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New research

Sustainable disruption: 12 decarbonising technologies for cities

Identifying impactful, scalable and investable
technologies to drive urban decarbonisation

Start



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Foreword

Written against the background of the COP26 summit, this report acknowledges that there is no silver bullet for climate change in cities. Instead, there is an arsenal of technologies that can be deployed to drive forward the decarbonisation imperative – 12 of which are highlighted and explored in this report.

Cities, by their nature, are equipped with the concentration of activity, finance and people needed to drive that effort.

Notwithstanding consensus on the need for change, the partnerships and collaboration needed to deliver it can be complex to secure, requiring the alignment of diverse interests and priorities. New relationships will need to be established across sectors. Where there is public sector involvement, subsidy controls and public procurement requirements may bite. Many collaborations will need care around competition law compliance and appropriate information flows.

Many of these technologies are underpinned by connectivity, data flows and software systems. Tech procurement contracts can be a less obvious corollary of a net-zero strategy. Digital regulation is increasing in scope and volume, so legal and compliance risk from digitalisation may require attention, as will cybersecurity of the business or a digitalised supply chain.

Sustained adoption of some of the featured technologies may need a cultural shift. As part of that, we are seeing a transition to green jobs and sustainable HR policies.

Of course, with change comes extraordinary opportunity. The global investment community is already focusing on green tech and climate tech. Intellectual property frameworks will continue to protect investment in innovation and help to secure the revenue streams that will power these technologies yet further.

In conclusion, it is clear that climate change has become a business issue. Policymakers are driving change through regulation, funding and financial incentives. But corporates are also creating their own impetus, rethinking their business models in line with strengthening Environmental, Social and Corporate Governance (ESG) strategies.

We are delighted to have commissioned Economist Impact to produce this wide-ranging analysis. These 12 technologies, if funded and deployed successfully at scale, can make a significant contribution to the arsenal needed to secure a sustainable future for our cities.

Climate change has become a business issue. Policymakers are driving change through regulation, funding and financial incentives. But corporates are also creating their own impetus, rethinking their business models in line with strengthening Economic, Social and Corporate Governance (ESG) strategies.



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Executive summary

Produced by Economist Impact and sponsored by Osborne Clarke, this research identifies technologies that can help cities achieve their carbon-emission targets while also creating jobs, lowering energy costs for residents, and improving overall quality of life.

Key findings include:

- **Technologies that support efficiency across key sectors will have the greatest impact on urban decarbonisation.** For example, high efficiency heat pumps, district heating and cooling systems, and smart grids/smart meters all improve energy efficiency and score well in the impact category of our research. In addition to reducing greenhouse gas emissions, many of these technologies have other benefits, including lower costs for consumers, job creation and improved quality of life.
- **Nascent, ‘smart’ technologies, such as autonomous vehicles, Mobility as a Service and digital twins, could also reduce greenhouse gas emissions,** but evidence on the efficacy of these technologies can be patchy and more rigorous research is required. Their impact would be greatly enhanced if fuelled by renewable energy sources.
- **Greater public and private investment across all technologies is required.** Among the ten cities studied, policies or funding were only available for an average of 16 out of the long-list of 26 technologies researched. Private investors could support cities looking to implement technologies with high upfront costs. Meanwhile, public funding is required to incentivise citizen uptake of decarbonising technologies.



