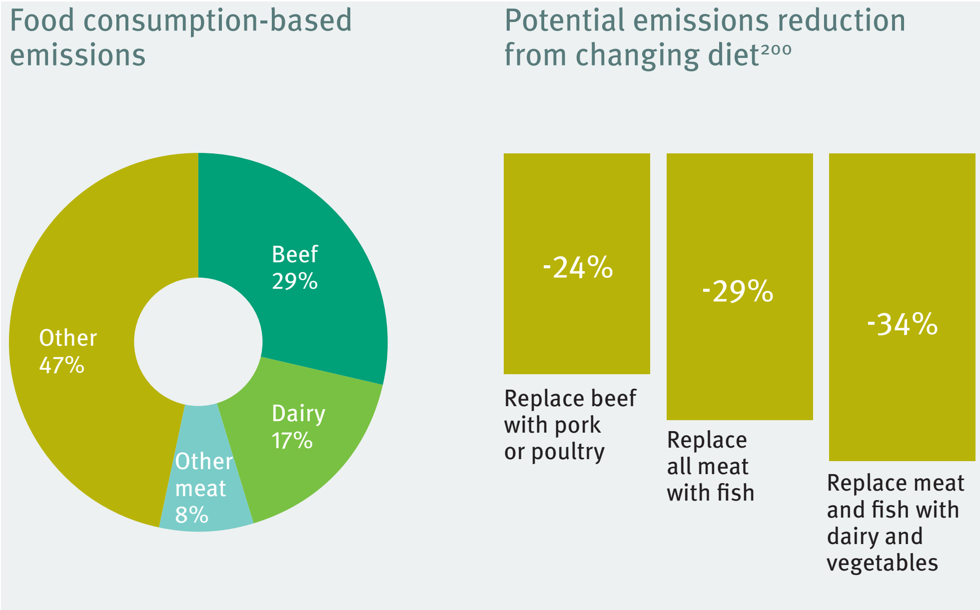
Toronto recently approved TransformTO, an ambitious climate action plan to cut its emissions by 80 per cent by 2050, with particular emphasis on expansion and electrification of the city's transport system, promoting community energy and upgrading the energy efficiency of its building stock. In developing its decarbonisation roadmap, the city has opted for a collaborative approach to maximise the benefits for its diverse communities. The preceding public consultation highlighted a desire for the city to include consumption-based emissions.

In Toronto, both food and construction are sectors associated with high consumption-based emissions. These are also sectors where Toronto has already shown leadership through its innovative retrofit financing schemes and initiatives to combat urban food deserts, ie areas that do not have access to good quality and affordable food. These are also sectors where efforts to curb consumption-based emissions could be integrated as part of a holistic strategy to cut in-boundary as well as supply chain emissions beyond the city (ie scope 3 emissions).

Future opportunity: a regional partnership on low carbon food

Food consumption is responsible for 5.8 per cent of Toronto's total consumption-based footprint. Household food consumption is responsible for 3.1 $kgCO_2e$ per person per day, with beef accounting for almost 30 per cent of food emissions.

Strategies to reduce beef consumption, or meat consumption more generally, could achieve emissions reductions between 24 and 34 per cent, depending on whether beef is replaced with lower carbon meat, whether all meat is replaced with fish or there is a shift to a vegetarian diet. To give a sense of the scale of the opportunity, if dietary changes were achieved across the whole city, emissions savings could be between 710 ktCO_2e and just over 1 MtCO_2e a year, equivalent to around two per cent of Toronto's total consumption-based footprint.[199]



What has Toronto done so far?

Toronto Public Health has published a report highlighting how a low carbon diet, high in vegetables and fruits and lower in animal products, can be of benefit to both health and climate change mitigation. Based on these findings, the Board of Health has requested that the federal ministries of Health, Agriculture and Agri-Food, and Environment and Climate Change include environmental sustainability and climate mitigation as key considerations in supporting healthy dietary patterns and across the food lifecycle.[201]

To date, work to support sustainable food systems in Toronto has been undertaken as part of its Food Strategy, which includes initiatives aimed at reducing food waste and promoting local food production.[202] It also launched the Grab Some Good initiatives. These provide underserved neighbourhoods in the city with healthy food options through a network of mobile and pop-up markets, as well as through convenience stores that offer healthier foods.[203]

How can Toronto cut food related emissions?

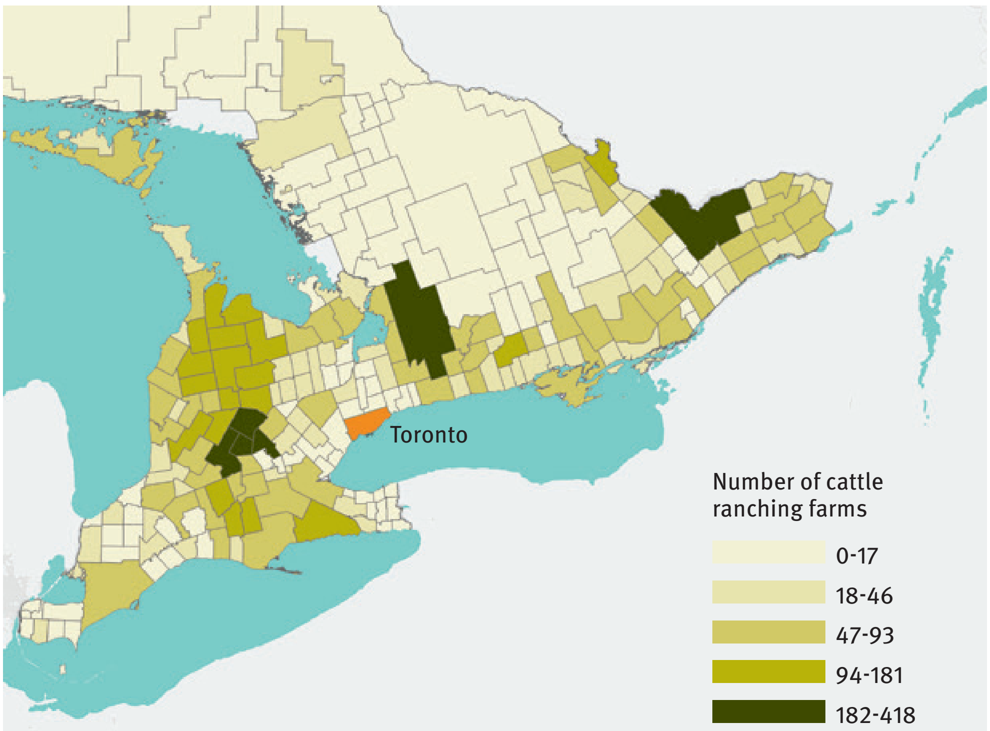
With beef responsible for nearly 30 per cent of food emissions, strategies to cut Toronto's footprint could focus on two approaches. One, seeking to decarbonise local supply chains, particularly for beef. The other, supporting the dietary shift to lower meat consumption through engagement with city and regional public and private stakeholders.

1. Make local foods low carbon

Toronto's local food procurement policy is focused on local economic development and expanding the agri-food sector in Ontario. Because locally sourced food is not necessarily low carbon, Toronto could prioritise support and the uptake of low carbon local products. To do this, Toronto could learn from Copenhagen's Food Partnership and link up with other municipalities in Ontario, 17 of which already have an existing food policy, to jointly procure low carbon food that strengthens local food supply chains.[204] The partnership could go beyond procurement and identify infrastructure needs, like low carbon food consolidation centres and transport infrastructure, and provide a standardised approach to the identification and tracking of low carbon produce.[205] Toronto and Copenhagen, which is also seeking to strengthen local food supply chains, could join up with Paris to identify and share strategies for low carbon logistics within their cities and neighbouring regions.

Toronto also has a major opportunity to influence the beef supply chain. Ontario and Alberta already participate in a Genome Canada project to selectively breed low carbon cattle.[206] Toronto could support the project through advanced commitment procurement to reward those farmers that opt for low emitting breeds. Since the majority of Ontario's beef and dairy production occurs in Kawartha Lakes, Perth and Waterloo counties, all within 150 km of Toronto, a food partnership approach with neighbouring municipalities could be highly effective.[207] About half the beef consumed in Ontario is produced in the province.[208] Measures to decarbonise the supply chain such as selective breeding (as discussed on page 29), could potentially reduce Toronto's annual food emissions by up to about 80 ktCO_2e, cutting the city's overall food emissions footprint by nearly 2.6 per cent.[209]

Cattle ranching around Toronto[210]



