Water-Energy-Carbon Nexus in our homes.

A blind spot for climate crisis?

Executive Summary

In the race to net zero, is there a blind spot? Are opportunities being missed to reduce carbon in homes through water efficiency?

This missed opportunity is the Water-Energy-Carbon (WEC) nexus – the intertwining relationship between water and energy systems and their subsequent impact on carbon emissions. Many studies and papers have documented, commented and advised on the impact of climate change on water resources, but few have focussed on how reducing water usage and associated activities in the home can mitigate climate change. A deeper understanding of the WEC nexus is required. At a broad scale, the nexus involves how energy is used to abstract, treat and transport water for domestic, commercial and agricultural use, and how water is used to produce different types of energy. This, however, does not provide a full picture of the WEC nexus and the information is missing on what happens inside homes. The focus of this paper is therefore on the WEC nexus at a domestic level and how it presents both a challenge and an opportunity. The challenge is the contribution of water and energy to greenhouse gas (GHG emissions); the opportunity is to provide solutions, such as the 50L home, as a building block to significantly reduce GHG emissions.

> *"The CO_2 cost of water is 80% what we do with it in our homes."*
>
> *Judith Thorton, Low Carbon Manager, Aberystwyth University*

The 50L Home Coalition has the vision of making water-efficient living an irresistible reality for all. To achieve this vision, the 50L Home Coalition are committed to promoting education of both policy makers and the general public on the consequences of domestic water use and the associated energy and carbon impacts. There is a tremendous opportunity to innovate and collaborate across public and private organisations taking the end consumer with us on the journey. The 50L Home Coalition are committed to promoting conditions for meaningful change and creating irresistible solutions that are easy for end users to adopt and to enable better-informed lifestyle choices for sustainable water use.

With the world's attention on the climate crisis, there is a huge focus on energy efficiency as part of climate action. However, the nexus of energy with water in climate action is unclear. Water is much less expensive than energy and easy to access so, as a result, there is less incentive to economise. To draw the world's attention to water-related energy consumption, particularly inside homes, four cities have been selected – Los Angeles, Beijing, Mexico and Mumbai – as representative of different stages of development. This problem has been reviewed from a systems perspective at a city level, profiling each city, highlighting patterns of water use inside the home and other issues affecting the nexus, including the sourcing and treatment of water.

Water end-use in the home accounts for approximately 80% of carbon emissions in the water cycle. Further, analysis confirmed that water-related energy in the form of hot water accounts for 6% of carbon emissions in most of the cities studied, making it the second biggest source of energy consumption in homes around the world after space heating. In this report the local conditions in these cities are assessed and potential opportunities identified to save on water use, in particular the energy consumed to heat water for domestic use. This analysis reveals that communities around the world need to learn from each other – no one city or nation has all the answers on its own.

Individuals cannot solve the impacts of the nexus without public-private partnership, integrated water and energy plans at a practitioner level and more importantly, obtaining robust data on water usage and subsequent energy usage on individual activities such as showering, washing clothes and dishes, etc.

There are significant challenges building a picture of the full implications of the nexus in each city. This is partly because of a fragmented water market and separate management of water and energy. Without data, nobody can assess the full problem, neither can the best steps to manage the WEC nexus be identified. From regulators to policy makers, utilities to practitioners, everyone looks at water and energy separately. This paper is an attempt to highlight this issue so that a better understanding can be built, breaking the siloed approach and creating a movement to enable integrated decision-making. Without this, the risk is the city leaders will prioritise areas other than water consumption and the blind spot will continue to exist.

One of the key findings of the paper is that water consumption behaviour is one of the most significant and most-readily influenced drivers of water and energy consumption in the home. Water consumption has increased as a result of behavioural change in Beijing as household wealth has increased. Paradoxically, water consumption has fallen in Los Angeles as behavioural campaigns have focused on consumption reduction. The keys to behavioural change are knowledge, education and motivation. Also, without data on water consumption, households are unaware of change that is needed and, without information on the options available, they do not know how they can contribute. Crucially, without financial or societal incentives, there is no driver for change.

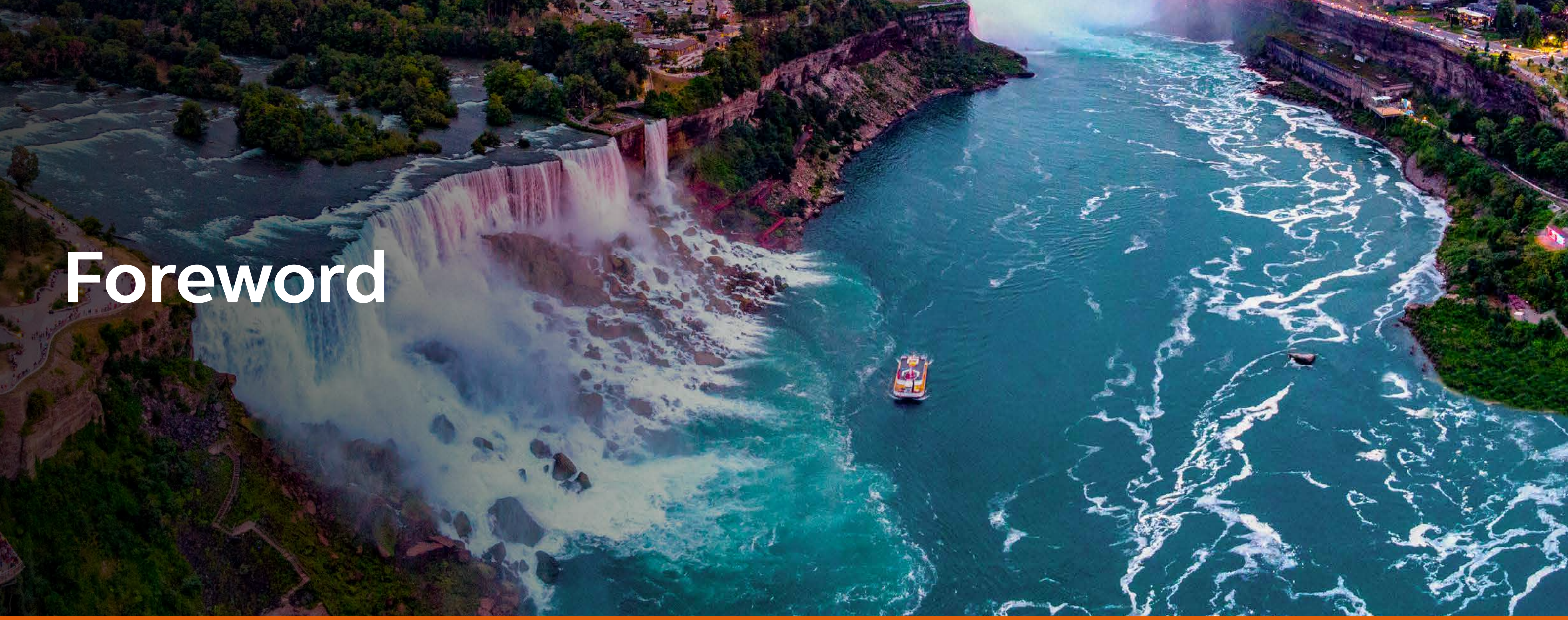
With relatively good data for Los Angeles and Beijing, it has been possible to undertake a deep dive on these cities and demonstrate a useful template that can be adopted across different cities around the world. The report also highlights the opportunities to save water, energy and carbon emissions through successive steps on reducing water use through the replacement of fittings and appliances and the incentivisation of behavioural change. This is what the 50L Home provides: building blocks of solutions ranging from changes in behaviour in the home to the replacement of fittings and appliances and influencing changes at a policy level. Most importantly 50L Home seeks to bring about change in a way that is irresistible to consumers.

So, what can citizens and city leaders do to address the WEC nexus?

Dialogue and partnership are essential. Policy makers, regulators, business and individual householders can come together to make a tangible difference and move the dial towards a net zero carbon economy by:

- Recognising the blind spot: Energy use through water in the homes, i.e. hot water usage, needs to be acknowledged as the blind spot. It is important to note that saving water alone will not realise the full opportunity, energy supplies need to be decarbonised as well.
- Urgently collecting for accessible, usable and understandable data: Collecting and managing data in a manner that is readily understood by consumers, communicating water and energy use using readily understandable analogous units like number of showers or number of kettles rather than litres and kWh. This will help consumers change behaviours and help them make decisions on where exactly to save water, energy and consequently money.
- Integrated water and energy decision making at all levels: This involves breaking silos across the entire water energy landscape. If all these silos are broken, this will enable consumers to change behaviours that will move us towards a 50L and net zero future in an equitable and inclusive way. This can be done through:
  - Regulators devising policies across the two sectors and using carbon as a common currency to inform decision-making
  - City leaders planning in an integrated manner, for example: when city leaders and councils plan a boiler replacement programme in a residential home, they should plan a retrofit for water efficiency programme at the same time
  - Practitioners drawing out plans and implementation programmes integrating water and energy for the fastest and biggest impact to meet net zero
  - Policy makers need to review pricing policy associated with energy, water and carbon as a system – balancing pricing signals across all three resources as an incentive to influence consumption behaviour, particularly in emerging markets where new consumption norms are being established

The call to action is for everybody to start watching out for that blind spot, becoming acutely aware of where water is being used and what impact it can have on energy consumption and related carbon emissions.



Foreword

As our world comes together at COP26, the overwhelming evidence supporting climate action shows systems transformation driven by the collaboration of multiple stakeholders is required to ensure our cities' long-term sustainability. Water systems are not exempt from this need to integrate, because they depend on other systems, too. Utility providers in our cities need energy to treat water and bring it to us; in our homes, we use energy to shower, wash and clean; and finally, our city infrastructure needs energy to treat and reuse (or dispose safely) the wastewater we produce in the process.

In exploring the relationship between water and energy in cities, our 50L Home Coalition partners have learned water conservation initiatives can play a key role in reducing overall energy consumption across the water value chain in cities. Crucially, how we use water in our homes accounts for a substantial amount of energy spent in buildings – in other words, domestic water use is a key driver of operational carbon emissions in cities. Unfortunately, this challenge is rarely explored, thus cities and their communities are unable to take action on this energy 'blind spot'.