Introduction

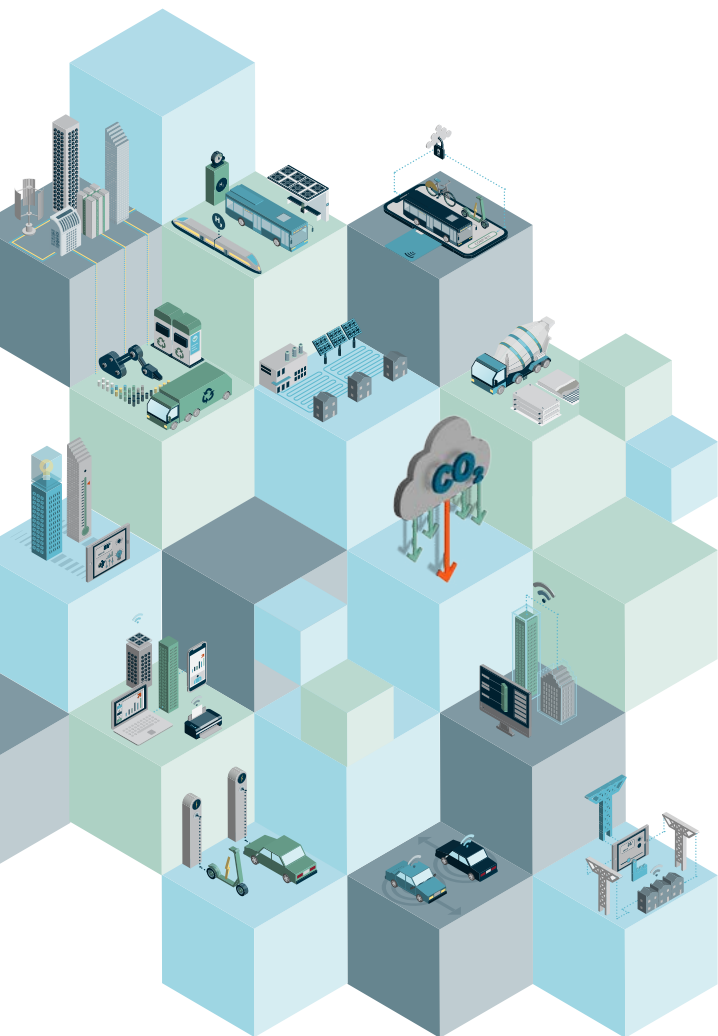
Cities are a vital part of the race to net zero – cities consume more than two-thirds of the world’s energy and account for more than 70% of global CO₂ emissions.¹

In 2019, emissions reached a record high of between 52.4 gigaton of CO₂ equivalent (GtCO₂e) and 59.1 GtCO₂e.² Although major contributors to greenhouse gas emissions, cities can often act faster and more efficiently to decrease emissions than regional or national governments.

But with a wealth of both new and established decarbonisation technologies to choose from, which ones should key decision-makers in the private and public sectors prioritise for investment?

The 12 decarbonisation technologies explored in this report show particularly exciting potential to radically impact cities’ carbon footprints and, as a result, emissions globally. They also have an interesting story to tell. In some instances, they already receive large amounts of investment or are easy to scale, in others they could create jobs, lower energy costs for residents, and improve overall quality of life.

However, some may require additional funds and/or infrastructure to scale in cities, may change the nature of cities in unwanted ways, or not live up to the hype surrounding their CO₂-reduction potential.



Definitions

- **Decarbonisation technologies:** Technologies that support the reduction and extraction of carbon-dioxide (CO₂) emissions, often through the use of low-carbon power sources or capture and storage, to achieve a net lower output of greenhouse gases into the atmosphere.
- **City:** A permanent and densely settled place of at least 50,000 residents with administratively defined boundaries.³
- **Decarbonisation:** The process of removing or reducing the carbon-dioxide output of a country's or city's economy. This is usually done by decreasing the amount of CO₂ emitted across sectors within that economy.⁴

Methodology

Economist Impact, sponsored by Osborne Clarke, set out to identify 12 impactful, scalable and investable decarbonisation technologies in ten cities around the world. These cities are: London, Berlin, Florence, Barcelona, Paris, New Delhi, Singapore, Seoul, San Francisco and New York. Both the long-list of 26 technologies and the methodological framework for analysis were chosen based on a literature review and in consultation with an expert panel.

At Economist Impact we use research frameworks to measure multi-dimensional concepts that cannot be captured by a single indicator – for example, food security, competitiveness, green growth, women’s empowerment, infrastructure development, and so on. Frameworks can be an important tool for policy analysis and public communication, while also enabling comparisons between countries and the measuring of progress over time.

Data were collected across three main categories:

Impact

- How well does the technology function in comparison to the traditional alternative?
- Is there evidence showing that this technology will help reduce carbon emissions? If yes, by how much is this technology expected to reduce greenhouse gas emissions?
- Is there evidence that the technology offers additional benefits beyond cutting emissions?
- Is there evidence that the technology could cause harm or other unintended consequences?