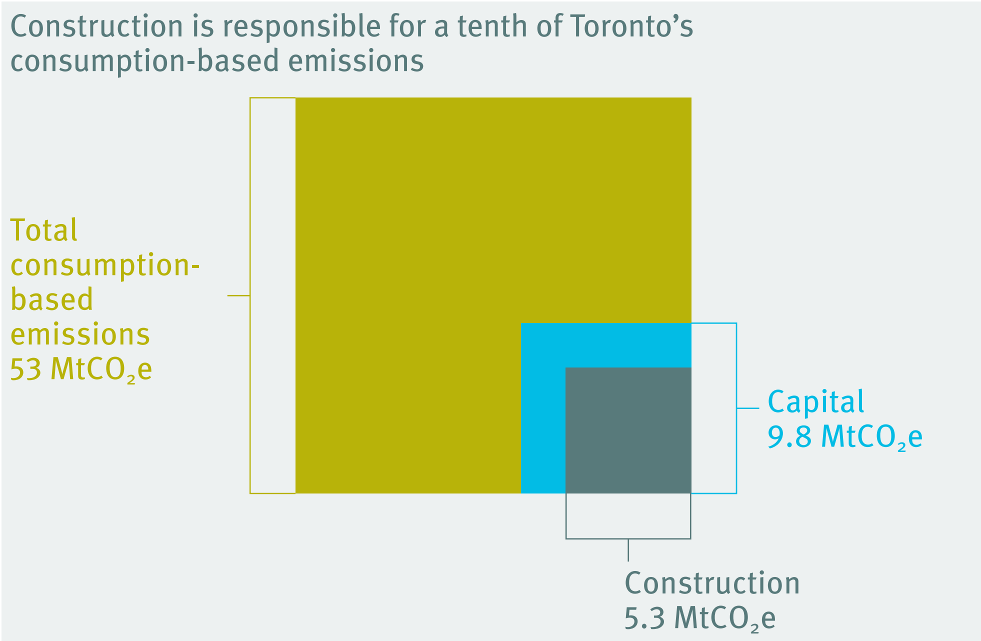
2. Broaden uptake of sustainable diets and reduce food waste
While the city's direct food purchasing power is relatively low, estimated to account for 1.2 per cent of overall city food purchasing, it could lead by example by adopting low carbon food procurement practices within its own municipal institutions. Furthermore there are opportunities to widen demand for low carbon foods by engaging with a wider set of stakeholders.[211] For example, it could engage the province to encourage low carbon food procurement across a wider spectrum of institutions, building on the recommendations put forward by Toronto Public Health, and use its strategic food partnership with other Ontario municipalities (as suggested on page 66) to strengthen low carbon public procurement.

The city could liaise with the private sector to promote the buying of low carbon foods. For example, it could encourage more businesses and restaurants to commit to buying a greater share of plant-based products as a way to improve their corporate reputation by supporting more sustainable diets. Building on the work of Menus for Change, the US initiative that brought together academics and the food hospitality sector to develop tasty, healthy menu options with a reduced environmental footprint, the city could establish a scheme to support private sector caterers in developing nutritious, low carbon menus.[212]

Finally, via its existing food strategy, the city could support low carbon diets and lower food waste, which also contributes to its consumption-based footprint, across the wider population. In partnership with other municipalities in Ontario, it could support the EcoSchools network to develop a programme on sustainable diets. It could also learn from Copenhagen, where children are involved in preparing meals in school canteens and learn about sustainable food, plant-based meals and how to reduce food waste. This aims to help them take lower carbon lifestyle decisions later in life. Through this programme, Copenhagen has reduced waste in school canteens to about 16 g per meal, compared with the average 500 to 750 g wasted per person a day in Canada. Emulating this success would not only contribute to reducing its carbon footprint, but would also cut costs for Toronto's households which, on average, waste $1,456 worth of food per year.[213,214]

Future opportunity: establishing the foundations for low carbon construction

Toronto has already outlined a set of measures to cut operational emissions from its building stock as part of TransformTO. However, construction is also associated with a large share of embodied emissions, responsible for 10.1 per cent of its total consumption-based footprint.



What has Toronto done so far?

There are no mandatory policies addressing embodied carbon in Canada, and action has so far been limited to voluntary initiatives such as the LEED Building and Design standard, which includes life cycle assessment optimisation, and the Canada Green Building Council's Zero Carbon Building Standard (currently in development) which includes a requirement for reporting embodied carbon.[215]

The Toronto Green Standard currently defines a Tier 2 performance measure which developers can voluntarily meet on the basis of higher environmental performance.[216] While the Tier 2 includes optional parameters to encourage reuse of building structures, materials recycling and sourcing of regional materials, there is no explicit reference to embodied carbon in construction operations.

There have been efforts recently to develop the evidence basis for addressing the carbon footprint of construction operations. For example, The Atmospheric Fund has supported a project to identify the embodied carbon of different construction materials to help inform lower carbon material selection across YMCA developments at the design stage.

What could Toronto do next?

1. Engage the industry to develop a knowledge base and tools

Because the local construction sector is largely unfamiliar with embodied carbon management, Toronto could begin by working with nearby municipalities to gather data for an Ontario-specific database for low carbon construction materials. Current carbon footprint data relies on Canada-wide averages and differences in material production processes and grid carbon intensity across provinces are likely to result in widely differing values.

Alongside gathering data on materials, Toronto could build on the UK's Royal Institute of Chartered Surveyors' (RICS) work to standardise embodied carbon assessment in the built environment. RICS is currently seeking to adapt its UK focused methodology to the North American context. Toronto could support this work by sponsoring a collaborative group to adapt the UK methodology.[217] It could work jointly with the Carbon Leadership Forum, which already has a network of North American industry experts on embodied carbon and could help speed up the process.[218]

Finally, as part of TransformTO, Toronto is evaluating skills gaps and training opportunities for high performance building construction. Research could include embodied carbon assessment and management skills. This would address the wide disparity in understanding across the industry. In the UK, for example, the water industry has been looking at embodied carbon in detail for years, while the telecommunications sector has hardly considered it. While regulation will inevitably play a role in the uptake of embodied carbon management practices, developing the knowledge base in the industry through a cross sector strategy could increase uptake and help to improve the competitiveness of the city's low carbon construction industry, even in the absence of policy drivers.

2. Create demand for low carbon buildings

Toronto could drive whole life carbon management in the construction industry by setting assessment requirements and reduction targets for its own operations.

There is a substantial pipeline of construction and infrastructure projects for the coming years, including the expansion of the subway and light rail networks, which could provide valuable opportunities to implement a carbon management approach in the city's infrastructure delivery.[219] For these projects, Toronto could liaise with Transport for London (TfL) in the UK specifically to share best practice on carbon management and engagement with the supply chain.

Alternatively, it could collaborate with the provincial government, since it is planning to identify potential infrastructure projects for life cycle assessment. These will act as a testbed for the development of tools and guidelines that Ontario is proposing as part of its long term infrastructure plan.[220] As reported by TfL, whole life carbon assessment and reduction applied to infrastructure delivery could also contribute to reductions in scope 1 and 2 emissions. For example, it may reduce the need for excavation and heavy machinery on site, as well as require fewer site deliveries, reducing air pollution and minimising congestion and scope 1 transport emissions.[221] Whole life carbon savings in infrastructure delivery also lead to capital savings.[222]

Finally, Toronto should consider using lower carbon concrete which can cut embodied carbon by about ten per cent without affecting costs or performance.[223] It could update its procurement policy to require that all concrete used is low carbon. If all new developments in Toronto used this, the city could cut yearly embodied emissions by 91 $ktCO_2e$ – about 1.7 per cent of the city's annual overall construction embodied carbon footprint – at no additional cost.[224]

3. Retain carbon stock in existing buildings
There is huge potential for retaining embodied carbon in the existing building stock through the refurbishment and reuse of materials, especially in high rise buildings, commercial spaces and larger infrastructure assets. It is possible to cut between 17 and 56 per cent of a building's embodied carbon through reuse.[225] Building on recommendations outlined in the TOCore plan for downtown Toronto, which proposes to "limit the loss of embodied energy contained within the existing building stock", Toronto could require developers to consider refurbishment as an alternative to demolition in a project's whole life carbon assessment.[226] And it could require projects involving demolition to undergo a pre-demolition assessment to enhance high value recycling and reuse of construction materials.[227] In identifying opportunities to extend the lifetime of the current building stock, the city could engage its neighbourhoods in identifying options for repurposing existing buildings for the benefit of local communities.

Finally, the city could pilot the use of sensors and digital technologies for predictive maintenance of existing and new buildings and infrastructure. This would enable the early detection of structural issues and support timely interventions to address them, helping to extend the lifetime of new and existing infrastructure. Examples of such applications are already being piloted for bridges, roads and other key infrastructure.[228] To test deployment of these emerging technologies, the city could broker an innovation partnership between researchers at the University of Toronto, who are already working on structural health monitoring, and stakeholders from the construction industry.[229]

Summary

Toronto has the opportunity to engage a range of actors in the city and neighbouring regions to tackle emissions arising from food consumption and embodied emissions from construction.