To create this white paper, we brought together a group of experts from across our Coalition. Their collective work was possible thanks to the technical leadership provided by our partners Arcadis who, based on their global expertise in shaping solutions to accelerate transition to net zero, helped us articulate our thinking and ideas.

This white paper on the water-energy-carbon nexus is the second knowledge product created by our Coalition. Exploring the challenges cities experience was our starting point; we analysed and learned from four global cities – Beijing, Los Angeles, Mexico City and Mumbai – and co-created a group of actionable suggestions for them. We envisage this paper will open new possibilities for cities and communities to take integrated action in addressing their water and energy challenges simultaneously, and to begin using carbon in their decision making.

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Introduction

The race for net zero is a global imperative. In recent years policy makers, utility providers and many citizens have engaged in identifying the best opportunities to accelerate progress towards reducing GHG emissions. Water systems have a key role to play through the Water Energy Carbon nexus. Recognising the scale of energy use and carbon emissions associated with water use in the home represents an opportunity to deliver a meaningful reduction in carbon emissions.

There is substantial research and data available that shows that the end-use of water in the home often has the highest energy use of all water-sector elements. However, this end-use of water has not traditionally been seen as a direct part of the water sector and the associated energy use is often unaccounted for in water or energy management and policy.

This white paper highlights how water is used inside the home, in four different water-stressed cities, and how much energy is used to heat that water. The report compares this energy use to how much energy is used, in those cities, to bring the water to the home and to take away and treat the wastewater.

Most consumers do not know how much water they use in the home each day. In the UK, the average person uses 142 litres per day in the home, but research shows nearly two thirds of people believe their household use is less than 40 litres a day [67]. Making the case for the 50L commitment is hard when people do not recognise how much water they are using.

Very few people appreciate how much energy is used (and carbon emitted) via their daily water use and how reducing their water use, and in particular their hot water use, will not only save on their utility bills, but will also reduce their carbon footprint.

As part of the drive towards net zero, everyone needs to be aware of their personal water use and needs to be incentivised to change their relationship with water.

Through water efficiencies and best practice, consumers can reduce their personal water use. However, by working together with policy makers, utility providers and business, consumers can be guided to realise the best overall water and energy efficiency targets . This will require leveraging the power of data and a range of innovations.

The 50L Home is an aspiration for how all can live on less water a day, which is more globally fair, not just for the now but for generations to come. This is not an unrealistic aspiration: millions of people consume 50 litres per day or less as part of their normal daily lives; astronauts on the International Space Station are able to live on 4 to 5 litres per day.

There are readily available ways to enable less water use, which reduces the strain on the planet, whether by changing fittings and wet appliances, by thinking about water use when upgrading heating systems or by actively thinking about behaviours in connection with water use.

In the following sections this report explores and analyses a number of topics, including:

- What is the water-energy-carbon nexus?
- The baseline position in four cities around the globe, from water resources to socio-economics
- The potential journey for two sample cities
- A summary of initial advice for householders on how to save water within their homes
- Guidance for policy makers on the support they can provide

What is a 50L Home?

The 50L Home is a dwelling that is fully equipped to enable people to use water and energy in a delightful manner at the highest efficiency levels.

Achieving an enjoyable living experience with an average daily consumption of 50 litres per person and net zero emissions will rely on a combination of behavioural steps – understanding own water and energy use patterns, using running water when it is needed, using hot water when required and choosing efficient fittings and appliances.

The 50L Home will be accessible for all in the long-term. It will have fittings that are designed to minimise water consumption and will also be fully equipped with highly efficient appliances that use less water than manual processes e.g. dishwashing.

By minimising water use, a well-equipped 50L Home will contribute to lower energy use and carbon emissions. The most obvious aspect of water-related energy use is hot water. Low water-use fittings combined with high-efficiency instantaneous water heating address this opportunity.

A 50L Home will feature water re-use technologies, such as greywater recycling, and rainwater collection. A new generation of appliances and solutions that allow immediate in-situ direct water reuse will be incorporated. Soapy water doesn't need to become sewage when it could be treated and reused. As such, the 50L Home aims to decentralise water reuse to points of use in the homes so that precious fresh water is not used for irrigation, car washing and other important but discretionary uses.

Real-time access to data plays an essential role in enabling 50L living. Real-time consumption data presented in units that are meaningful to consumers will support the behaviour changes that are needed. Smart meters that integrate water and energy use and that report using relatable data units like 'shower equivalents used' rather than litres/day will play a big role in the 50L home.

Innovation enables people to reduce their water and energy use but does not automatically ensure that will happen. The 50L Home also needs a new mindset.

The Water- Energy-Carbon Nexus

The water-energy-carbon (WEC) nexus describes the complex links between water, energy, and carbon. Energy is used across all steps in the water value chain in cities – substantial amounts of energy are used to treat, transport, use, reuse, and discharge water safely.

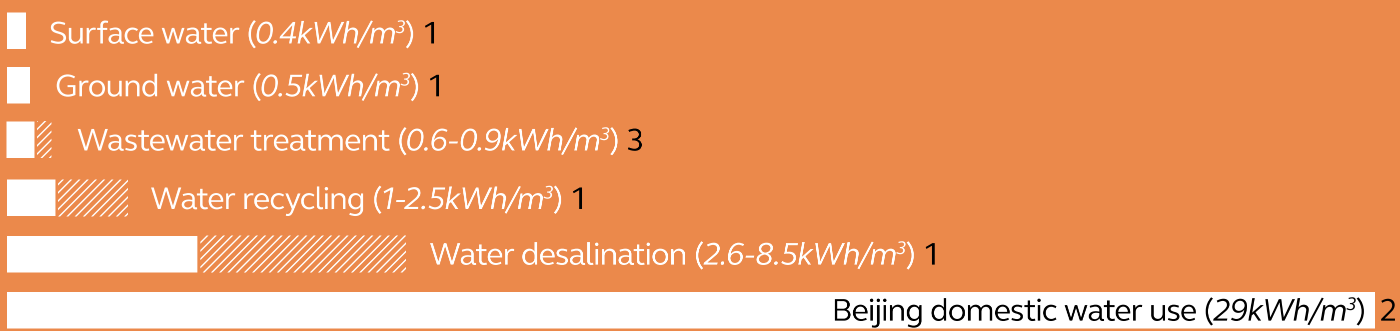
The water treatment cycle upstream and downstream of the end user

This section examines where energy is consumed in the water cycle. Figure 1.0 highlights typical energy consumption involved at different stages of the water treatment cycle against domestic water use in Beijing.

The water-energy-carbon (WEC) nexus describes the complex links between water, energy, and carbon. Energy is used across all steps in the water value chain in cities – substantial amounts of energy are used to treat, transport, use, reuse, and discharge water safely.

The water treatment cycle demands substantial amounts of energy. Most energy is generated from fossil fuels such as coal or gas, which in turn require large amounts of water for extraction and production. At the same time, energy production from fossil fuels and consumption of energy in the water treatment cycle generates significant greenhouse gas (GHG) emissions.

Amount of energy consumed for different water treatment cycle stages for 1m^3 of water



Source: *WBSCD 2009[690] and He, G. et. al. (2019)[249]*

Note: Different upstream options for the water treatment cycle are highlighted with a '1', the downstream element is highlighted with a '3' and the End Use element is highlighted with a '2'. Also - Energy intensities do not account for elements such as distance water travels or is lifted.

Figure 1.0. Energy consumption in the water cycle

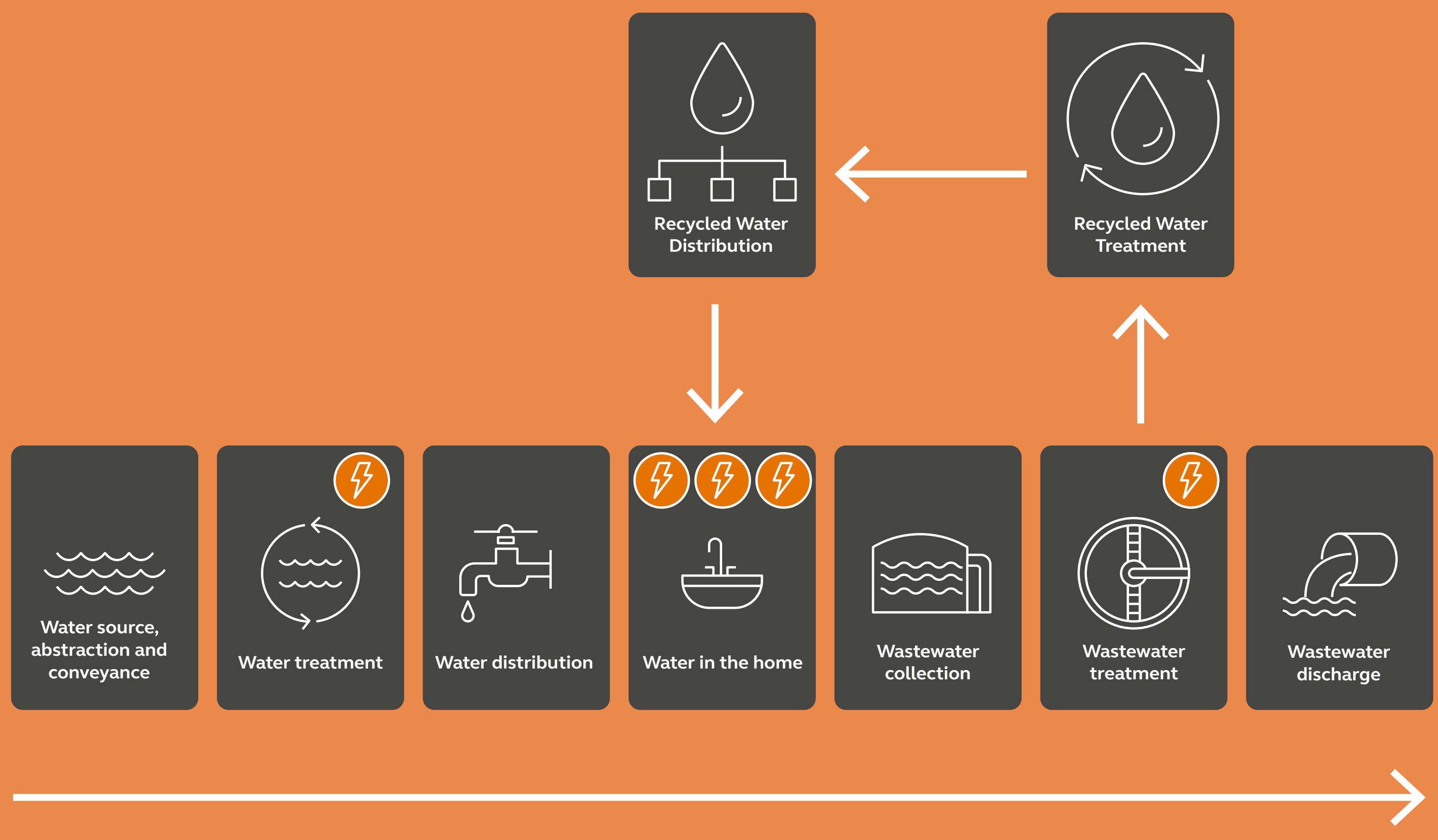


Figure 2.0 Key elements of the domestic water cycle; the sparks represent those elements which use most energy

For consumers, energy and water are connected in homes, businesses, industries and agriculture.