Scalability

- To what extent is the technology currently developed?
- How high are the initial investment costs for governments or individuals?
- What is the technology's ease of integration into a city based on additional infrastructure required, in addition to the technology itself?

Investment

- What is the total equity funding amount for companies producing this technology (in US\$)?
- What is the total number of investment firms and individual investors investing in companies that produce this technology?
- What national/regional/city regulations exist to support technology/R&D investments for this technology?

Technologies highlighted in this report perform well on *at least one* of the indicators mentioned above and have an interesting story to tell. The research and analysis at the core of this programme provides unique insights into the technologies that could have the greatest impact in helping cities achieve their carbon emission reduction goals.

12 impactful, scalable and investable decarbonisation technologies:

Technology and Thematic area	Impact	Scalability	Investment
Buildings and Construction			
Building automation systems (BAS)	Medium	Medium	Low
Digital twins	Medium	Medium	Medium
High-efficiency heat pumps	High	Very high	Medium
Low-carbon cement & concrete alternatives	High	Very high	Low
City Infrastructure			
District heating & cooling systems (DHC)	High	Medium	Medium
Smart grids & smart meters	High	High	High
Unified communications (VOIP)	Medium	High	High
Waste robotics	High	Very high	Low
Transportation			
Autonomous vehicles (AV)	Medium	Medium	High
Hydrogen transport vehicles	Medium	Medium	Medium
Mobility as a Service (MaaS)	Medium	High	Medium
Vehicle-to-grid technologies (V2G)	High	Medium	Low



Buildings and construction

The buildings and construction sector accounts for 38% of global energy-related CO₂ emissions – totalling about 13.5 GtCO₂ in 2019.⁵ Running buildings, including heating and cooling them, produces 28%, and the buildings construction industry emits another 10%, according to the Global Alliance for Buildings and Construction.⁶

Construction is expected to spiral: half of the buildings needed in 2060 have yet to be built, especially in Africa and Asia, says the Global Alliance for Buildings and Construction.⁷

In Europe, a vital priority is to accelerate the pace of retrofitting buildings to reduce their energy consumption.

To keep global warming to 1.5°C above pre-industrial levels (in line with the Paris Agreement), all new buildings must operate at net-zero carbon from 2030 and 100% of buildings must operate at net-zero carbon by 2050, according to the World Green Building Council.⁸

Cities have a critical role in decarbonising this sector because they understand the building stock and local needs, says Dr. Richardson, Europe Director of the World Green Building Council.



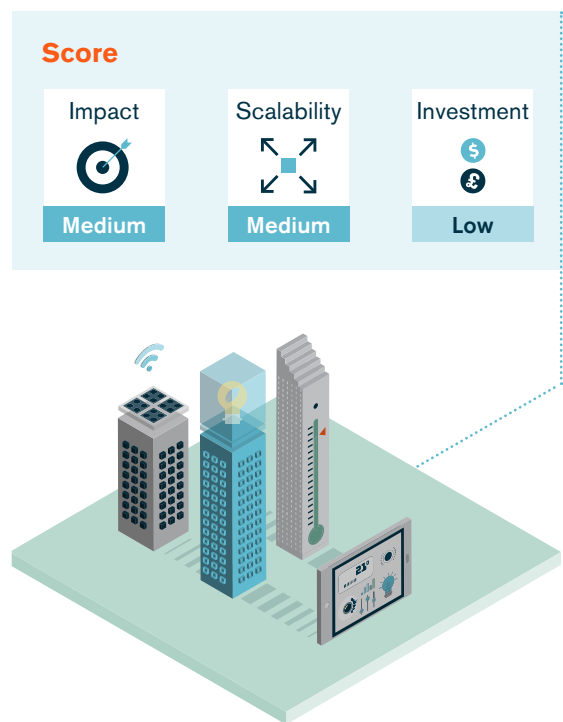
Building automation systems (BAS)

Building automation systems (BAS) equip buildings with sensors that scan and adjust systems (e.g. lighting) for maximum efficiency, particularly as regards energy consumption.