Key recommendations are summarised in the tables below:

Opportunity for action	
Consumption category	Food
Consumption-based emissions (2011)	3.1 $MtCO_2e$
Share of Toronto's consumption-based footprint	5.8%
Key recommendations	
Push measures Support decarbonisation of local supply chains	Establish a food partnership with neighbouring municipalities to support low carbon local food supply chains through procurement and logistics infrastructure
	Support ongoing research into the selective breeding of low carbon cattle through advanced forward procurement
Pull measures	Engage the Province to encourage low carbon food procurement across its institutions
Encourage a dietary shift towards lower meat consumption	Engage and support the private sector on developing low carbon menus
	Work with the EcoSchools network to develop a school programme on sustainable diets
Potential impact	Between 24 and 34 per cent (per capita) emissions reduction is achievable through dietary shifts to lower carbon meat or vegetarian diets Based on initial findings, selective breeding could potentially cut beef emissions by up to about 80 $ktCO_2e$, equivalent to 2.6 per cent of the city's overall food footprint
Co-benefits	A plant-based, balanced diet has positive health implications[230] Decarbonisation of the domestic beef industry could contribute to greater competitiveness through climate leadership

Opportunity for action	
Consumption category	Construction
Consumption-based emissions (2011)	5.3 $MtCO_2e$
Share of Toronto's consumption -based footprint	10.1%
Key recommendations	
Push measures Support the construction sector in lowering embodied carbon	Work with Ontario municipalities to establish a low carbon materials database
	Collaborate with construction industry bodies on a standardised embodied carbon assessment methodology
	Broker a collaboration between industry and academia for the predictive maintenance of buildings
Pull measures Create demand for low carbon construction and reward leading practice	Collaborate with the province to pilot whole life carbon assessment for the city's infrastructure delivery
	Adapt existing procurement policy to require all concrete used to be low carbon
	Update planning policy to require developers to consider refurbishment as an alternative to demolition
Potential impact	Ten to 20 per cent reductions in embodied carbon are achievable in new buildings at no additional cost. The use of low carbon concrete in new developments could save 91 $ktCO_2e$ per year, equivalent to 1.7 per cent of Toronto's overall construction footprint. Reuse and refurbishment can cut between 17 and 56 per cent of a building's embodied carbon.
Co-benefits	Potential reductions in scope 1 and 2 emissions and improved air quality, for instance through fewer deliveries to site, and the reduced need for non-road mobile machinery Capital savings as a result of reductions in embodied carbon in infrastructure

Conclusion

Cities can be major players in addressing consumption-based emissions. The combined consumption footprint of C40 cities alone makes them the fourth largest global emitter, after the combined nations of the European Union. By addressing the consumption-based emissions which arise outside their borders, alongside their sector-based emissions, cities can extend their climate mitigation action by up to twice as much.

Over 80 per cent of emissions are associated with cities able to exercise a high degree of influence over them. To succeed in cutting emissions along global supply chains, however, cities will have to join forces and use their power, as consumers and as economic centres, to drive the development and use of low carbon products and processes. The examples we have given in this report show just some of the opportunities available for joint action.

Methodology

Assessing consumption-based emissions

Information on the methodology used to assess city consumption-based emissions is detailed in the report, *Consumption-based GHG emissions of C40 cities* (C40, 2018).

Note that the results of the study are presented at the global and regional level to illustrate how consumption-based GHG emissions compare to sector-based GHG inventories, and which sectors most consumption-based GHG emissions can be attributed to. Data is not provided at a city level as the purpose here is not to focus on individual city emission profiles. Due to the many assumptions made in the methodology, the results provide an indicative approximation of the GHG emissions associated with C40 cities' consumption activities.

Sectors included in C40's analysis of consumption-based emissions are:

Food and non-alcoholic beverages
Alcoholic beverages and tobacco
Clothing and footwear
Housing, water, electricity, gas and other fuels
Furnishings, household equipment and routine household maintenance
Health
Transport
Communication
Recreation and culture
Education
Restaurants and hotels
Miscellaneous goods and services
Government
Capital
Other
Residential housing
Residential transport

Within each sector, consumption-based emissions were further disaggregated based on the categories listed under the Global Trade Analysis Project (GTAP). These are 57 consumption categories, which comprise a number of manufacturing and consumer products. (For more details, see C40's report, *Consumption-based GHG emissions of C40 cities*.)

Assessing city powers

City powers discussed in this study are based on C40's data, an overview of which is provided in the report *C40 Cities: The power to act* (C40, 2014). Examples of the types of powers under each category are listed in the table below.

Power	Examples of city powers
Private buildings	Sets and enforces policy for existing and new commercial, industrial and residential buildings
Public buildings	Owns or operates municipal offices and municipally-owned housing, controls budget for existing and new municipal buildings
Energy supply	Owns or operates district heating infrastructure, sets policies for distributed power generation
Finance and economy	Able to set business tax, sales or VAT tax, property or municipal tax, can influence policy on economic development
Food and agriculture	Owns or operates commercial urban food production, can influence operation of farmers markets
ICT	Owns or operates (wireless) internet communications infrastructure
Other transport	Owns or operates ports or airports
City roads	Owns or operates city roads, on-street car parking, bus stops
Public transport	Owns or operates a municipal fleet, can influence policies for underground and other intra-city rail systems
Private transport	Sets and enforces policy for private vehicles
Urban land use	Sets and enforces policies on land use planning, can influence area redevelopment or regeneration, sets policies on air quality management
Waste	Owns or operates waste processing facilities, sets and enforces policies for residential waste collection
Water	Owns or operates water supply and distribution, and wastewater treatment infrastructure

Powers that cities can use to reduce 'scope 3' consumption-based emissions (see explanation on page 11) were assessed based on: a high level mapping of possible interventions to cut scope 3 emissions for each consumption sector, followed by identification of the powers that could be used to support those interventions. For example, scope 3 emissions in construction (measured as part of the consumption sector 'capital') can be reduced through better design and low carbon materials. Cities with powers over public or private buildings could use regulation and procurement to require developers to cut their embodied emissions from construction. Note that powers considered in this analysis are limited to those assessed by C40. Cities may have other relevant powers for tackling consumption-based emissions.

Assessment of relevant city powers was conducted only for the consumption sectors that, based on their scope 3 consumption-based emissions, are in the top five emitting sectors of at least one C40 city, since those are more likely to be prioritised.

Each city's overall power (detailed on page 12) was assessed based on C40's analysis, in which every power was given a weighted score depending on ownership, ability to set and enforce policies, control budgets and set the vision for particular areas (see *C40 Cities: The power to act* (C40, 2014)).

A city's overall power to address its main sources of its scope 3 consumption-based emissions was calculated as follows: for each city, the five highest emitting consumption sectors (considering only the share of scope 3 emissions) were identified; the city's power to cut scope 3 emissions for a given sector was calculated as the average of weighted power scores for those powers that can be used to address scope 3 emissions (as detailed on page 11); based on the average weighted score of powers for each of the top five sectors, the city's overall power was calculated as the average of powers across five consumption sectors.

Finally, overall powers scores were segmented as 'limited', 'partial' or 'strong', based on C40's methodology.

Note:
This analysis is an overview of the strength of C40 cities' powers at an aggregate level. Identification of specific opportunities for action and the effectiveness of a given set of powers to cut consumption-based emissions in a specific city should be assessed at the city level.

The coverage of powers to tackle consumption-based emissions detailed on page 12 does not add up to 100 per cent since data was not available for all cities for which emissions were reported.

Cluster analysis

Cities were clustered using two main approaches.

1 The first approach considers all types of consumption-based emissions (ie including scope 1 and 2), but includes only sectors in the top five emitting sectors for at least one C40 city. This is to be able to cluster based on the larger share of emissions, ie the most relevant sectors for each city). These include all sectors listed in on page 74, except for 'Alcoholic beverages and tobacco', 'Health', 'Communication', 'Education'. This approach was used to identify the high level clusters presented in on page 18.

2 The second approach focuses on specific sectors, products (ie GTAP consumption categories) and the origin of emissions, and was used as the basis for the examples discussed on pages 21 to 38. In this case clustering was done using the following approach: looking at one sector at a time and considering only the product categories responsible for the top 80 per cent consumption-based emissions for that sector (across all 79 C40 cities), cities are clustered

based on the main sources of emissions; then considering the origin of those emissions, ie whether generated domestically or imported, to identify opportunities for collaboration at national or international level.

For each sector, clustering was only conducted for those cities for which that sector is amongst their top five scope 3 emitting sectors. This enables to group cities based on the sectors and products they are likely to prioritise in addressing consumption-based emissions.

Clustering was done using 'k-means' clustering. Clustering was done using the share of each sector's emissions relative to the city's overall consumption-based footprint (ie if a city has ten $MtCO_2e$ arising from food consumption and its total consumption-based emissions are 100 $MtCO_2e$, clustering was done using the percentage emissions associated with food, ie ten per cent). Similarly, clustering based on individual sectors (ie using the second approach described above) was done using the share of emissions for each product (ie GTAP consumption category) relative to the total consumption-based emissions for that sector.

Using the relative composition of cities' consumption based emissions allows them to be clustered regardless of the absolute magnitude of their emissions, allowing the identification of priority sectors across cities of different size and wealth.

Note:
Emissions were clustered without data normalisation. This allows clustering based on larger variations in relative emissions within specific sectors or products, aiding the identification of common emissions hotspots across cities.

Assessing the reduction of beef emissions for the transatlantic beef partnership

Total emissions reductions estimated for the 18 C40 cities within a proposed transatlantic beef partnership (see pages 27 to 30) are based on three interventions.

1 A reduction in beef consumption by 20 per cent across the 18 cities. This is based on previous estimates of beef consumption reduction potentials, as suggested under the 'Ambitious beef reduction scenario' (described in J Ranganathan et al), 'Shifting diets for a sustainable food future' (World Resources Institute, 2016, p46), for countries where beef is consumed above the world average of protein and calorific intake, for which the lower estimated reduction in beef is 20 per cent; this is also in line with the procurement target of Paris, ie 20 per cent reduction in meat products (*Sustainable Food Plan 2015-2020*, (Maire de Paris, 2015)). Emissions cut across 18 cities: 9.9 $MtCO_2e$.