The WEC nexus means that end-use efficiency which saves water will also save energy and carbon and vice versa.

The WEC nexus is a valuable concept because it helps to address three key challenges.

First, it encourages a systems approach to resource use. Because of the nexus, **approaches that do not consider the overall system are likely to be less effective and more costly** than co-ordinated approaches.

Second, in many cities, **the cost of water is relatively low and energy consumption and carbon emissions are unknown**. Once data is available, these costs and impacts are better understood, and households will be motivated to change and to adopt 50L Home thinking.

Third, it can support governments to address water stress and energy shocks, hence **contributing to the overall resilience of the city**. As the impacts of climate change evolve putting greater stress on water and energy infrastructure this is an important consideration.

Energy Consumption Determinants

The amount of energy consumed (and carbon emitted) in supplying water to homes and how much water is used in the home are related to:

Climate and topography cannot be changed through water and energy efficiencies. But it is possible to take the nexus into account when addressing the issue of water demand outstripping water supplies to cities. The nexus of the whole water treatment cycle should be understood to select the best solutions for water scarcity.

Operational efficiencies (upstream/downstream utility) are determined by the municipal water companies – i.e. providing energy-efficient water supplies to people. Since the majority of the water cycle energy consumed is through water use in the home (approximately 90%)[29], it is important to focus on the home: how much water is used in the home and, in particular, how much hot water is used (water use patterns).

Water use Patterns[39] **and socio-economic status**[33]: Human behaviour influences how much energy and water is consumed in the home i.e.[24]. Figure 1.0 illustrates how much more intensive end-use is in the water treatment cycle.

Where water is supplied from determines how much energy is consumed to supply it. Depending on how much fossil-fuels are used to provide energy, the carbon emissions are directly related to the energy consumed in supplying water.

The most energy-efficient water supply is from surface waters, such as rivers and reservoirs. However, these sources are the most affected by climate change e.g. where and how much rain falls. Groundwater supplies are the next most energy-efficient water supplies if the water is not located too deep. However, over-exploitation of groundwater has been a problem for many years in Mexico City[8] and Beijing[75]. Transporting water over long distances can also have environmental issues resulting from the transfer of a water scarcity problem from one place to another.

Supplementary water sources for cities will generally require more energy than existing sources. For example, importing water over long distances or treating sea water to drinking water (desalination).

The energy usage around the water cycle only increases once water distribution is factored in, domestic water heating, wastewater collection and wastewater treatment and discharge. Clearly reducing domestic water demand will reduce the need for freshwater supplies. It will also reduce the need for water heating that is typically powered using fossil fuels.

The WEC nexus is a useful concept to understand holistically the climate implications of water consumption.

With 68% of the world's population expected to live in urban areas by 2050[59], it is essential that the nexus is understood at the scale of the city as well as nationally.

The challenge with energy-intensive cities is that the high percentage of energy use and carbon emissions associated with industry and transport may result in city- leaders prioritising areas other than water consumption.

The WEC nexus is held back in making this case for households by a lack of high-quality and representative data, which is often the result of a fragmented water market.

The Water-Energy-Carbon Nexus - City Scale

The following analysis sets out an assessment of water usage in four representative cities:

- **Beijing** – Emerging economy mega-city with increasing levels of water consumption
- **Los Angeles** – Advanced economy city taking steps to reduce water usage
- **Mexico City** – Intermediate economy mega-city with high levels of water stress and a high water-related energy consumption
- **Mumbai** – Developing economy mega-city with water -related energy consumption rising from a low base

Data availability and data quality has been problematic across all these cities. Tracing energy use across the full water cycle is challenging, and, in fast-growing cities, capturing the full scale of water use including is hampered by the lack of current data. As a result, the analysis in this paper must be caveated, even though the findings are compelling.

The four cities, each at different stages of economic development represent different challenges for the 50L ambition – from adjusting cultural norms in Beijing to managing the reality of high levels of discrimination in access to water in Mumbai.

The analysis has three sections:

- **City case studies**: A profile of each city highlighting patterns of water use and other issues affecting the nexus including the sourcing and treatment of water in the supply and treatment system.
- **City water consumption analysis**: A summary of data covering water-related energy use in cities that highlights significant differences in water use, energy consumption and carbon emissions at the heart of the Nexus.
- **Water reduction pathway**: Where sufficient data is available to support an analysis, water reduction pathways have been developed for cities like Beijing and Los Angeles. These set out the measures that can be taken on the trajectory to 50L and the energy and carbon savings that will follow.

Beijing

Beijing has a population of 21.9 million people. The city lies on low and flat land, with elevation generally between 30-40 metres[43]. The climate is a continental monsoon with an extreme temperature range of -4 – 26°C, with 132 days of freezing temperatures between October and March[43]. It has an average annual rainfall of 635mm, of which most falls within the months of June and to August[43].

The responsibility of water supply and sanitation policies at the national level is shared between ministries. Services are typically provided by municipally owned water bureaus and wastewater bureaus/utilities; water and wastewater bureaus are typically separate from each other.

China's electricity consumption per capita is 66% fossil fuels (61% coal, 5% natural gas and oil, 18% hydropower, 5% nuclear and 11% renewables)[5].

Water supply to Beijing is from three main sources: from rivers and reservoirs (7%); groundwater (47%) and water imported from the South-north North water Water Transfer Project (SNWTP) (46%)[32]. The SNWTP diverts water over a distance of 1,267km[63].

DAILY FOOTPRINT FOR A PERSON IN BEIJING

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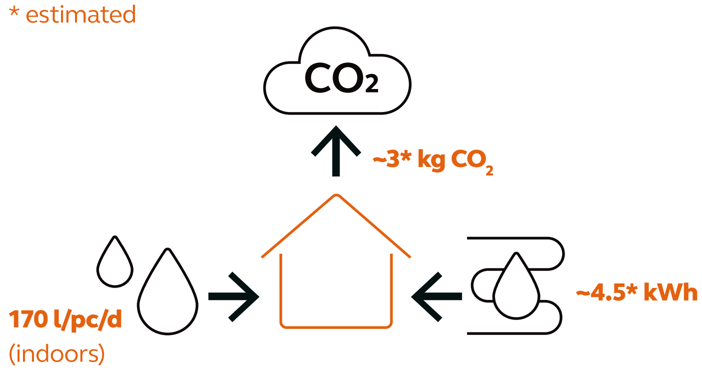
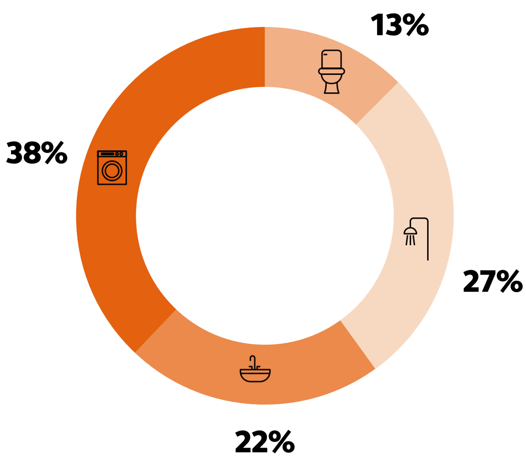




Average water use in the home[55]

The average annual carbon emissions between 2006 and 2012 from urban water utility operation in China accounted for 41 million tonnes of carbon emissions[74].

In 2015, a study showed total energy consumption by water production, treatment and distribution, end use, and recycled water reuse amounted to about 33% of the total urban energy usage[28].

China has pledged to peak its emissions by 2030 and achieve carbon neutrality by 2060 (that means cutting out all carbon emissions from fossil fuels but still allowing farm emissions of methane – another planet-heating gas)[50].

Both China and the United States have also agreed to help developing countries finance a switch to low-carbon energy.

Los Angeles

Los Angeles is a sprawling city in southern California, with a population of about 4 million. The topography varies across the city, being both flat and hilly and the Mediterranean climate provides a mild temperature range and relatively low annual rainfall[46].

Water and power is supplied by the Los Angeles Department of Water and Power (LADWP) and wastewater is managed by a different utility, Los Angeles Sanitation and Environment (LASAN).

Electricity supplied to the city is 44% fossil fuels (28% natural gas and 16% coal), 37% renewables, 14% nuclear and 5% hydropower[83]. Los Angeles hopes to transition to a 100% carbon-free power supply by 2035 [84].

The primary sources of water to the city are from the Los Angeles aqueducts, local groundwater, and supplemental water purchased from the Metropolitan Water District of Southern California (MWD). The three aqueducts bring water into the city from hundreds of miles away. Over the coming years, the city's reliance on recycled water will likely increase through OperationNEXT, a city-led initiative designed to increase recycled water supplies by providing further treatment and distribution of wastewater which is currently discharged to the ocean. Stormwater capture projects for groundwater recharge to improve groundwater reliability are also being developed for the city [85].