One estimate finds that BAS could deliver 20% more efficient heating and cooling and 8% more efficient energy use for lighting, appliances, etc – saving building owners US\$1.8–3.1trn (€1.5–2.7trn) in lifetime operating costs.⁹ The upfront costs to procure and install the systems needed to achieve that would be US\$225–312bn¹⁰ (€193.8–268.7bn).

BAS are ready to purchase in all the cities studied¹¹ but investment in BAS remains low. Research showed a total investment of US\$377m (€324.7m) and fewer than 500 investors as of 2021. Their high up-front costs and the complexity of building systems, have been barriers to their implementation beyond large commercial buildings in the US and EU.¹²

Public investment is rare but there are some exceptions. South Korea's Ministry of Land, Infrastructure and Transport launched a pilot scheme in 2021 to incentivise zero-energy building development. The programme offers subsidies to cover up to 80% of the cost of installing a building energy management system enabled with sensors and monitors for automated control of building lighting, heating, cooling, and ventilation.¹³



Osborne Clarke view



The spotlight shines ever brighter on technology businesses that are looking to deploy and integrate BAS and building management systems into the built environment. An increasing number of solutions now exist that seek to solve not only the integration of technology into the real estate market, but also look to address the impact that property (whether an existing or new development) has on the environment. And so the move from PropTech to ClimateTech, and a focus on the need for a more holistic solution, begins. As BAS and building management systems become more sophisticated they provide the ability for users of the technology to have tangible returns on investment, whether in terms of data use and reporting, or increased efficiencies in energy use and management. The full investment stack is understandably showing an interest in ClimateTech – whether as standalone investments or for integration into an existing property portfolio.



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Digital twins

A digital twin is a digital representation of a physical object, process or service. Digital twins rely on real-time data flows and machine learning to assess not only what is happening with a physical object today, but also make predictions about the future.¹⁴

Digital twins technology can be used to create a connected digital replica of different aspects of a city (e.g. its physical shape, how traffic and people move through it, airflow and pollution, utilities or transport). The twin can monitor and alter performance in real-time, and help city planners make decisions about existing and future problems and performance.

The technology is available to purchase in all cities included in this research.¹⁵

The technology could be very useful for planning efficiencies in the city space, helping understand the interplay between buildings and infrastructure and the built environment as a whole, says Dr. Richardson of the World Green Building Council.

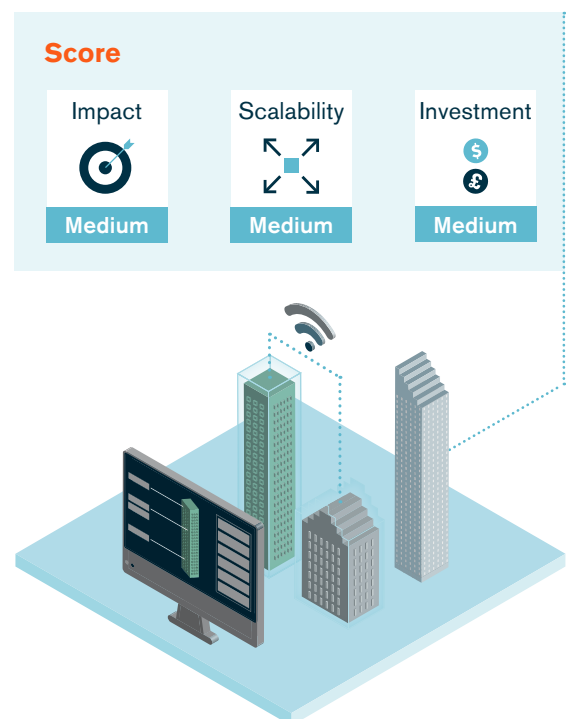
It has already been used to create virtual replicas of entire cities, including Singapore.¹⁶

The technology can also be used in the construction and running of buildings, helping to make construction more efficient, buildings more sustainable, and reduce their energy consumption. Because of its costs and complexity, the technology is better suited to large building complexes than smaller residential homes, making it quite a niche market at present, says Dr. Richardson.