2 A replacement of half of the ground beef sold (assumed to constitute 40 per cent of all remaining sold beef, based on: 'Fact sheets: Breeding beef', (France AgriMer, 2015)) by plant based meat alternatives. These are assumed to cut emissions by 87 per cent compared to beef, as reported for Impossible Burgers, see www.impossiblefoods.com/burger/. Potential emissions cut across 18 cities: 6.9 $MtCO_2e$.

3 Decarbonisation of cattle farming, thanks to the commercialisation of novel feeds and selective breeding, achieving emissions reductions comparable to those so far reported in preliminary studies (80 per cent and 36 per cent reduction in enteric fermentation emissions from novel feeds and selective breeding, respectively).[231] We have assumed that selective breeding and seaweed based feeds are applied in combination to all cattle (except for the fraction of beef in EU cities assumed not to be imported from Latin America, ie 50 per cent of imports, based on EU average import data: 'Beef and veal market situation'(European Commission, 2018)). Their combined implementation cuts emissions from beef consumption by a further 13.9 $MtCO_2e$.

Note:
We assume that innovation in selective breeding and seaweed based feeds allows for these practices for both grain-fed and grass-fed farming. Emissions from enteric fermentation are assumed to contribute to 50 per cent of beef's overall greenhouse gas (GHG) footprint.[232]

Our analysis is based on the average emissions footprint of cattle farming, which we understand does not reflect the variation in footprint for different farming practices.

Copenhagen and Toronto: assessing the emissions reduction from changing diet

Emissions reduction from dietary shift were estimated as follows: grammes of beef, other meat products, fish, dairy products and beans were estimated based on the city's food consumption-based emissions (according to GTAP categories) assuming the following GHG footprint: 28 gCO_2e/g of beef, 5.4 gCO_2e/g of other meat (taken as the average footprint of pork and poultry), 3.5 gCO_2e/g of fish, 1.8 gCO_2e/g of dairy (assuming a ratio of milk to cheese consumption of 11:1) and 1.3 gCO_2e/g of beans.[233]

Emissions reduction for each alternative dietary change were based on replacing grammes of beef, meat or fish currently consumed (as estimated above) with the same amount (in grammes) of the alternative food, as described under the three scenarios in the graphics on pages 54 and 65.

The scenario for which all meat and fish are avoided assumes they are replaced with 50 per cent dairy and 50 per cent plant-based proteins (assumed to be beans) by weight. Overall emissions reduction reported in the graphics on pages 54 and 65 are calculated based on the per capita GHG footprint of the alternative diet, as opposed to the current per capita consumption-based footprint for food.

Note:
This analysis has not assessed potential changes in calorific and nutrient intake of the different dietary options.

Endnotes

[1] World Bank, 2017, *Urban development overview*; UNEP, 2018, *Resource efficiency as key Issue in the new urban agenda*

[2] A Stephan et al, 30 November 2016, 'Our cities need to go on a resource diet', *The Conversation*

[3] *The Guardian*, 6 January 2015, 'Five reasons why local government should influence climate change plans'

[4] J Barrett et al, 2013, 'Consumption-based GHG emission accounting: a UK case study', Climate policy, 13, pp 451-470; *Carbon Brief*, 5 July 2017, 'Mapped: The world's largest CO_2 importers and exporters'

[5] World Bank, *Total greenhouse gas emissions data* (reference year 2011)

[6] World Resources Institute, 11 April 2017, 'This interactive chart explains world's top 10 emitters, and how they've changed'; country data refers to territorial emissions; India's emissions for 2013 are reported to be 2.9 $GtCO_2e$ (note that these refer to 'territorial emissions', rather than consumption-based emissions).

[7] Ibid; data for C40 cities is based on C40, 2017, *C40 cities consumption-based emissions data, 2011*

[8] C40, 2018, *Consumption-based GHG emissions of C40 cities*

[9] Ibid

[10] Consumption-based emissions not currently included in sector-based emissions assessment are 2.2 $GtCO_2e$, which is the same amount of emissions that are currently estimated using a sector-based approach (ie 2.2 $GtCO_2e$). Note that, in combining consumption-based emissions with sector-based emissions to estimate the overall potential for climate action across the entire set of 79 cities, there might be a small share of emissions arising from trade between cities that are double counted. These are, however, estimated to be a small proportion, given that most trade between cities is related to services, which generally have a small GHG footprint. Furthermore, it should be noted that different reference years are used in this work, 2011 for consumption-based emissions and various years between 2011 and 2015 for sector-based emissions. Therefore, the comparison should be considered as an indicative estimate for the overall potential for climate action. For more information, see C40, 2018, *Consumption-based GHG emissions of C40 cities*

[11] For an overview of the consumption-based data used in this report, see C40, 2018, op cit

[12] This data is robust but limited. Future work to provide more detailed analysis of individual city consumption patterns, including the specific origins of international emissions and where these emissions arise across the life cycle of different products, will be critical to developing a comprehensive set of targeted policies to address all consumption emissions. C40, 2017, *C40 cities consumption-based emissions data, 2011*

[13] C40, 2014, *C40 cities: the power to act*

[14] Power categories are based on C40 data and cover only those geographical areas within direct control of C40 cities. See methodology (page X) for an outline of the types of powers considered under each category and analysis of city powers. Note: the table only lists sectors that are amongst the top five (scope 3) consumption-based emitting sectors for at least one of the C40 cities (therefore, percentages in the bar chart do not add up to 100).

[15] These powers were estimated based on C40's data. See methodology section for analysis of the strength of city powers.

[16] Note that per cent values do not add up to 100 since powers data is not available for all cities for which consumption-based emissions were assessed. See methodology section for analysis of the strength of city powers.

[17] www.lwarb.gov.uk

[18] LSE Cities, 2012, *Going green: how cities are leading the next economy*

[19] TAF, 2018, *2017 Business plan approach: embracing a regional approach*, p 20; Government of Canada, 2017, 'Greenhouse gas emissions by Canadian economic sector', accessed on 20 September 2018; emissions for Canada's oil and gas sector in 2015 are 190$MtCO_2e$

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[21] Transform TO, 2017, *2050 pathway to a low-Carbon Toronto: Report 2: highlights of the city of Toronto staff report*

[22] Green Alliance, 2015, *Circular economy Scotland*

[23] *Huffington Post*, 21 September 2016, 'Cities offer a great platform to bring about change'

[24] CIWMB, 2003, cited in Worrel et al, 2016, *The role of material efficiency in environmental stewardship, annual review of environment and resources*, p 590

[25] Personal communication with Örjan Lönngren, Policy analyst energy and climate, City of Stockholm.

[26] Maire de Paris, 2015, *Sustainable Food Plan 2015-2020*

[27] GLCN, Oslo & SPP, www.glcn-on-sp.org/cities/oslo/, accessed on 30 July 2018; BuyZET, www.buyzet.eu, accessed on 30 July 2018

[28] *The Independent*, 26 April 2016, 'Denmark ethics council calls for tax on red meat to fight 'ethical problem' of climate change'; Futures Centre, 9 March 2016, 'Signals of change: Sweden considers meat tax to encourage sustainable diets'

[29] LSE Cities, 2012, op cit

[30] The Danish National Travel Survey, 2015, *Fact sheet about cycling in Denmark*

[31] LSE Cities, 2012, op cit

[32] *The Independent*, 29 September 2017, 'Sadiq Khan seeks to ban wood-burning stoves in bid to tackle pollution'

[33] Consumption-based emissions data used in this analysis is taken from: C40, 2017, *C40 cities consumption emissions data, 2011*

[34] See methodology section for analysis of city clusters. Note that this clustering serves as an example of how the data can be analysed, but there are other ways in which data on city emissions could be clustered.

[35] OECD, 2016, *The role of public procurement in low-carbon innovation*; C40, 21 December 2015, 'Cities continue to show commitment to low emission bus fleets by signing onto the C40 Clean Bus Declaration'

[36] LSE Cities, 'Resource urbanism', www.lsecities.net/objects/research-projects/resource-urbanisms; and 'Cities and energy', www.lsecities.net/publications/reports/cities-and-energy-urban-morphology-and-heat-energy-demand/, both accessed on 15 July 2018

[37] C40, 11 July 2017, 'How sustainable neighbourhoods are the building blocks of green, climate-safe cities'; LSE Cities, 2012, op cit

[38] C40, 14 September 2017, 'Cities100: Copenhagen – Mapping real-time consumption to plan efficiency updates'

[39] *ITI Manufacturing*, 23 November 2015, 'The 5 largest cities In China For manufacturing'

[40] McKinsey & Co, 2009, *China's green revolution*; emissions reductions may be achieved through eg process automation, improved efficiency of blast furnace gas use or substitution of blast furnace steel (from iron ore) with recycled steel produced in electric arc furnaces.