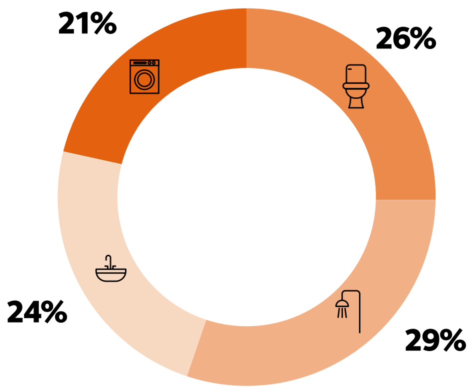
Supplying water to its customers is highly energy-intensive, with roughly 8% of the state of California's electricity consumption used in sourcing, conveying and treating water[86].

Residential water heating consumes about 3.5% of the total energy demand of the United States (US)[47].

In Los Angeles, high-income residents emit an average of 25% more carbon emissions than low-income residents[25].

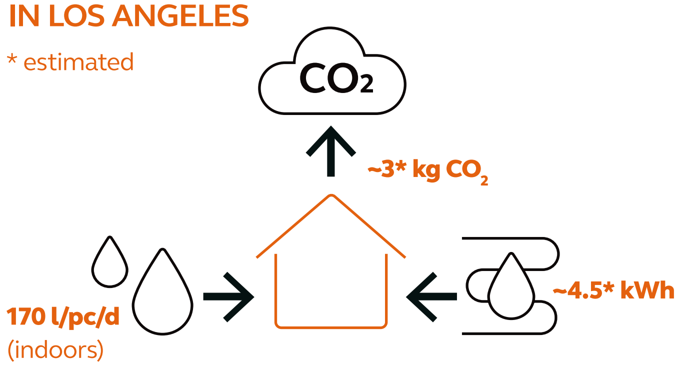
Los Angeles has committed to be carbon zero by 2050, and the United States has given a 2030 GHG Pollution Reduction Target. In 2019, Los Angeles launched a Green New Deal which aims to run on 100% renewable energy by 2045 and to recycle 100% of its wastewater by 2035[87].

In 2021, the United States set a goal to reach 100% carbon pollution-free electricity by 2035, to be achieved through multiple cost-effective pathways each resulting in meaningful emissions reductions in this decade[88].

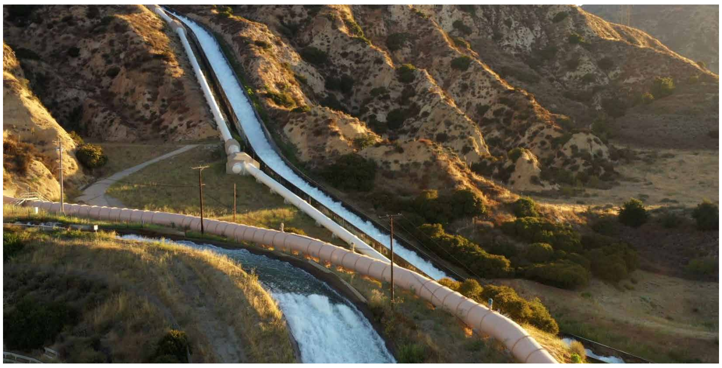


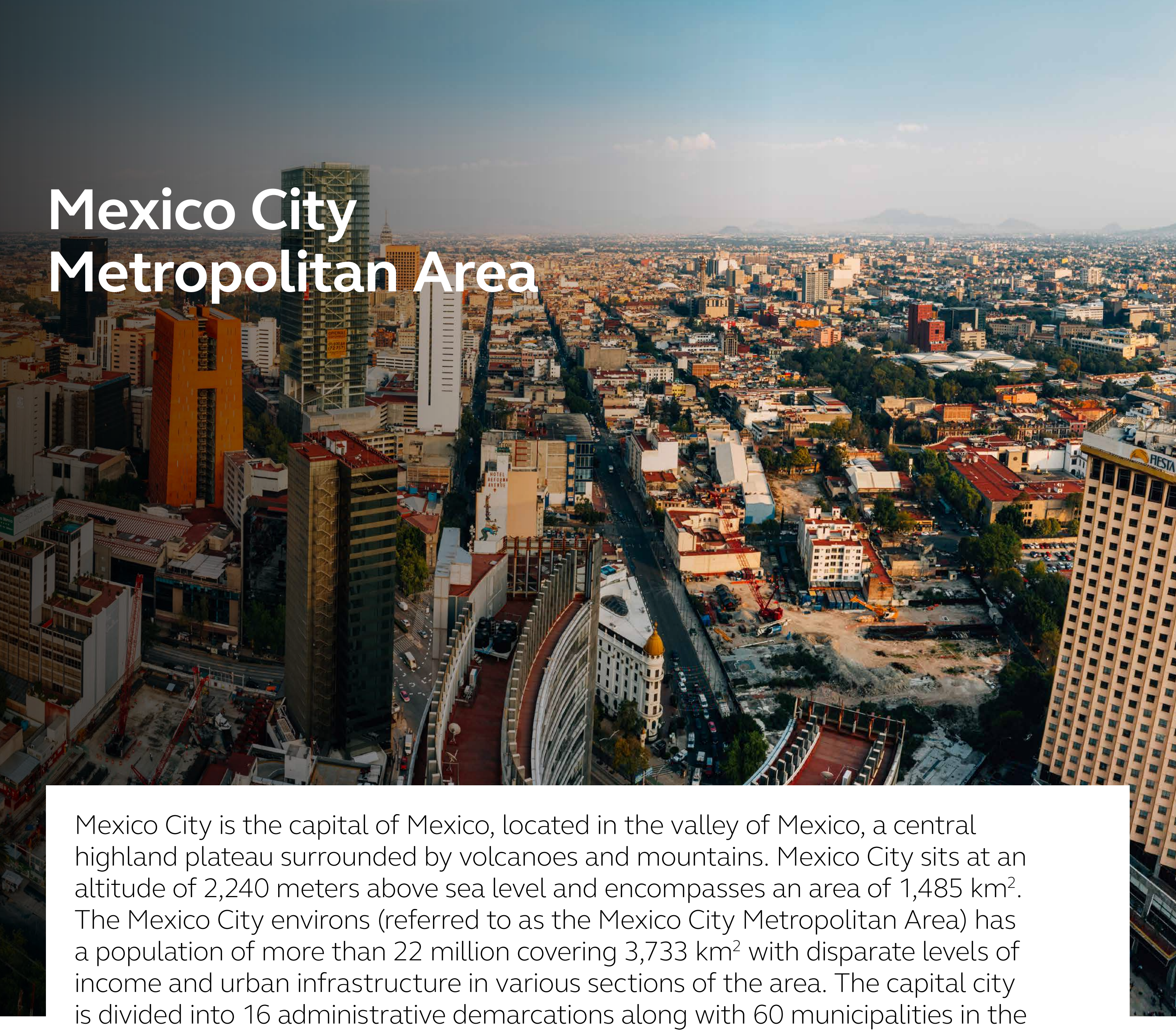
Average water use in the home (with internal leaks included)[57]

DAILY FOOTPRINT FOR A PERSON IN LOS ANGELES



The United States Environmental Protection Agency (EPA) sponsors a voluntary partnership program called WaterSense, which is both a label for water-efficient products and a resource for helping consumers save water[65]. It covers showerheads, toilets and faucets, but does not cover washing machines and dishwashing machines. There is also a government-backed scheme for energy efficiency, called Energy Star that covers all white goods[19]. This provides simple, credible, and unbiased information that consumers and businesses rely on to make well-informed decisions including, for example, equivalent water consumption on washing machines and dishwashing machines.





Mexico City Metropolitan Area

Mexico City is the capital of Mexico, located in the valley of Mexico, a central highland plateau surrounded by volcanoes and mountains. Mexico City sits at an altitude of 2,240 meters above sea level and encompasses an area of 1,485 km^2. The Mexico City environs (referred to as the Mexico City Metropolitan Area) has a population of more than 22 million covering 3,733 km^2 with disparate levels of income and urban infrastructure in various sections of the area. The capital city is divided into 16 administrative demarcations along with 60 municipalities in the surrounding area constituting the Metropolitan Area of the Valley of Mexico [77].

Water administration in the environs is fragmented and more than 50 water operators are involved in water supply and treatment. The water supplies for the Mexico City environs are mostly derived from the local aquifers and from external surface water catchments. The local aquifers supply the Mexico City environs with about 68% of its water needs. However, the aquifers currently operate at a deficit, with a recharge of only approximately 30% of the water that is extracted [78] [79].

With urbanisation, impermeable land surfaces have increased, reducing the potential for rainfall to recharge the underlying aquifer by infiltration. Local water authorities have begun to exploit deeper aquifers which will result in increased operational and purification costs. Furthermore, the over-exploitation of the aquifer has caused land subsidence within Mexico City. In some locations the rate of movement is up to 30 cm/yr. Subsidence has created additional problems of flooding, and runoff accumulation now requires active pumping for removal[80].

Two principal external water systems provide about 32% of the Mexico City environs water needs. The Cutzamala is a pumped system that conveys water over a distance of 127 km and up a rise of 1,100 m to the level of the valley of Mexico. The Lerma system within the State of Mexico pumps groundwater and surface water for delivery to the Mexico City environs. The Cutzamala system has significant operating costs. 80% of the energy costs of the responsible utility SACMEX are associated with pumping and conveyance [81]. It is estimated that the Cutzamala energy requirements is equal to 0.4% of all of Mexico's energy usage [82].