However, digital twins technology could be prone to cyber attacks¹⁷ and challenges exist around data quality and interoperability.¹⁸ It also requires high initial and upkeep costs.¹⁹

As digital twins for buildings and city planning become increasingly popular, the number of investors is likely to increase – according to Crunchbase they currently number fewer than 500²⁰. This is especially likely as existing private-sector investors have already made large financial contributions totalling US\$1.2bn (€1bn).²¹

Public-sector funding is emerging. For example, Singapore has policies that support the implementation of this technology.²²



The technology could be very useful for planning efficiencies in the city space, helping understand the interplay between buildings and infrastructure and the built environment as a whole.



Virtual Singapore

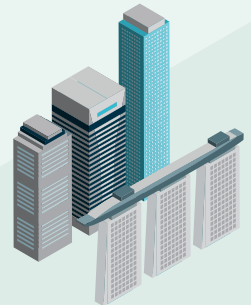
Singapore's Nanyang Technological University (NTU) used a digital twin of its campus to help curb its energy use. Analysis of the data gathered resulted in a 21% reduction in campus energy consumption and saved SG\$3.9m (US\$2.9m/€2.5m) over five years. The technology was also used to identify which energy-saving technologies would produce the greatest return on investment. These were then installed on campus, increasing energy reduction to 31%.²³

Separately, Singapore is using the technology to create Virtual Singapore – a dynamic three-dimensional (3D) city model and collaborative data platform for use by public, private, and research sectors. Many of its uses are not directly related to curbing emissions.

According to its developers, the model enables different sectors to develop tools and applications for test-bedding concepts and services, planning and decision-making, and research on

technologies to solve emerging and complex challenges for Singapore.²⁴ It can also be used to analyse light and temperature for solar energy potential.²⁵

The SG\$73m (US\$54m/€46.5m) project involves the National Research Foundation of Singapore's Prime Minister's Office, the Government Technology Agency of Singapore and the Singapore Land Authority (SLA). The SLA will become the operator and owner when Virtual Singapore is completed, the exact date of which has not yet been confirmed.



Osborne Clarke view



It is easy to see the potential benefits of digital twins for a decarbonised urban future. These will be amplified as individual digital twins become able to exchange data via open, secure and standardised protocols. But their use inevitably throws up a host of legal issues. For example, who owns the data used by the digital twins? Who has the rights to control its use? Can we ensure that historical data is retained and

kept accessible over the lifespan of a building? How can personal data be protected? What are the cybersecurity challenges that come with it? Who is liable for errors made from reliance on a digital twin? Will governments mandate the use of digital twins as part of planning processes and will financial backers of projects insist on them as a condition of funding? How will digital twins interact with the regulation of AI and data?



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While digital twin technology is relatively new, we have seen increased application of the technology in a wide range of sectors in China, from industry 4.0, which is transforming the industrial and manufacturing industries, to various public sectors. The benefits are obvious. However, has enough thought been given to the potential legal issues presented by it, especially from a cybersecurity perspective? By way of example, does

the project use any intellectual property, technology or equipment that is potentially subject to national security review requirements? Has the project implemented sufficient safeguards to protect it from cyberattacks and other malicious uses, as required by PRC Cybersecurity Law and underlying standards, especially those under China's multi-level protection scheme (MLPS) for cybersecurity, as increased connectivity inevitably brings increased security vulnerabilities? Last, but by no means least, are privacy and data protection issues. Has consent been obtained from the individuals whose personal information is used in the operation of the project? And if so, how?



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High-efficiency heat pumps

Heat pumps use electricity to extract heat from the air or ground and transfer it either outdoors to cool buildings, or indoors for heating. They have the potential to reduce emissions by 1.8 Gt annually.²⁶

They are available to implement in all ten of the cities investigated. However, they are more expensive to purchase than domestic boilers or air conditioners, and require the installation of new infrastructure in buildings. For example, heat pump heating systems require larger radiators or an underfloor heating system – both of which can be disruptive (and expensive) to retrofit for private homeowners and commercial properties. The long lifecycle of real estate means that the challenge is not only to ensure that new developments and periodic redevelopments adopt this technology, but also that retrofitting is incentivised. High-rise buildings raise further challenges for retrofitting.