[41] HM Treasury, 2013, *Infrastructure carbon review*

[42] N Stern et al, 2017, 'China's leadership on sustainable infrastructure: lessons for the world', *Grantham Research Institute Policy Brief*

[43] Overview of the Indian Auto Industry, www.knowindia.net/auto.html, accessed on 20 July 2018, the number of registered cars in 2016 for Jaipur, Kolkata and Bengaluru is, respectively, 0.33, 0.33 and 1.19 million; EPA, 'Greenhouse gas equivalencies calculator', www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (9.2 $MtCO_2e$)

[44] N Arunrat and A Pumijumnong, 2017, 'Practices for reducing greenhouse gas emissions from rice production in northeast Thailand', *MDPI Agriculture*, 7, 4

[45] P Smith et al, 2014, 'Agriculture, forestry and other land use (AFOLU)' in *Climate change 2014: mitigation of climate change*, contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, p 824; emissions from paddy rice cultivation were 0.52 $GtCO_2e$ in 2010, compared to total anthropogenic GHG emissions of 49 $GtCO_2e$ in the same year (based on IPCC, 2014: Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, p7)

[46] T Adhya, et al, 2014, 'Wetting and drying: reducing greenhouse gas emissions and saving water from rice production', *World resources Institute working paper*; A Garthorne-Hardy, 2013, *Greenhouse gas emissions from rice – working paper*

[47] J Choi et al, 2014, 'Effect of SRI water management on water quality and greenhouse gas emissions in Korea', *Irrigation and drainage*, 63, 2

[48] T Adhya et al, 2014, op cit

[49] *World Resources Institute blog*, 16 December 2014, 'More rice, less methane'

[50] J SU et al, 2015, 'Expression of barley SUSIBA2 transcription factor yields high-starch low-methane rice', *Nature*, 523, pp602-606

[51] E Hasan, 2013, 'Proposing mitigation strategies for reducing the impact of rice cultivation on climate change in Egypt', *Water Science*, 27, pp69-77; N Gogoi, KK Baruah and P K Gupta, 2008, 'Selection of rice genotypes for lower methane emission', *Agronomy for sustainable development*, 28, pp 181-186

[52] *The Economic Times*, 2017, 'How stubble burning in Haryana & Punjab is the biggest culprit for poor air quality in Delhi'; *New York Times*, 2016, 'Farmers' Unchecked Crop Burning Fuels India's Air Pollution'; S Tripathi, R N Singh and S Sharma, 2013, 'Emissions from crop/biomass residue burning risk to atmospheric quality', *International research journal of earth sciences*, 1 (1) pp 24-30

[53] *Financial Times*, 2017, 'Smog-choked Delhi pushes farmers to stop burning straw'; Down to Earth, 2 June 2017, 'India's burning issue of crop burning takes a new turn'

[54] Emissions reduction potentials are calculated with respect to the overall GHG footprint of rice production, for which methane emissions from cultivation account for 81 per cent and stubble burning for 3.7 per cent of the overall footprint (based on N Arunrat and A Pumijumnong, 2017, op cit). Emissions reduction from water management is reported as the average of reduction values referenced in this report. Emissions reduction for low methane rice refers to reductions achievable based on findings from short duration rice varieties. Emissions reduction potential for straw-mushroom cultivation vs stubble burning is taken from Arai et al, 2015, cited in R R Romasanta, 2017, 'How does burning of rice straw affect CH4 and N2O emissions? A comparative experiment of different on-field straw management practices' Science Direct, 239, pp 143-153

[55] EEA, 2017, *Annual European Union greenhouse gas inventory 1990-2015 and inventory report 2017*; country emissions for Austria are 78.9MtCO_2e, reference year 2015.

[56] C40 data: Of the 10,000 unique actions reported by C40 cities until 2015, 1,051 focused on private transport and 813 on mass transit. See http://cam3.c40.org/#/main/globalaction, accessed on 15 December 2017.

[57] *The Independent*, 14 October 2017, 'European cities announce bans on petrol and diesel cars as green initiative spreads across continent'

[58] Transport and Environment, 2014, *Life cycle analysis of the climate impact of electric vehicles*, p 11

[59] R Modaresi et al, 2014, 'Global carbon benefits of material substitution in passenger cars until 2050 and the impact on the steel and aluminium industries', *Environmental Science & Technology*, pp 10,776-10,784; C Arnold and S Alston, 'Environmental impact of composites' webinar, Welsh Composites Centre, www.welshcomposites.co.uk/downloads/environmental%20webinar.pdf

[60] Geyer, 2008, cited in R Modaresi et al, 2014, op cit

[61] Green Alliance blog, *Inside Track*, 2016, 'What the government can learn from Jaguar Land Rover about staying competitive'

[62] *World Economic Forum*, 10 November 2017, 'This map shows every country's biggest import'

[63] R Modaresi et al, 2014, op cit

[64] ATAG, *Facts and figures*, www.atag.org/facts-figures.html, accessed on 3 August 2018 (midpoint emissions savings are 578 MtCO_2e per year vs 859 MtCO_2e aviation emissions in 2017); average yearly emissions cut through recycling are 156MtCO_2e, which is comparable to the total CO_2 emission from lignite power plants in Germany in 2016 (153MtCO_2), based on Fraunhofer ISE, www.energy-charts.de/emissions.htm?source=lignite&view=absolute&emission=co2&year=all, accessed on 8 August 2018

[65] Committee on Climate Change, 2013, *Reducing the UK's carbon footprint*; Transport and Environment, 2014, op cit

[66] E Helmers, M Weiss, 2017, 'Advances and critical aspects in the life-cycle assessment of battery electric cars', *Energy and emission control technologies*, 5, pp1-18

[67] *Edie*, 23 September 2016, 'BMW opens energy storage facility built from used EV batteries'

[68] Casals et al, 2015, cited in E Helmers, M Weiss, 2017, 'Advances and critical aspects in the life-cycle assessment of battery electric cars', *Energy and emission control technologies*, 5, pp1-18; K Richa et al, 2015, 'Environmental tradeoffs across cascading lithium-ion battery life cycles', International Journal of Life Cycle Assessment, pp1–16, also reports emissions reduction potentials for cascading EV batteries of between 15 per cent (under conservative conditions) and up to 70 per cent (under ideal refurbishment and reuse).

[69] *Energy Storage News*, 26 August 2016, 'Repurposed EV batteries could rival first-life storage systems – BNEF'

[70] Emissions reduction potential for lightweighting and lightweighting and recycling refers to overall emissions from vehicle fleet, including the use phase, materials production and recycling, and energy supply for the global passenger fleet, based on R Modaresi et al, 2014, op cit; lower and upper emissions reduction values refer to the Drucker scenario (-6%, and -8% with closed loop recycling), which assumes a moderate lightweighting based on the material mix forecast for the US fleet; and the LWE-Al-extreme scenario (-14%, and -20% for closed loop recycling), which assumes extensive substitution of car components by aluminium; emissions reduction of repurposing EV batteries for second life applications are reported as a reduction in overall battery footprint, based on Casals et al, 2015, cited in E Helmers, M Weiss, 2017, op cit

[71] *Conquer China*, 17 March 2014, 'China's Automotive Clusters'

[72] Cluster mapping, Automotive, www.clustermapping.us/cluster/automotive, accessed on 15 January 2018

[73] Japan External trade Organization, 2017, *Regional information: industrial cluster information – Automobile and transport equipment*, www.jetro.go.jp/ext_images/en/invest/region/icinfo/pdf/cluster_auto_en_2017.pdf

[74] Green Alliance, 2017, *Getting it right from the start: developing a circular economy for novel materials*

[75] *The Telegraph*, 17 July 2014, 'Government cars go electric', the UK's central government has a fleet of around 25,000 vehicles; Fleet News, 9 February 2015, 'UK council fleet drops below 50,000 vehicles', local authorities control around 50,000 vehicles.

[76] European Commission, 2018, *Beef and veal market situation*; more than half the beef imported into the EU comes from Brazil and Argentina.

[77] Calculated using EPA, Greenhouse gas equivalencies calculator, www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (49 MtCO_2e)

[78] See methodology (page 74) for details on the assessment of emissions reduction for beef consumption. Emissions reductions for a single city vs 11 European cities vs a European-Latin American partnership of 18 cities are also discussed in Green Alliance, 2018,*Consumption emissions: the new frontier for climate action by cities*.

[79] FAO, 'Key facts and findings' from 'Major cuts of greenhouse gas emissions from livestock within reach' www.fao.org/news/story/en/item/197623/icode/, accessed on 5 August 2018; total emissions from global livestock represent 14.5 per cent of all anthropogenic emissions and cattle is responsible for 65 per cent of the livestock sector's emissions.