DAILY FOOTPRINT FOR A PERSON IN MEXICO CITY METROPOLITAN AREA

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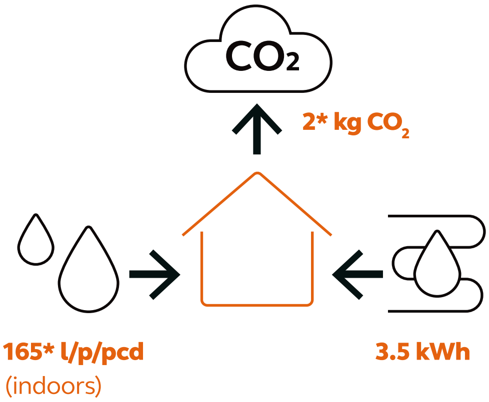
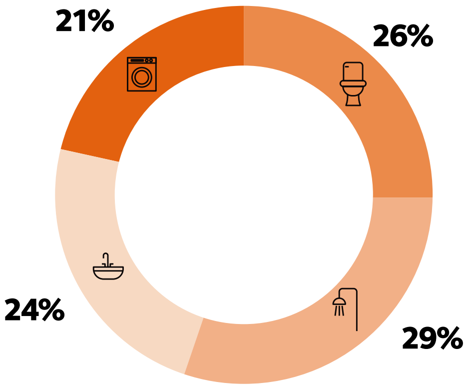


Water supply is problematic in some neighbourhoods, requiring delivery by truck. Water is becoming a flashpoint in some of the localities given issues of scarcity and quality.



Average water use in the home is estimated (based on other Latin American cities[16, 43] due to a paucity of reliable data for household use in Mexico City).

Final energy consumption of the residential sector represented 16% of the total final energy consumption in Mexico (2006 energy balance data).

Currently, wind and solar account for approximately 10% of Mexico's electricity source production. As part of the Paris Agreement, Mexico pledged to cut its emissions by 22% by 2030.

At the household level, an emphasis is made on energy efficiency norms for domestic appliances. In the public sector, the Program for Energy Efficiency in the Federal Government promotes actions to decrease the use of energy in more than 1000 public buildings.

Mexico City aims for carbon-neutrality by 2050 but, at a federal level, Mexico does not yet have a policy in place. It launched a National Strategy to Reduce Short-Lived Climate Pollutants for climate change, air quality and human health in 2020. Implementing the strategy will achieve Mexico's climate change goal to reduce black carbon emissions by 51% in 2030.

Mumbai

Mumbai is a city with a population of around 22 million, of which 41% lives in slums – both authorised and unauthorised[70]. The city lies on low lying plain with low ridges[49]. The population of Greater Mumbai has nearly doubled from 12 million since 2011, when the latest census was held[15].

The public water works supplies approx. 3,850 million litres of water daily to Mumbai against the city's demand for 4,200 million litres[62].

The water supply for Mumbai is sourced from a combination of surface water stored in lakes and river water[42]. The complex water supply system of Mumbai has another unique feature, in that almost the entire water supply distribution is driven by gravity even though water is conveyed to the city from the sources located about 100 km away. This is due to the typical geography of the region.

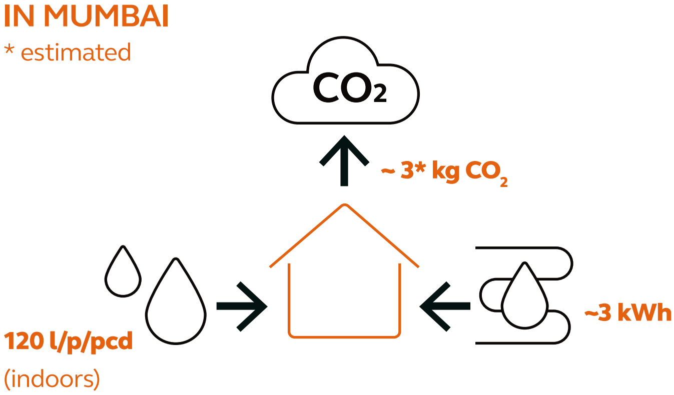
In 2019/20, the domestic electrical energy consumption was 43% of the city and the Public Water Works was approximately 1%[26]. Energy costs account for approximately 40–60% of the operating expense of supplying water[36].

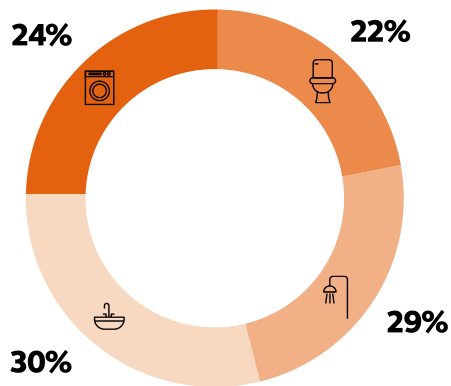
Most water and wastewater facilities in India were constructed decades ago, when electricity costs were low and therefore of limited concern[36]. Operational assets were designed to run continuously, without regard for energy efficiency[36].

The water supply is unable to meet the demand in the city, leading to intermittent daily supply[15]. Water supply is not evenly distributed to the population with 41% of the population living in slums and receiving an average of 40 l/p/d, compared to an assumed average supply to non-slums of 120 l/p/d[48]. Collection tanks and containers can provide continuity of supply but, if these are not kept hygienic, can lead to health issues.

DAILY FOOTPRINT FOR A PERSON IN MUMBAI

* estimated





Average water use in the home [48]

It is estimated that 71% of Mumbai's carbon emissions are due to electricity usage and 95% of all electricity consumed in Mumbai is coal-based. 55% of the 71% carbon emissions component is due to residential electricity usage[3]. The Mumbai government, as stated in a commitment to a 'Race to Zero' campaign, aims to cut carbon emissions in half by 2030 and aims to achieve net zero emissions by the year 2040[3].

India had three components in its Paris target[12]. India has reduced emissions intensity by 21% (2030 target is to reduce emissions intensity of GDP by 33-35%)[12]. The second target was 38% of non-fossil fuel capacity, including renewables, large hydro and nuclear (now 2% short of the 2030 target of 40%)[12]. The third component is to achieve 2.5 - 3 billion tonnes of carbon dioxide equivalent in forest cover by 2030, which needs work[12].

City level WEC nexus analysis

This section sets out a comparison of the results of an analysis of the four cities. There are many challenges associated with putting this analysis together. Data is inconsistent and often incomplete, and more than five years old. A picture of the WEC is based on multiple data sources. In itself, this highlights a problem that there is no clear understanding of how much energy is consumed by the full water treatment and use cycle.

City-wide findings

	Beijing	Los Angeles	Mexico City Metropolitan Area	Mumbai
Water consumption per home (l/h/d)	430	460	630	530
Water-related energy consumption per home (kWh/h/d)	5.7	9.6	5.9	7.1
Water-related carbon emissions per home (gCO_2/h/d)	2,880	2,380	2,060	1,330
% of city energy use associated with water use	6%	2%	6%	6%

The results from Los Angeles highlight **the importance of energy mix**. Los Angeles residents are big water and energy consumers, but due to the energy mix, the carbon footprint of this consumption is much lower than it would otherwise be.

The other three cities highlight the importance of the WEC nexus, given that carbon emissions typically represent 6% of city emissions. In Mexico City and Mumbai, **water consumption and associated energy use will only increase as poverty is reduced** and a greater share of the population have access to water networks and energy grids. In cities in emerging economies, the nexus is a growing challenge. The effective management of water use in new settlements in these cities requires particular focus.

Experience from Los Angeles shows that **efficient fittings and appliances associated with the 50L Home can make a material contribution to managing the WEC nexus**. The key area for applying these lessons is in fast -growing developing world cities, however all cities can learn from the examples presented.

Whilst cities with similar characteristics to those studied in this whitepaper may find the most easily identifiable pathway to 50L, if each city around the world enacted even some of the good practices, there would be a truly global impact.

A City Journey to 50L

The city level comparison highlights significant differences in water usage and resultant energy consumption between cities. This section focuses on cities like Los Angeles and Beijing to illustrate potential pathways towards a 50L Home for different city circumstances. Not all measures would be suited to all cities. Instead, opportunities to save water, energy and carbon emissions are highlighted through successive steps taken to manage water use through the replacement of fittings and appliances and the incentivisation of behavioural change.

The following pages illustrate two possible journeys for cities to achieve highly efficient water use couple with a decrease in energy consumption. Inspired by Beijing and Los Angeles, the city journeys proposed would be suitable to:

- a growing mega-city with rapidly increasing levels of water consumption; and
- a developed city taking steps to reduce water usage

For each journey, the following is presented:

- A graphical summary of the available steps to progressively reduce water consumption
- An analysis of the consequential energy savings
- A summary of consequential carbon reduction. The analysis is accompanied by a summary of the strategies available to encourage changes in water consumption

International standards have been overlaid to highlight how a staged water reduction programme could be mapped out, combining both behavioural and equipment-led changes.

The growing mega-city with rapidly increasing levels of water consumption is a pattern that is likely to be repeated in other cities including Mexico City and Mumbai as they continue their economic development. The adoption of the highest standards of water-efficient fittings and appliances should be a priority at the outset of these development programmes so that the need for future water efficiency retrofit is minimised. For the Mexico Metropolitan Area where water subsidies reduce the price by an order of magnitude compared to other areas of Mexico, the establishment of a new tariff system that reflects the true value of water would significantly contribute to water savings.

Outline of common water efficiency standards

WaterSense is a voluntary partnership program sponsored by the U.S. Environmental Protection Agency (EPA). It is both a label for water-efficient products and a resource for helping consumers save water.

Energy Star is the U.S. government-backed symbol for energy efficiency, providing simple, credible, and unbiased information that consumers and businesses rely on to make well-informed decisions.

BREEAM sets best practice standards for the environmental performance of buildings through design, specification, construction and operation. This standard is mainly for scale of the development (area or project budget: BREEAM does not lend itself to developments less than 1,000 m^2 and with project budgets below £1,000,000 or EUR 1.2M as the scope for improvement in projects of this size is limited).

Fixture / wet appliance	US EPA WaterSense and Energy Starv	UK BREEAM 'Excellent Performance'
Toilet	4.8 litres/flush	3 litres/flush
Bath faucet	5.7 litres/min	3 litres/min
Shower head	7.6 litres/min	3.5 litres/min
Kitchen faucet	6.8 litres/min	5 litres/min
Dishwasher	13.2 litres/load	10 litres/load
Washing machine	49.2 litres/load	30 litres/load

Journey to 50L for a growing mega-city with rapidly increasing levels of water consumption

This page presents a person's average current indoor daily water use in a city like Beijing. It provides estimated water savings that could be achieved through behavioural change in water use and retrofitting of fittings and wet appliances to increasingly stringent standards. The bottom figures then estimate the associated savings on water-related energy and carbon emissions for these water savings.