All the cities studied, except Paris and Delhi, have city- or national-level policies that support the implementation of high-efficiency heat pumps. In general, high-efficiency heat pumps are heavily promoted through governmental support schemes. For example, under the UK's Domestic Renewable Heat Incentive (RHI)²⁷, households are offered incentives to install eligible heating systems, including high-efficiency heat pumps. Decarbonising heating systems is a major priority for the UK.

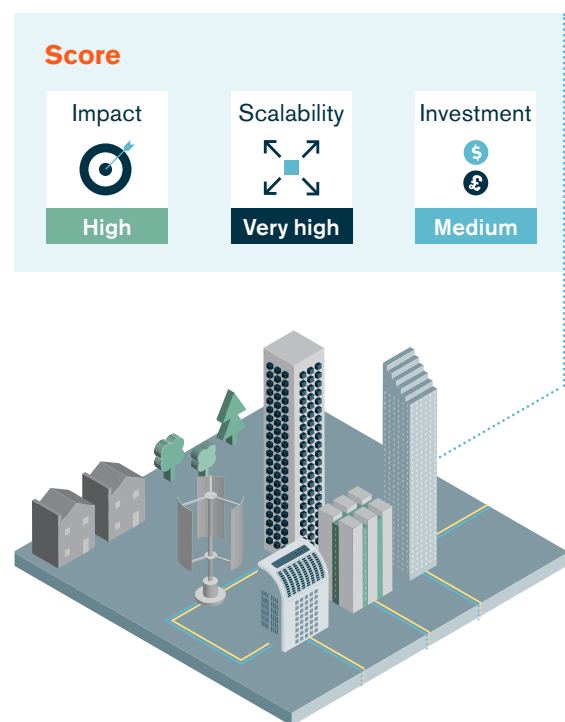
In Germany, federal funding will subsidise up to 50% of the planning and project management and up to 45% of the investment costs of high-efficiency heat pumps.²⁸

Meanwhile, parts of France have set up centres that offer customers technical support and financial advice on heat pumps.

But private investments in this technology amount to only US\$267m (€230m) from fewer than 100 investors.

The reasons behind the low uptake of this technology vary depending on the city. In the UK, for example, a strong gas lobby has slowed the roll-out of heat pumps, says Dr. Richardson of the World Green Building Council. And the sector's lack of expertise and experience in fitting and repairing heat pumps makes installers reluctant to switch to them. In 2020, the UK had just 950 accredited heat-pump installers, compared to 96,000 installers of fossil-fuel systems, primarily gas boilers.²⁹

However, one of the most important requirements around installing heat pumps is to ensure buildings maintain their temperature more effectively, says Dr. Richardson. *"There's no point in installing highly efficient technology if you've not done anything about the building's poor insulation."*



The long lifecycle of real estate means that the challenge is not only to ensure that new developments and periodic redevelopments adopt this technology, but also that retrofitting is incentivised.

Low-carbon cement and concrete alternatives

Cement is the largest manufactured product on Earth by mass, and the second most used substance in the world after water.³⁰ It already produces 8% of global CO₂ emissions³¹, with each tonne of Portland cement emitting 622 kg of CO₂.³²

Currently, 3.5bn tonnes of cement are produced annually and the Global Alliance for Buildings and Construction³³ says use is expected to expand rapidly, especially in developing countries.

Low-carbon cement and concrete alternatives can operate as well as, or better than, Portland cement, the most commonly-used cement.³⁴

Switching fully to these alternatives could reduce CO₂ emissions by between 1.7 and 2.9 Gt annually, depending on the type of cement technology used.³⁵

Low-carbon cement and concrete alternatives are already on the market in much of Europe, the US, Singapore, India and South Korea,³⁶ and there is no evidence that additional investment is needed to integrate them.³⁷ The substitution of clinker, and better mixing and packing of multi-sized aggregates in concrete, can be integrated into existing cement plant capacity.³⁸

However, low-carbon alternatives have only attracted US\$47.8m (€41.16m) in private investment as of 2021 from just a handful of investors.