[80] Average based on: Chatham House, 2014, *Livestock – climate change's forgotten sector: global public opinion on meat and dairy consumption* (39 per cent); Production systems and sustainability, 'Comparison of greenhouse gas emissions from beef finishing systems: feedlot vs pasture, kb.wisc.edu/dairynutrient/375fsc/page.php?id=48431, accessed on 20 July 2018 (63 per cent); D Boucher, 2016, 'Book review: the global climate and a defense of beef', blog.ucsusa.org/doug-boucher/book-review-the-global-climate-and-a-defense-of-beef (36.5 per cent); FAO, 2017, 'Low-emissions development of the beef cattle sector in Argentina' (62.2 per cent)

[81] P J Gerber et al, 2013, 'Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities', *Food and Agriculture Organization of the United Nations (FAO)*

[82] *National Geographic*, 29 November 2016, 'A sprinkle of seaweed could deflate gassy cows'; R D Kinley et al, 2016, 'The red macroalgae Asparagopsis taxiformis is a potent natural antimethanogenic that reduces methane production during in vitro fermentation with rumen fluid', *Animal Production Science*, 56, pp 282-289; Future feed, research.csiro.au/futurefeed/why-future-feed/, accessed on 30 July 2018; *The Independent*, 25 May 2018, 'Feeding cows seaweed cuts 99% of greenhouse gas emissions from their burps, research finds'

[83] *Agritech blog*, 2017, 'Cattle, feed efficiency and lower carbon footprint'

[84] R Roehe et al, 2016, 'Bovine host genetic variation influences rumen microbial methane production with best selection criterion for low methane emitting and efficiently feed converting hosts based on metagenomic gene abundance', *PLOS Genetics*

[85] Impossible Burgers, www.impossiblefoods.com/burger/; Breakthrough blog, 11 September 2017, 'Where's the fake beef?'; similar GHG emissions reduction (90 per cent) have been reported for plant-based meat alternative Beyond Burger in MC Heller and GA Keoleian, 2018, *Beyond Meat's Beyond Burger Life Cycle Assessment: A detailed comparison between a plant-based and an animal-based protein source*.

[86] Emission reduction potentials refer to reduction of the overall GHG footprint of beef. Reduction potential for seaweed based diet and selective breeding are calculated assuming that enteric fermentation contributes to 50 per cent of the overall footprint. The emissions reduction potential are based on: Future feed, op cit (seaweed based diet); Agritech blog, 2017, op cit (-7.5%) and R Roehe et al, 2016, op cit (-18%) assuming that selective breeding allows to select cattle for the lowest possible methane emission based on their genetic variation (selective breeding); average GHG emissions reduction reported for plant-based meat alternatives, Impossible Burgers, op cit, Breakthrough blog, 11 September 2017, op cit, MC Heller and GA Keoleian, 2018, op cit (-89%); while replacement with 50 per cent mushroom is assumed to cut the emissions by 49 per cent, based on same weight replacement of beef with mushroom and GHG footprints equal to 0.27 gCO_2e/g mushroom and 29 gCO_2e/g of beef, based on S Clune et al, 2017, 'Systematic review of greenhouse gas emissions for different fresh food categories', *Journal of cleaner production*, 140, p 766-783 (plant-based meat). Note that our analysis is based on average footprint of cattle farming, which we understand does not reflect the variation in footprint for different farming practices. Furthermore, we assume that innovation in selective breeding and seaweed based feeds allows for these practices to be suitable for both grain-fed and grass-fed farming.

[87] Centre for Cities, 2017, *Collected case studies: collaborations between universities and businesses*

[88] Maire de Paris, 2015, *Sustainable food plan 2015-2020*

[89] C40, Food systems network, www.c40.org/networks/food_systems

[90] Committee on Climate Change, 2018, *Reducing UK emissions – 2018 progress report to parliament*, charts and data for executive summary; transport emissions in 2017 were 126 $MtCO_2e$

[91] Based on GDP and regional data for 2016, www.bea.gov

[92] Chinese Internet Watch, 28 January 2016, 'Top 30 Chinese Cities by GDP in 2015'

[93] Green Alliance, 2015, *A circular economy for smart devices: opportunities in the US, UK and India*

[94] WRAP, 2011, *EP priority products*

[95] Green Electronics Council, EPEAT overview, www.epeat.net/about-epeat/

[96] European Environment Agency, 2016, *Circular by Design*, p 20; lifespan of consumer products has generally decreased

[97] iFixit, Smartphone repairability scores, www.ifixit.com/smartphone-repairability; for example, see European Commission, 2013, *Material efficiency eco-design report and module to the methodology for the eco-design of energy-related products (MEErP)*

[98] HVM Catapult, 2014, *Triple win: the social, economic and environmental case for remanufacturing*; Ellen MacArthur Foundation, 2015, *Potential for Denmark as a circular economy*; Green Alliance, 2015, *A circular economy for smart devices*; European Environment Agency, 2016, *Circular by design*

[99] Emission reduction potentials refer to reduction in embodied emissions, based on: Green Alliance analysis in Green Alliance, 2015, *A circular economy for smart devices*, where lower emissions reduction refers to a one year life extension for laptops or smart phones and upper emissions reduction is for extension to a device's maximum economic life (emissions reduction for electronic equipment); data based on data reported for ink and toner cartridges (HVM Catapult, 2014, *Triple win: the social, economic and environmental case for*

remanufacturing) and Caterpillar's engine cores: ARUP, 2016, *The circular economy in the built environment* (emissions reduction for machinery).

[100] *The Guardian*, 16 July 2012, 'Apple rejoins EPEAT environmental ratings system'

[101] www.lwarb.gov.uk

[102] Scottish Institute for Remanufacture, 2018, 'Promising early results in Glasgow 'WEEE' collection and recycling trial'

[103] Danish Cleantech Cluster, www.cleancluster.dk, accessed on 2 July 2018; Green Cape, www.greencape.co.za/, accessed on 2 July 2018

[104] European Environment Agency, 2016, op cit

[105] *Bloomberg*, 7 July 2017, 'China, EU bolster greener global shipping to curb emissions'

[106] European Commission, Reducing emissions from the shipping sector, ec.europa.eu/clima/policies/transport/shipping_en, accessed on 15 July 2018

[107] *Marine Insight*, 28 June 2017, 'Top 10 busiest ports in the world'

[108] *BBC News*, 13 April 2018, 'Global shipping in 'historic' climate deal'

[109] H Winnes, L Styhre and E Fridell, 2015, 'Reducing GHG emissions from ships in port areas', *Research in transportation business and management*, 17, pp 73-82

[110] WPCI, 'Climate', wpci.iaphworldports.org/onshore-power-supply/environment-and-health/climate.html, accessed on 15 July 2018; Ship Technology, 2016, 'Shore-side power: a key role to play in greener shipping'; a potential to cut emissions by 50 per cent through OPS coupled to environmental charging scheme (assuming it can apply to all ships) is also reported by European Commission, 2017, *Study on differentiated port infrastructure charges to promote environmentally friendly maritime transport activities and sustainable transportation*, p 106

[111] *Daily Telegraph*, 31 March 2016, 'Cruise ship pollution threatens London, say campaigners'

[112] WPCI, Ports using OPS, wpci.iaphworldports.org/onshore-power-supply/ops-installed/ports-using-ops.html; WPCI, Ports planning to use OPS, www.ops.wpci.nl/ops-installed/ports-planning-to-use-ops/

[113] European Commission, 2017, *Study on differentiated port infrastructure charges to promote environmentally friendly maritime transport activities and sustainable transportation*

[114] European Commission, 2017, op cit, p 103; the estimate is based on the assumption that the efficiency improvements apply to 30 per cent of the fleet.

[115] European Commission, *Reducing emissions from the shipping sector*, op cit; European Commission, 2017, op cit, p 104

[116] Emission reduction potential for onshore power based on: Green Alliance analysis based on 15 per cent share of overall ship CO_2 emissions arising in ports (taken from estimate for cruise ships in EU ports in 2009, see European Commission, 2017, op cit, p 179), assuming that all EU ports are equipped with OPS, that 30 per cent of vessels are equipped to use OPS and that the average grid intensity lowers port emissions by 39 per cent compared to conventional fuel, as reported by Ecofys, 2015, *Potential for shore side electricity in Europe*, p 26). Emission reduction potential for harbour fees based on: European Commission, 2017, op cit, p 103, assuming that the efficiency improvements apply to 30 per cent of the fleet.

[117] *Bloomberg*, 7 July 2017, op cit

[118] *Carbon Brief*, 15 March 2017, 'Explainer: The challenge of tackling aviation's non-CO_2 emissions'

[119] *Carbon Brief*, 26 September 2016, 'Explainer: How aviation could, finally, agree a climate deal'

[120] Committee on Climate Change, 2009, *Meeting the UK aviation target – options for reducing emissions to 2050*; European Environment Agency, 2017, *Aviation and shipping*

[121] European Environment Agency, 2017, op cit, p 51

[122] *The Independent*, 7 March 2018, 'Tourism is responsible for nearly one tenth of the world's carbon emissions'

[123] *The Economist*, 18 November 2015, 'British Airways is the least fuel-efficient transatlantic carrier'

[124] D Ivanova et al, 2017, 'Mapping the carbon footprint of EU regions', *Environmental Research Letters*, 12

[125] C40 analysis of consumption-based emissions data.

[126] Carbon Trust, 2011, *Steel*; the carbon footprint of steel produced using electric arc technology is 0.2-0.4 tCO_2e/tonne of recycled steel, while virgin steel produced using blast oxygen furnace has a footprint of 0.7-3 tCO_2e/tonne (depending on whether it uses coal or gas) and inefficient open hearth furnace plants can emit up to 12 tCO_2e per tonne of virgin steel.

[127] C40, Land use planning network, www.c40.org/networks/land-use-planning; C40, www.c40.org/networks/transit-oriented-development.