Indoor Average Water Use (Litres per capita per day)

Revisit of cultural water behaviours and/or changes to the fabric of the home – new pipework for non-potable supply, water reuse locally or regionally

Water conservation practices and replacement of fittings and wet appliances to BREEAM 'Excellent Performance' level

Replacement of Star standard washing machines to most efficient standard Energy Star standard

Water conservation practices and replacement to highest WaterSense efficiencies for all taps, shower heads and toilets

Find and fix any internal water leaks

50L 50L home Home ambition based on Beijing's % water use

79L UK BREEAM 'Excellent Performance'

129L EPA's WaterSense and Energy Star

140L EPA's WaterSense Specification V1.0

153L Current Average Use (without any indoor leaks)

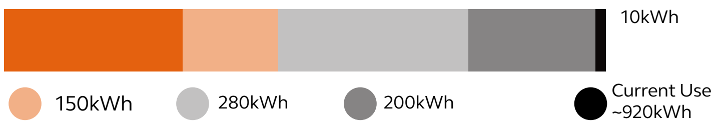
173L Current Average Use

Increasing household income leads to increasing per capita domestic water and energy use, increasing ownership of wet appliances, changing lifestyles, behaviours and perceptions on personal hygiene (such as more frequent bathing and clothes washing).

Utility providers and policy makers need to help households understand how much water they use in their homes and how it is related to energy consumption and carbon emissions.

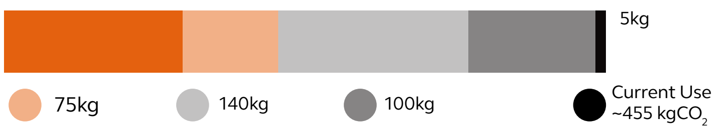
Behavioural change is behind increasing water and energy consumption and will be one of the most effective solutions to reduce it. Small changes in the home can make a significant difference, such as: reducing the length of time of a daily shower, or, when purchasing a new dishwasher, selecting the most efficient water and energy rated unit. Knowledge and education on water and energy consumption will help motivate consumers' habits.

Estimated energy savings through water efficiencies in the home kWh per person per year*



Approximately 90% of the energy consumed in the water treatment cycle is consumed in the home in heating water (the current annual water-related energy consumed through heating water in the home is estimated as 830kWh).

Estimated carbon emission savings through water efficiencies in the home $kgCO_2$ per person per year



Approximately 80% of the carbon emitted in the water treatment cycle is produced in heating water in the home.

* Covers the energy consumed in the full water treatment cycle plus heating of water

Journey to 50L for a developed city taking steps to reduce water usage

This page presents a person's average current indoor daily water use in a city like Los Angeles. It provides water savings that have already been achieved, and estimated water savings that could be achieved, through behavioural change in water use and retrofitting of fittings and wet appliances to increasingly stringent standards. The bottom figures then estimate the associated savings on water-related energy and carbon emissions for these water savings.

Indoor Average Water Use (Litres per capita per day)

Revisit of cultural water behaviours and/or changes to the fabric of the home – new pipework for non- potable supply, water reuse locally or regionally

Water conservation practices and replacement of fittings and wet appliances to BREEAM 'excellent performance' level

Replacement of dishwasher and washing machines to most efficient standard Energy Star standard

Water conservation practices and replacement to highest WaterSense efficiencies for all taps, shower heads and toilets

Find and fix all internal water leaks

Further improvements in water efficiencies were made in the home and better water conservation practices

Improved water efficiency of clothes washers and toilets accounts for most of the decreases

50L	79L	129L	139L	148L	170L	222L	262L
50L Home ambition based on LA% water use	UK BREEAM 'Excellent Performance'	EPA's WaterSense and Energy Star	EPA's WaterSense Specification V1.0	Current Average use (without and indoor leaks)	Current Average Use (with 13% indoor leaks)	Residential End Users Water (REUW) Study 2016	REUW Study 1999

Los Angeles, and greater Southern California, have a long history of water conservation that other cities could emulate. From cash for grass to free water fixtures, the city has made historical strides in water conservation reducing demand nearly 30% over the last two decades.

Key strategies to reduce demand include:

- Adopting rigorous plumbing standards and landscaping / fixture ordinances
- Adopting tiered pricing to incentivise conservation
- Promoting conservation through education, campaigns, and outreach in communities and public schools
- Rebate programs primarily catered towards residential dwellings

These strategies are transferrable to other cities, but they require good quality data of water and water-related energy use in the home to help educate householders to change their behaviours and make better informed decisions. Mandating improved efficiencies, and combining with water and energy metering, water and energy labelling schemes and enforced building regulations will help realise the most overall benefit. Water tariffs should also be reviewed for being adequate for their supply and incentivising.

Estimated energy savings through water efficiencies in the home kWh per person per year*

200kWh 450kWh 260kWh Current Use ~1380kWh

Approximately 90% of the energy consumed in the water treatment cycle is consumed in the home in heating water (the current annual water-related energy consumed through heating water in the home is estimated as 1240kWh).

Estimated carbon emission savings through water efficiencies in the home $kgCO_2$ per person per year

50kg 120kg 65kg Current Use ~360 $kgCO_2$

Approximately 80% of the carbon emitted in the water treatment cycle is produced in heating water in the home.

* Covers the energy consumed in the full water treatment cycle plus heating of water

Moving towards net zero 50L living – making the proposition irresistible

The analysis has contextualised the WEC nexus for overall city energy consumption and carbon emissions. It highlights the significant role that water plays in the city energy and carbon economy and indicates potential pathways towards a 50L Home.

But how do cities make progress? What is the combination of citizen and city action necessary to create a movement that makes the 50L Home an irresistible proposition?

This section outlines the steps that need to be taken and the levers can be used by city and national authorities. These are summarised as:

- A prioritised schedule of interventions ranging from behavioural changes by individual households to system-wide initiatives including smart-metering
- System-level changes introduced by utility companies, regulators and suppliers
- Measures beyond the scope of the ambition of the 50L Home that will contribute to reduced energy use and carbon emissions

The pathway outlined in this section shows that, whilst there are a range of routes that can be followed in pursuit of the 50L objective, ultimately all of the levers must be used. Improved access to data, integrated working by water and energy utilities regulatory incentives to reduce water use will all accelerate this process.

How households can save water, energy, carbon emissions and money!

Potential household water reduction initiatives that can be implemented include behavioural changes, metering, retrofitting water-saving devices, and installing or upgrading wet appliances. For each of these initiatives the annual water-saving potential for the household is estimated based on information from the EPA WaterSense website[65] and the average Los Angeles household water use[60]. The below are examples of individual savings and are not cumulative.

Los Angeles provides the most consistent, complete dataset of the four cities analysed. This table explores what could be done and what the potential benefits are. It is expected that this could be transferable to the other cities with improved data on household usage.

The opportunity with the most potential is behavioural change saving up to 74 m^3 and $305 annually per household, with no household investment required. Rolling this opportunity out across other cities could provide potential water savings of 20 to 70 m^3 given parts of Spain and Denmark have managed to reduce per capita consumption of water to 100 litres without major interventions.

Area	Example	Annual Savings (household)		
		Water	Direct energy / Carbon[1]	Money on utility bills[3]
Behavioural changes in home water use to reduce consumption through change to everyday habits	Use of dishwasher instead of manual dish washing. In Los Angeles it is– reported that 16 million Americans do not use their dishwasher ; there is a potential water saving of 11 litres per day if they did so.	Up to 4 m^3	Up to 130 kWh / 30 kg CO_2	Up to $7 per year in water and $5 for heating water
	Halving shower time to 5 mins, showering instead of bathing, not rinsing plates before putting in dishwasher, turning taps off when not in use – e.g. brushing teeth, shaving	Up to 70 m^3	Up to 2,300 kWh / 535 kg CO_2	Up to $200 per year in water and $92 for heating water
Retrofit of water saving devices e.g. low/variable/ dual flush toilets and cistern displacement devices, low flow/aerated taps, efficient shower heads, flow regulators, low volume baths	Los Angeles – change from an inefficient toilet to EPA WaterSense labelled	Up to 49 m^3	-	Up to $140 per year in water costs
	Los Angeles – replace toilet flappers to solve toilet leaks	Up to 35 m^3	-	Up to $100 per year in water costs
	Los Angeles – change from an inefficient shower head to EPA WaterSense labelled	Up to 10 m^3	Up to 330 kWh / 70 kg CO_2	Up to $30 per year in water costs & $11 for heating water
	Los Angeles – change from an inefficient faucet to EPA WaterSense labelled	Up to 3 m^3	Up to 100 kWh / 20 kg CO_2	Up to $10 per year in water costs & $4 for heating water
	If 15% (i.e. 1000 homes) of Los Angeles Housing Authority housing stock was upgraded to all the above	**Up to 97 m^3**	**Up to 2,200 kWh / 510 kg CO_2 [2]**	**Up to $280 per year in water costs and $84 for heating water**
Residential install or upgrade of wet appliances for better water and energy efficiencies (e.g. dishwashers and washing machines)	Los Angeles – old dishwasher upgraded to a 10 litre/cycle United Kingdom BREEAM 'excellent performance' equivalent (~7 litre saving every day/household)	Up to 2.5 m^3	Up to 80 kWh / 20 kg CO_2 [2]	Up to $7 per year in water costs and $3 for heating water
Metering/smart metering Installing smart meters for customers to understand and enable greater control over their use)	United Kingdom Consumer Council found that unmetered households use about 30 litres more water than metered homes. If ~0.5% of Los Angeles households (10,000) installed new smart water meters, each home could save up to 10m^3 a year.	Up to 10 m^3	Up to 225 kWh / 50 kg CO_2 [2]	Up to $30 per year in water and $10 for heating water

1. Energy saving based on heating water, converted to carbon saving based on 400 kg CO_2/kWh and based on data from [6],[19],[65]

2. Assume 50% hot water saving

3. Monetary rates are based on assumed $/m3 and $/kWh based on average household utility bills for Los Angeles

System-level support to 50L Home initiatives

This section explores steps that can be taken at the system-level to encourage adoption of 50L thinking. The analysis focuses on four levels of intervention, from small-scale changes in the home to whole-system management facilitated by the regulator.