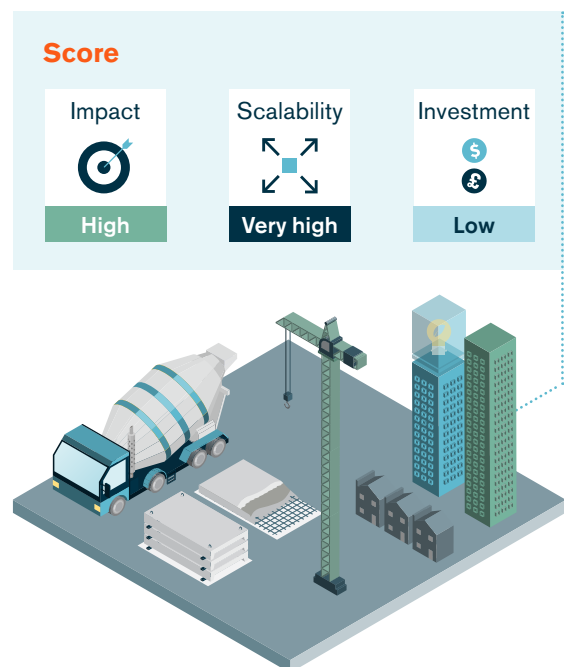
There are few regulatory incentives to make the switch and demand in many markets is low, says Dr. Richardson. In the past, companies have had to withdraw these products from the market in some European countries because of lack of uptake.

The main challenges for products already on the market are lack of supply chain awareness, and motivation to change practices that have evolved slowly over time.³⁹ Cement industries operate with very low profit margins in very competitive markets, and firms cannot generally pass on costs without losing market share.⁴⁰

Systemic change is needed: both industry leaders and government regulations must push this forward, so that low-carbon cement and alternative concrete products coming to market can succeed, says Dr. Richardson.

Changes in public procurement could have a major impact. For example, as much as 39% of all concrete in North America is purchased by public agencies.⁴¹

Paris⁴², London⁴³, New York⁴⁴ and San Francisco⁴⁵ have some local or national policies encouraging the use of lower-carbon cement and concrete. India⁴⁶ and South Korea⁴⁷ are exploring options.



Paris has adopted embodied carbon requirements ahead of the rest of France. These include assessments of emissions from construction activities and materials which must be applied to all new builds in Paris.⁴⁸

The French Ministry of Ecological Transition's 2021 cement sector decarbonisation roadmap sets out €1.2bn (US\$1.4bn) in decarbonisation support to the cement industry⁴⁹. The plan includes investing in production of new lower-carbon cements⁵⁰.

In 2021 New York State passed a bill to establish guidelines for the procurement of low-carbon concrete⁵¹.

And the UK capital's London Plan includes requirements on reducing embodied carbon⁵² – the carbon footprint of constructing a building – for all new builds. *“It’s normalising a whole life-cycle approach for the industry – one of the key things that needs to shift,”* says Dr. Richardson.



City infrastructure

Installing decarbonisation technologies into city infrastructure could help reduce energy consumption and/or carbon emissions from heating/cooling systems, transport use and waste.

Energy production and use is the single biggest contributor to global warming,⁵³ accounting for two-thirds of greenhouse gas emissions attributed to human activity. With more than half of the world's population living in cities, the energy consumption of cities has a disproportionate impact on CO₂ emissions. More efficient energy-distribution systems and the overall decarbonisation of the electricity grid will have a significant impact on the decarbonisation of cities.

Efficient waste management could also have a major impact, cutting 10-15% of greenhouse gas emissions globally.⁵⁴



District heating & cooling

A district heating and cooling system uses a central plant to channel hot or cool water via a network of underground pipes to multiple buildings.

Replacing stand-alone heating and cooling systems with district systems could reduce CO₂ emissions by 6.3–9.8 Gt between 2020 and 2050.⁵⁵ Implementing this technology can also lower investment costs for heating and cooling and reduce operating costs.⁵⁶