[128] IIED blog, 2016, 'Why low-carbon urban development in African cities makes economic sense'

[129] C40, 2018, op cit; sector-based data taken from C40, www.c40.org/other/gpc-dashboard, accessed on 1 August 2018

[130] *C40 Case study*, 2017, 'C40 good practice guides: London – FoodSave Scheme'

[131] Depending on how they are assessed, construction embodied emissions may also include repair, maintenance, refurbishment and end of life of a built assets.

[132] UKGBC, 2017, *Embodied carbon: developing a client brief*

[133] Adapted from UKGBC, 2017, op cit, Figure 1, reproduced with permission; note that the graphic is based on the 80 per cent reduction scenario reported in the 2013 Green Construction Board *Low Carbon Routemap*. Data has been updated to the baseline reported in the Green Construction Board's *Low Carbon Routemap for the built environment 2015 routemap progress - technical report*, available at www.greenconstructionboard.org/otherdocs/2015%20Built%20environment%20low%20carbon%20routemap%20progress%20report%202015-12-15.pdf

[134] Green Alliance assessment based on consultation with experts from the construction sector. See also WRAP, *Cutting embodied carbon in construction projects,* for an overview of cost effective actions. Exact emission reductions and costs will always be specific to each project.

[135] Green Alliance, 2018, *Less in more out; The Guardian*, 27 May 2016, 'University of East Anglia pioneers thatched roof campus'.

[136] *The Guardian*, 20 April 2017, 'How to stop the construction industry choking our cities'; currently construction sites are responsible for approximately 7.5 per cent of damaging nitrogen oxide (NOx) emissions, eight per cent of large particle emissions (PM10) and 14.5 per cent of emissions of the most dangerous fine particles (PM2.5).

[137] J Giesekam et al, 2014, 'The greenhouse gas emissions and mitigation options for materials used in UK construction', *Energy and buildings*, 78, pp 202–214.

[138] RSSB, 'Reducing whole life carbon', www.rssb.co.uk/improving-industry-performance/sustainable-development/case-studies/reducing-whole-life-carbon; and RSSB, 'Rail carbon tool', www.rssb.co.uk/Library/research-development-and-innovation/case-study-5-rail-carbon-tool.pdf, both accessed on 30 July 2018

[139] HM Treasury, 2013, *Infrastructure carbon review*; Anglian Water, *Managing our greenhouse gas emissions*, www.anglianwater.co.uk/environment/why-we-care/carbon-management.aspx, accessed on 30 July 2018.

[140] Mayor of London, 2017, *London environment strategy*

[141] Copenhagen Together, 2017, *Sustainability in construction and civil works 2016*

[142] RICS, 2017, *Whole life carbon assessment for the built environment*, 1st edition

[143] UKGBC have recently published a guidance for clients, see www.ukgbc.org/sites/default/files/UK-GBC%20EC%20Developing%20Client%20Brief.pdf

[144] Note that the Greater London Authority already engages with councils on the delivery of the mayor's housing strategy

[145] UKGBC, 2015, *Tackling embodied carbon in buildings*

[146] This could build on the fact that, as proposed in the new London Plan, boroughs are encouraged to request energy strategies for other development proposals where appropriate (see Greater London Authority, 2017, *The London Plan*, draft for public consultation, chapter nine, p 328)

[147] Greater London Authority, 2017, *The London Plan*, draft for public consultation, chapter 9. The minimum improvement over the Target Emission Rate (TER) will increase over a period of time to achieve the zero carbon London ambition and reflect the costs of more efficient construction methods. This will be reflected in future updates to *The London Plan*.

[148] 'What powers does the mayor have for planning applications?', www.london.gov.uk/what-we-do/planning/planning-applications-and-decisions/what-powers-does-mayor-have-planning, accessed on 10 January 2018

[149] Greater London Authority, 2017, *The London Plan*, draft for public consultation, chapter six, p 226

[150] Green Alliance analysis of: office space forecast to 2041, Greater London Authority, 2017, *The London Plan*, draft for public consultation, chapter 6, p 226; average embodied carbon for office superstructure of 445 kgCO_2/m2, UKGBC, 2017, *Developing a client brief*, p 53

[151] Green Alliance analysis of: 65,000 new homes every year up to 2029 (based on Greater London Authority, 2017, *The London Plan*, draft for public consultation, chapter four), average surface of 65 m^2 per home (calculated as the average between one and three bedroom dwelling, see RIBA, 2015, *Space standards for homes*) and embodied carbon for residential superstructure of 190 kgCO_2e/m2 (UKGBC, 2017, *Developing a client brief*, p 53)

[152] As a rule of thumb, ten to 20 per cent embodied carbon reductions can be achieved through optimised design and material choice without incurring in additional costs. Green Alliance assessment based on expert consultation with representatives from the construction sector.

[153] WRAP, *Cutting embodied carbon in construction projects*; WRAP, *Waste minimisation through offsite timber frame construction*

[154] London Assembly Planning Committee, 2017, *Designed, sealed, delivered: the contribution of offsite manufactured homes to solving London's housing crisis*

[155] Greater London Authority, 2017, *The London Plan*, draft for public consultation, chapter four

[156] London Assembly Planning Committee, 2017, op cit; Construction Industry Council, 2013, *Offsite housing review*.

[157] *The Guardian*, 20 April 2017, op cit; currently construction sites are responsible for approximately 7.5 per cent of damaging nitrogen oxide (NOx) emissions, eight per cent of large particle emissions (PM10) and 14.5 per cent of emissions of the most dangerous fine particles (PM2.5)

[158] Build Offsite, 2013, *Offsite construction: sustainability characteristics*

[159] *The Guardian*, 8 September 2015, 'Return of the prefabs: inside Richard Rogers' Y:Cube homes

for homeless people'; Energy Prices Statistics, 2017, *Domestic energy bills in 2017: the impact of variable consumption*

[160] Y:Cube, www.rsh-p.com/projects/ycube/, accessed on 10 July 2018

[161] London Assembly Planning Committee, 2017, op cit; Dalston Works, www.ramboll.co.uk/projects/ruk/dalston-lane, accessed on 20 July 2018.

[162] Isabelle Priest, 8 May 2017, 'Timber gains in stature', *The RIBA Journal*; Stephen Cousins, 14 March 2018, 'Is cross-laminated timber coming of age?', Bimplus

[163] C40, 2018; op cit; sector-based data taken from C40, www.c40.org/other/gpc-dashboard, accessed on 1 August 2018

[164] 'Copenhagen – Carbon neutral by 2025', stateofgreen.com/en/profiles/city-of-copenhagen/solutions/copenhagen-carbon-neutral-by-2025, accessed on 30 June 2018.

[165] C40, 14 September 2017, 'Cities100: Copenhagen – Mapping real-time consumption to plan efficiency updates'

[166] Data based on C40, 2018, *C40 cities consumption-based emissions data, 2011*

[167] Green Alliance analysis of Copenhagen's consumption-based emissions data based on C40 analysis. See methodology (page 74) for details on emissions reduction potentials from changing diets.

[168] The City of Copenhagen, 2016, 'Copenhagen's organic food revolution'

[169] eatforum.org/initiatives

[170] This assumes that average daily per capita footprint for food consumption in the hospitality sector is the same as the average daily footprint based on C40 consumption-based emissions data, ie 3.3 $kgCO_2e$ per person per day emissions reduction from menu changes based on assumption that the reduction potential for no beef is comparable to household consumption estimates (ie 19 per cent cut in GHG emissions).

[171] State of Green, 2017, 'New efforts to sort organic waste in Copenhagen'; A Halloran et al, 2014, 'Addressing food waste reduction in Denmark', *Food Policy*, 49, pp 294-301

[172] C40, 2017, 'C40 good practice guides: London – FoodSave Scheme'

[173] Assuming that enteric fermentation is responsible for 50 per cent of dairy's emissions footprint, and that selective breeding and alternative feeds can cut methane from enteric fermentation by 15 to 80 per cent (see references for transatlantic beef partnership on pages 27-30); to calculate final potential footprint reductions for Copenhagen, emissions savings of 7.5 to 40 per cent are applied only to the fraction of dairy that is sourced domestically (ie 85 per cent)

[174] www.arla.com/company/responsibility/sustainable-dairy-production/

[175] A Flysjö, 2012, 'Greenhouse gas emissions in milk and dairy product chains', Aarhus University; AHDB, 2014, *Carbon footprint report 2014*; Carbon Trust, 'Bord Bia – footprinting & resource efficiency', www.carbontrust.com/our-clients/b/bord-bia/

[176] Danish Agriculture and Food Council, Danish dairy industry, agricultureandfood.dk/danish-agriculture-and-food/danish-dairy-industry, accessed on 15 July 2018

[177] C40, 'City greenhouse gas emissions interactive dashboard', www.c40.org/other/gpc-dashboard; transport emissions are 567 $ktCO_2e$

[178] Green Alliance assessment based on expert consultation with representatives from the construction sector. See also WRAP, *Cutting embodied carbon in construction projects* for an overview of cost effective actions. Exact emission reductions and costs will always be specific to each project.

[179] J Giesekam et al, 2014, op cit; *The Guardian*, 20 April 2017, op cit, Construction sites are responsible for damaging nitrogen oxide (NOx) emissions, large particle emissions (PM10) and emissions of the most dangerous fine particles (PM2.5).