The analysis highlights that multi-party action is needed at all levels of intervention, from encouraging the purchase of fittings with a high water rating to incentivising investment in new water recycling plant.

The following table sets out a range of possibilities and suggestions for consideration by utility providers, policy makers and the supply chain.

WHAT	WHO TO ACTION	HOW TO ACHIEVE
Retrofit of water saving devices, residential install or upgrade of wet appliances and; behavioural changes in water use	Water utility providers	• Educational material to homeowners including school and community education programmes • Promote water and energy efficiency schemes using multiple channels including peer peer-to to-peer and social media • Home audits including promotion for meters/ smart meters and retrofitting • Utility charge rebate schemes for evidenced use of water water-saving devices • Assistance for retrofitting, including discounted products and online material and videos
	Policy makers	• Set enforceable minimum water and energy efficiency standards for new builds and major refurbishments • Set a route map for progressive improvements in water and energy efficiency standards • Mandate and publicise water and energy- labelling scheme for fittings and appliances and set a route map for performance improvement • Consider reduced consumption incentives including metering, rebate schemes or consumption taxes for inefficient products • Consider investment incentives including fitting and appliance scrappage schemes • Fund industry innovation schemes to stimulate improvements in product or installation efficiency or to increase product availability
	Supply chain	• Develop low-cost mass-market product lines with high energy and water efficiency ratings • Invest in continuous product development in line with product efficiency rating systems • Limiting wet appliance programme settings to water and energy efficiency standards only • Positive promotion of high efficiency products – selling the 50L lifestyle

WHAT	WHO TO ACTION	HOW TO ACHIEVE
Large-scale retrofitting programme to most efficient water and energy standards	Policy makers	• Set enforceable minimum water and energy efficiency standards for new builds and major refurbishments • Establish regional retrofit strategies including links to water and fuel poverty aligned to net zero targets • Provide financial support to asset owners • Provide long-term visibility of investment programmes to support investment in the development of skills and supply-chain capacity
Metering/Smart metering, and behavioural changes in water use	Water utility providers	• Consider consumption incentives aligned to reduced water and energy use • Home audits, education and promotion of smart energy and water meters • Promotion of voluntary adoption of energy and water metering using multiple channels including peer to peer and social media • Cross-over schemes with energy utility providers • Providing improved water consumption data back to consumers and policy makers and include it in demand management decisions across the full water treatment cycle
	Policy makers	• Develop strategic objectives for smart metering in the home. Set a programme to meet these objectives • Develop strategic objectives for smart metering to promote resource efficiency across the full water treatment cycle Develop Set a programme to meet these objectives • Develop the regulatory frameworks for smart meter roll-out including funding, data sharing and security • Consider options for mandating adoption, including criteria for adoption (all homes / new build / water-scarce cities) and broader factors in decision-making including issues of equity and privacy • Consider revenue cost assistance for transition to metered water bills for vulnerable and hardship cases
	Energy utility providers	• Promote the installation of smart meters and promote installation of water smart meters • Cross-over schemes with energy water utility providers
Utility Supply Business Model	Water utility providers	• Develop tariffs that incentivise lower water usage • Design water tariffs that are fair and equitable that support the efficient operation of the network and investment in new assets • Billing to be informative to affect behavioural efficiencies • Work in partnership with other utilities to reduce total energy usage associated with the water cycle
	Policy makers	• Support utility companies in the introduction or revision of tariffs to provide fair and equitable water and energy supply across consumers and to change consumption behaviours • Support consumer transition to different water tariffs including vulnerable and hardship cases • Adopt city-wide ‘system-of-systems’ approach by water supply, treatment and energy utilities focused on optimising resource use across the water cycle • Enable public-private partnerships and collaboration where these will contribute to changing water consumption • Support investment in water recycling and other water efficiency projects through investment support and charging mechanisms

In addition to the steps listed above, other measures that can be taken to make a fundamental contribution to the reduction of energy consumption and carbon emissions in rapidly growing cities include.

1. **Reducing leakage from the network**
2. **Stormwater recovery and rainwater harvesting**

Energy associated with network leakage is substantial, representing a significant opportunity for energy saving. For example, based on a population-weighted energy loss average of 16 kWh/p/a, for a city of 22 million, the network leakage energy is approximately 350 GWh per year. Additionally, water transfer schemes are energy intensive. Furthermore, water extraction is exceeding aquifer recharge rates. Large scale stormwater recovery and rainwater harvesting have the potential to reduce the need for water transfer and therefore, reduce associated energy usage and carbon emissions.

Many of the measures that are outlined in this analysis are applied in water markets in the developed world including the United States and United Kingdom. In particular, the focusing of efforts by water utilities and the fittings and appliances supply chain has supported the development of a far greater awareness of issues associated with water consumption.

The missing link is often data. Smart meter programmes are complex and costly and are typically implemented across an integrated water network. Nevertheless, in pursuit of the 50L Home target, all cities need to plan a trajectory towards measurement and data capture to unleash consumer engagement. Simple effective communication of data is also important so that users can respond to the information they are given.

The final missing link is price sensitivity. Families are careful about energy and food consumption because both are a material household expense. In most markets, water is a low-cost, plentiful necessity. Without increasing the total cost of utilities, regulators need to consider how the costs of water, energy and carbon in the nexus can be better balanced. Price signals will play a key role in incentivising the water-energy-carbon nexus and in making the 50L Home an irresistible idea.

Application of system thinking

The WEC nexus describes a complex system that extends from the water use in energy production to the energy use in water heating. The economic, political and regulatory landscape that sits behind the nexus is typically fragmented. Actions taken by one player to improve performance or profitability may have a negative impact elsewhere in the system. This reality highlights the need for wider adoption of 'system-of-systems' thinking. Opportunities to encourage 'system-of-systems' thinking include:

- Facilitating more cross-over opportunities between utility companies, across the whole water treatment cycle
- Making better use of data to increase awareness by operators and consumers of system efficiency and consumption issues
- Linking water and energy sector policies to avoid solutions that have large externalities including:
  - Energy and carbon-intensive water processing (such as desalination schemes)
  - Large scale inter-basin water transfers that move water scarcity from one location to another

Conclusion

This paper has focused on the WEC nexus in the home. The analysis highlights that water-related energy use is large enough to justify an intervention. The 50L Home interventions provide excellent water efficiency building blocks towards meeting city net zero targets.

The cities examined are diverse in nature. Across them all, water consumption is well in excess of the 50 litre ambition. In energy- and carbon-intensive cities like Beijing, domestic water use accounts for 3% of city energy and 6% of carbon emissions.

There is huge opportunity to act in fast-growing cities in emerging and developing economies where water use will increase as economic development accelerates.

The case for the 50L Home

Although there is a strong case for the 50L Home, and for a 'system-of-systems' view of the WEC nexus, public awareness of the sustainability case for managed water use is low – even in water-stressed areas.

What causes this gap? Firstly, there is far more attention on energy efficiency as the focus for climate change action. The nexus of energy with water in climate action is missing. Furthermore, water is much less expensive than energy and easy to access so, as a result, there is less incentive to economise. Only in Mexico City and Mumbai, where a large proportion of the population does not have access to plumbed water, there is a section of the population motivated to save water.

Water and energy are not generally viewed as integrated systems, and in most cities the services are provided separately. Even collaboration between water and energy providers in the water supply and treatment stages of the cycle is limited. The regulators of water and energy do not have integrated plans for efficiency interventions in general, let alone to address the climate crisis holistically.

The final missing link is data. In putting together this study there have been significant challenges building a picture of the full implications of the WEC nexus in each city; without data, no one – consumers, suppliers or regulators –can realistically identify the best steps to take, to manage the WEC nexus.

Key findings

The water-energy-carbon nexus is a blind spot and needs to be recognised as such. Water-related energy in the form of hot water accounts for 6% of carbon emissions in most of the cities studied. The nexus is a particular challenge in rapidly growing cities. Further, because of the nexus, the full opportunity to move towards net zero through water savings cannot be realised without decarbonising energy supplies.

There is an urgent need for accessible, usable and understandable data on water and energy usage. Water reduction targets cannot be met through macro measures alone and consumer behaviour must change. However without this data, and its effective communication to consumers, it will be very difficult to encourage or sustain changes in consumer behaviour.

Decision-making needs to be integrated at all levels. As noted above, because of the nexus water, energy and carbon need to be considered as a system for interventions to have maximum effect. This means policy makers, regulators, city leaders and practitioners all need to review their ways of working and decision-making frameworks to remove unnecessary barriers to change.

So, what can households do?

1. Check water touchpoints inside homes which use energy
2. Speak to city councils or appropriate governing bodies and ask for plans to reduce water and energy use, and what incentivising options are available to retrofit the home
3. Research how practitioners can help the move towards a 50L home

Preparing for growth – the 50L imperative

Fast-growing cities like Mexico City and Mumbai have the biggest opportunity to gain from the application of the 50L principles – broadening access to scarce water resources and managing water stress more effectively.

For this to succeed, residents in these cities need to be connected with their water use. They need to know how much they are using and understand the wider impacts. Behavioural change is needed. The win-win situation is efficient use of water to address water scarcity, using less energy to contribute towards meeting city's net zero targets and, in this process, saving money – as well as driving towards a more equitable and inclusive water future for all.

As a global community, those with good potable water access need to reduce their water consumption, without compromising lifestyle and for that new level of consumption to be the irresistible desire that everyone wants to achieve.

Using less water cuts energy usage, reduces carbon emissions, saves money and, most importantly, helps address climate change.