[180] Copenhagen Together, 2017, *Sustainability in construction and civil works 2016*

[181] International Energy Agency, 2016, *Evaluation of embodied energy and CO_2eq for building construction (Annex 57)*

[182] RSSB, 'Reducing whole life carbon', www.rssb.co.uk/improving-industry-performance/sustainable-development/case-studies/reducing-whole-life-carbon, accessed on 30 July 2018

[183] Forestry Innovation Investment, 2017, *Embodied carbon of buildings and infrastructure*

[184] www.dgnb-system.de/en/system/international/

[185] The city of Copenhagen, 2012, *CPH 2025 climate plan*

[186] Green Alliance analysis of: proposed new build to 2025, based on The city of Copenhagen, 2012, *CPH 2025 climate plan*, which is equivalent to 0.97 million square meters of new build per year to 2025; we assume new build has embodied carbon intensity similar to that reported for multifamily dwellings in Sweden, estimated to be about 350 $kgCO_2/m^2$ (of which 84 per cent arises from construction materials, 13 per cent from the construction process and three per cent from transportation to the site), see Royal Swedish Academy of Engineering Science, 2014, Climate impact of construction processes, p 13; we calculate emissions reduction based on a 15 per cent reduction potential, based on expert feedback.

[187] Including suggesting a lifecycle assessment calculation, see R Zizzo et al, 2017, *Embodied carbon of buildings and infrastructure: international policy review*

[188] M Löfsjögård, 2018, *Development of concrete with low climate impact in Sweden*, Swedish Concrete Federation

[189] BSI, 'PAS 2080:2016, Carbon management in infrastructure'; Mott MacDonald, 2016, 'PAS 2080: A low carbon game-changer'

[190] Copenhagen Together, 2017, *Sustainability in construction and civil works 2016*

[191] Zero Waste Scotland, Scottish Materials Brokerage Service, www.zerowastescotland.org.uk/brokerage

[192] C40, 2017, 'Cities100: Copenhagen – mapping real-time consumption to plan efficiency updates'

[193] K G Jensen and J Sommer, 2016, *Building a circular future*, www.buildingacircularfuture.com/book/

[194] Danish Cleantech Cluster, www.cleancluster.dk, accessed on 2 July 2018

[195] Green Alliance, 2015, *Circular economy Scotland*

[196] Deloitte, 2015, *Construction and demolition waste management in Denmark*; 86 per cent recycling reported for Denmark in 2012, though this is largely as a result of recycling of crushed concrete and bricks.

[197] L Aleksandrowicz et al, 2016, 'The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: a systematic review', *PLoS One*, 11 (11)

[198] C40, 2018, op cit; sector-based data taken from C40, www.c40.org/other/gpc-dashboard, accessed on 1 August 2018.

[199] Green Alliance analysis of Toronto's consumption-based emissions data based on C40 analysis. See methodology (page 74) for details on emissions reduction potentials from changing diets.

[200] Ibid

[201] Toronto Board of Health, 2017, *Sustainable diets – healthy eating, healthy planet*

[202] Toronto Food Strategy, www.toronto.ca/community-people/health-wellness-care/health-programs-advice/toronto-food-strategy/, accessed on 15 June 2018

[203] Ibid

[204] R MacRae and K Donahue, 2013, *Municipal food policy entrepreneurs: a preliminary analysis of how Canadian cities and regional districts are involved in food system change*

[205] Ibid; L Oates, 2011, *Local food procurement,* www.toronto.ca/legdocs/mmis/2011/gm/bgrd/backgroundfile-39120.pdf

[206] *Wired*, 6 September 2017, 'Canada is using genetics to make cows less gassy'; Genome Canada, 2016, *Increasing feed efficiency and reducing methane emissions through genomics: a new promising goal for the Canadian dairy industry*

[207] Ontario Ministry of agriculture, food and rural affairs, *2011 census of agriculture maps*, www.omafra.gov.on.ca/english/landuse/gis/census_ft.htm, accessed on 30 May 2018

[208] Beef farmers of Ontario, 'general statistics', www.ontariobeef.com/industry/general-statistics.aspx, accessed on 30 July 2018

[209] Green Alliance analysis: emissions reduction resulting from selective breeding applied to 50 per cent of beef consumed (assuming all beef sourced within Ontario has been selectively bred); selective breeding is assumed to cut methane emissions between 15 and 36 per cent, based on initial research findings (for references, see transatlantic beef partnership section of this report, on pages 27-30)

[210] Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA), '2011 census of agriculture maps', www.omafra.gov.on.ca/english/landuse/gis/census_ft.htm, accessed on 30 May 2018; copyright: Queen's Printer for Ontario, 2011. Reproduced with permission

[211] L Oates, 2011, *Local food procurement*, www.toronto.ca/legdocs/mmis/2011/gm/bgrd/backgroundfile-39120.pdf

[212] Menus of Change, www.menusofchange.org

[213] FAO, 2015, *Food wastage footprint & climate change*

[214] Toronto Food Policy Council, *Food waste: the issue of food waste*, tfpc.to/food-waste-landing/food-waste-theissue, accessed on 15 July 2018; *The Globe and Mail*, 5 August 2014, 'Canadians waste seven billion kilograms of food a year'

[215] R Zizzo et al, 2017, *Embodied carbon of buildings and infrastructure: international policy review*

[216] Toronto Green Standard, www.toronto.ca/city-government/planning-development/official-plan-guidelines/toronto-green-standard/, accessed on 1 May 2018

[217] The collaborative group could also identify whether there are aspects of the methodology that need to be specifically adapted to Ontario.

[218] The Carbon Leadership Forum is based at the University of Washington and has established an Embodied Carbon Network of industry experts.

[219] Toronto city planning division, 2017, *How does the city grow?*

[220] BuildOn, 2017, *Building better lives: Ontario's long-term infrastructure plan 2017*

[221] RSSB, 'Rail carbon tool', www.rssb.co.uk/Library/research-development-and-innovation/case-study-rail-carbon-tool.pdf, accessed on 20 July 2018

[222] HM Treasury, 2013, *Infrastructure carbon review*

[223] R Zizzo et al, 2017, *Embodied carbon in construction – case study: Kingston road YMCA, Toronto*; low carbon concrete refers to use of Portland-limestone cement and high content of Supplementary Cementitious Material.

[224] Green Alliance analysis of: Toronto City Planning, 2017, *How does the city grow?*; we assume that the 272,004 new residential units proposed are delivered at a rate of 16,552 dwellings per year, based on the average number of dwellings completed between 2011

and 2016, and average dwelling size of 74m² (calculated based on the number of units and surface area reported in table eight); non-residential developments of 644,000m² (based on current proposed pipeline for non-residential developments of about 6.4 million square metres, which is assumed to be delivered over ten years); embodied carbon per m2 are taken as the baseline value as reported in R Zizzo et al, 2017, *Embodied carbon in construction – case study: Kingston road YMCA, Toronto*, table 1, and savings in embodied emissions are calculated based on a ten per cent reduction achieved through use of low carbon concrete.

[225] Retaining 15-30 per cent of the existing structure and non-structural building elements was reported to reduce the carbon footprint by 17.3 per cent for high rise concrete buildings in Hong Kong (Chau et al, 2012, cited in F Pomponi and A Moncaster, 2016, see www.ncbi.nlm.nih.gov/pubmed/27558830); while SEGRO opted for dismantling and re-erecting 3,180m2 of office and warehouse space based on whole life carbon assessment, achieving 56 per cent embodied carbon savings, 25 per cent cost savings and six per cent lower whole life carbon footprint compared to new build, see '9 Cambridge Avenue', www.sturgiscarbonprofiling.com/9-cambridge-avenue/, accessed on 2 July 2018.

[226] TOcore: planning downtown, 2018, www.toronto.ca/city-government/planning-development/planning-studies-initiatives/tocore-planning-torontos-downtown/, accessed on 15 January 2018

[227] For example, enabling access to structural steel, which if reused is generally between 50 and 75 per cent cheaper than new steel, see Dr M Gorgolewski et al, 2006, 'Facilitating greater reuse and recycling of structural steel in the construction and demolition process', Ryerson University

[228] *The Conversation*, 2017, 'Scotland's new Queensferry Crossing reveals how smart technologies monitor and maintain the health of bridges'

[229] CIVMEN blog, 2017, 'Concrete check-up: Fae Azhari develops diagnostics for critical infrastructure'

[230] Toronto Public Health, 2017, *Diets for a cool planet*

[231] *National Geographic*, 29 November 2016, op cit; R D Kinley et al, 2016, op cit; Future feed, research.csiro.au/futurefeed/why-future-feed/, accessed on 30 July 2018; *The Independent*, 25 May 2018, op cit; R Roehe et al, 2016, op cit

[232] Average based on: Chatham House, 2014, op cit (39 per cent); FAO, 2017, op cit (62.2 per cent)

[233] Based on L B Werner, A Flysioe and T Tholstrup, 2014, 'Greenhouse gas emissions of realistic dietary choices in Denmark: the carbon footprint and nutritional value of dairy products', *Food and nutrition research*, 58; these values are comparable to GHG footprints reported in: S Clune, E Crossin and K Verghese, 2017, 'Systematic review of greenhouse gas emissions for different fresh food categories', *Journal of cleaner production*, 140, pp 766-783

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