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Appendix - Water Consumption and Water Use Analysis

The following analysis focuses on three key questions:

- How much water and water-related energy is consumed by households in each city?
- How is water used in households in each city?
- What share of total city energy use is taken up by the domestic water cycle?

The analysis is focused on domestic water use alone – water use for commercial, industrial and agricultural uses is excluded.

	Beijing	Los Angeles	Mexico City Metropolitan Area	Mumbai
Water use per capita (l/p/d)	170	170	165	120
Water use per household (l/d)	430	460	630	530
Water-related energy use per capita (kWh/p/d)	2.3	2.4	1.5	1.6
Water-related energy use per household (kWh/h/d	5.7	9.6	5.9	7.1

Comparison of water consumption

Data describing water consumption is available for on-grid consumers in the four focus cities. In Beijing and Los Angeles, the data describes the behaviours of most water consumers. This is because grid connection to water is practically universal.

In Mexico City and Mumbai, a significant proportion of the population occupies informal housing developments with a variable degree of sanitation and clean water provision. Given the informal nature of water supply in these areas, it is not possible to calculate the city-wide average household and per capita water consumption.

The data obtained for all four cities highlights that water use on a per capita basis is relatively consistent at around 160 to 170 litres, providing a baseline against which initiatives progressing towards the 50L target can be assessed.

Data figure for energy consumption associated with water use in the home for Beijing has been taken from an assessment by HeE G. et al (2019)[29]. Data on energy consumption, for the other cities, has been estimated using city-specific energy intensity coefficients. The main variables behind variation in energy use are household size, the volume of water used, mix of water uses and energy mix. Los Angeles and Beijing present the most complete and consistent data, albeit data available for Beijing is from 2012-2015. Los Angeles is interesting because the 'normal' level of water consumption (170l/p/d) is associated with a much higher level of energy consumption. This strengthens the case for the 50L manifesto in developed economies. This finding highlights the importance of more current and better higher quality data in developing cities as a tool to avoid unintended increases in energy use and carbon emissions.

Comparison of water use

The data describes patterns of water use in four focus cities for on-grid consumers. Volumes of water use in all cities other than Mumbai is similar, at 165 to 170 l/p/d, so the differences reflect variations in consumption behaviour that may have implications for energy consumption. Variations between all cities other than Beijing are not that significant – typically +/-3%. Mumbai is associated with greater use of water for culinary purposes. Our proxy data for the Mexico Metropolitan Area, shows a greater proportion of water is used for washing.

Greater differences are found in Beijing associated with a much higher consumption of water for laundry and a lower level of consumption associated with Water Closet (WC) use resulting from a cultural preference for low-water consumption floor pan toilets. The data highlights that in most cities, efforts across all aspects of water consumption are necessary to aspire to 50L Home consumption targets.

Modelling at a city level provides insights into the significance of the WEC nexus as a source of potential improvement. The modelling of water water-related energy consumption and carbon emissions in Mexico City and Mumbai considers low levels of water-related energy use associated with low-income households as well as wider issues associated with the completeness of the data. This means that the assessments of energy use and carbon emissions are subject to higher levels of uncertainty.

	Beijing	Los Angeles	Mexico City Metropolitan Area	Mumbai
Kitchen and faucets (%)	22	28	24	30
Washing (%)	27	26	30	24
WC (%)	13	28	26	22
Laundry (%)	38	18	21	24

	Beijing	Los Angeles	Mexico City Metropolitan Area	Mum wbai
Water-related energy use^ (GWh/d)	54	15	15	19
Water-related carbon emissions^ (tCO_2/d)	27,000	4,000	20,000	6,000
Total city energy use (GWh/d)	1,647	884	1,013	417
Total city (domestic) energy use per capita (MWh/d/cap)	75	219	46	19
Total city carbon emissions (tCO_2/d)	426,000	172,000	207,000	115,000
Total city carbon emissions per capita ($kgCO_2$/d/cap)	19	44	9	5
% Energy use related to water	3	2	2	5
% Carbon emissions related to water	6	2	6	6

Comparison of energy consumption and carbon emissions at the city level (^ denotes estimated energy consumed across the whole water treatment cycle)

Beijing combines near-universal access to plumbed water with levels of water use comparable to Los Angeles. Per capita energy use in Beijing is 30% of levels in the US, but the carbon intensity (carbon footprint per unit of energy) is significantly higher. As water consumption increases in grids with high carbon intensity energy sources, carbon emissions will increase rapidly. In Beijing the carbon case for 50L is very powerful.

Los Angeles, has comparatively high levels of energy consumption and carbon emissions. By contrast, as water use is relatively efficient, and appliances and fittings are typically very modern, water-related energy use and carbon emissions are quite low – below 2%. Los Angeles may be atypical compared to other US cities as previously published data suggests that water use in the US accounts for 5-6% of national carbon emissions. In practice however, developed cities have much higher levels of carbon emissions than suggested by the national average. City water use accounts for a small share of city energy use but is still a material issue at national level – this highlights the value of the 50L message to make the case for household savings.

Mexico City is another very large city, but only around 60% of the population have consistent access to water. The water consumption analysis highlights that Mexico City combines relatively high household water use with a very high energy and carbon intensity, partly related to water transfer loads as well as heating. Looked at a city-wide basis, this accounts for potentially around 2% of energy use and 6% of carbon emissions. The scale of water consumption reinforces the case for the 50L strategy in fast growing cities with carbon intense infrastructure.

Mumbai has the lowest level of connected water users and the lowest per capita energy use at 19MWh/d/cap. However, because water use by connected consumers is relatively high, the share of energy consumption and carbon emissions is the higher than both Los Angeles and Beijing, 5% and 6% respectively. Water heating in Mumbai has a relatively high carbon footprint – energy use is higher than LA. Electric immersion devices and geysers are the most common heating elements.

Terms of Reference

Approach

Through research on the relationship between water, energy and carbon, it was found that the majority (approx. 90%) of energy consumed in supplying water to homes is in heating the water in the home. This also means that carbon emissions in the water cycle are correlated to how much hot water is used in the home.

The analysis explored if this is common across four focus cities, considering how many people live in each city, how many people are in each household, their water and water-related energy use, and the percentage of water that is used for different activities in the home.

The energy consumed by the municipal supplier as the energy consumed in supplying water to the home and taking wastewater away from the home is estimated. The carbon emissions associated with this water cycle are also estimated.

The investigation identified where each city gets its water supply from, what the source of energy supplying the city is and how people generally heat water in the home. This estimates how much energy is consumed in different stages of the water cycle.

By understanding what type of energy is used the amount of carbon emitted was estimated.

Documented heating factors and efficiencies for water activities in the home have been used to estimate the energy consumed at each stage and, using carbon coefficients on the energy, the carbon emitted per person per year in the home for each city.

Comparisons were undertaken of what water efficiencies can be established in a home for each city using the U.S. WaterSense, Energy Star rated water devices and wet appliances, and the UK's BREEAM 'excellent performance' rating. This considered what a 50 litres per person per day water use would look like across two of the cities and how much energy and carbon emissions could be saved in each.

End user

The end user for water is made up of the following main groups: domestic, agriculture and industry. This paper is focused on the domestic end user, specifically on the water used inside the home in the four global cities and with a few best practice examples. Water usage for each city is given in litres per person per day (l/p/d).

Net zero

Net zero is to achieve a balance between the carbon emitted into the atmosphere, and the carbon removed from it. This balance (or net zero) happens when the amount of carbon added to the atmosphere is no more than the amount removed. In this white paper, the focus is on water and associated energy use in homes (in four global cities). Other sectors will also need to reduce carbon emissions to achieve net zero.

Water stress and water scarcity

Levels of water use vary across the world and relate to growing populations and economic shifts towards more resource-intensive consumption patterns. This increases the need for more freshwater use globally. When a country or territory withdraws 25% or more of its renewable freshwater resources it is said to be 'water-stressed'. There are 2.3 billion people living in water-stressed countries, of which 733 million live in high and critically water-stressed countries.

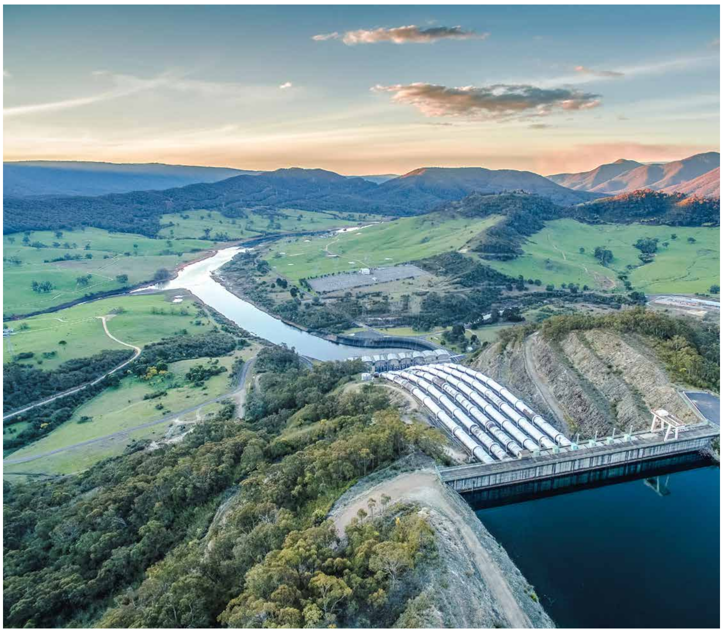
Water scarcity relates to the availability of water, due to a physical shortage or access to water because of the failure of institutions or adequate infrastructure to ensure a regular supply.

Key assumptions and caveats on data presented

The data used in this white paper has been sourced widely to present as complete a picture as possible. Data and analysis contained are estimates only and are dependent on the quality, completeness and consistency of the source data. Assumptions have been made to enable comparisons for each city on the water and water- related average energy use and their related carbon emissions for the whole water cycle, including in the home.

Analyses do not take into consideration: the range of numbers in each data set (especially with the discrepancies across wide socio-economic groups); high-rise pumping energies; wet appliance electrical energy; diurnal or seasonality of water use.

Sourced data is referenced. The age of source references should be noted, which reflects one of the data quality issues.



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