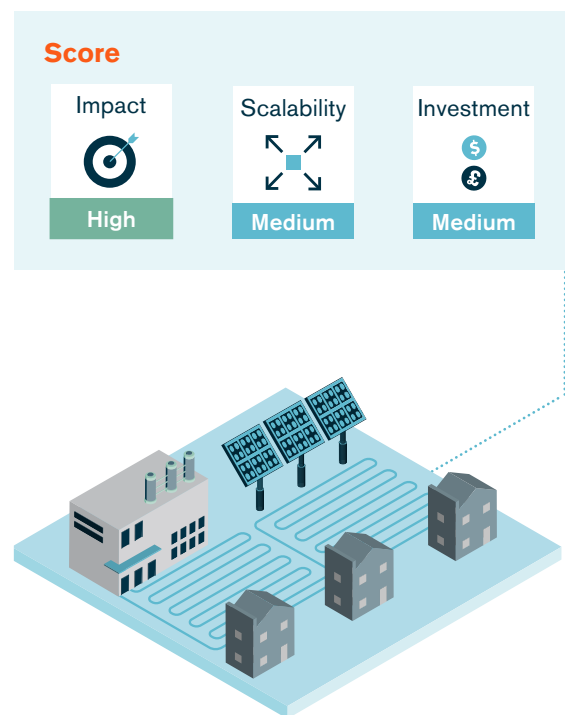
The system has strong potential to reduce the carbon emissions of cities at a systems level by reducing temperature-control-related energy consumption. The systemic nature of implementation and its costs mean that governments play a key role in providing the financial support and political will to switch to this more efficient and eco-friendly heating and cooling solution.

Globally, district heating systems cover 8.5% of space and water-heating demand in buildings.⁵⁷ Approximately 60m EU citizens are already served by district heating, with an additional 140m living in cities with at least one district heating system.⁵⁸

By contrast, district cooling systems are still a nascent market but are expected to grow rapidly.⁵⁹

New district heating or cooling systems can be built in all 10 cities.⁶⁰ Investing US\$226.8–337.4bn (€195.3–290.6bn) in installing them could save US\$1.6–2.4trn (€1.4–€2trn) in energy costs.⁶¹ However, it is very difficult to install them in built-up areas due to space constraints and the disruption involved in installing pipe networks.⁶² A major challenge for cities is the complexity of pre-existing infrastructure. However, digital geographical information system (GIS) models and heat maps can help choose optimal pipe routes and areas with high heat demand.⁶³

One of the biggest barriers is the inconvenience of installing new heat systems in existing buildings. *“One good solution is making sure that any new builds are technology-ready, so that if at a later stage you want to do electrification or district heating and cooling, you can plug in,”* says Dr. Rachel Huxley, Director of Knowledge and Learning at C40.



The system has strong potential to reduce the carbon emissions of cities at a systems level by reducing temperature-control-related energy consumption.

The extent to which they are scalable also depends on public acceptance, says Dr. Rachel Huxley. In London, for example, households are used to controlling their heating using individual boilers. Newer district heating and cooling systems rely on advanced control technology that allows individual users to better regulate heating based on their individual needs, but this is not the case with older systems.⁶⁴ Despite this, several district heating systems are being built with the aim of supplying thousands of homes, as well as commercial and office space.⁶⁵ The UK's Committee on Climate Change estimates that 13% of urban households could be converted to district heating.⁶⁶

Most of the 10 cities have public policies supporting the implementation of district heating and cooling systems, the exceptions being Florence, San Francisco and New York.

District heating and cooling systems have attracted about US\$1.5bn (€1.3bn) in private investment as of 2021 – but from only 24 investors – according to Crunchbase and Economist Impact analysis.

Public investment in some cities has been substantial. The Ministry of Trade, Industry and Energy is overseeing the rollout of district heating and cooling systems in Seoul with a total of ₩6trn (US\$5bn, €4.3bn) to be invested in district heating and cooling systems between 2019 and 2023 under the Fifth Basic Plan for the Supply of Integrated Energy.⁶⁷

City planning at an early stage in the project is essential, and regulations or policies are needed to support implementation,⁶⁸ people involved in Singapore's district cooling system say.

Osborne Clarke view



District heating and cooling has significant potential to reduce greenhouse gas emissions if generated from renewable resources or unavoidable waste heat or cooling which, by itself, may be a challenge yet to be met.

Decentralised generation of heating and cooling, as well as local heating and cooling systems with high-efficiency heat pumps powered by electricity from renewable sources, will play an important role in the future, especially against a background of rising carbon prices.



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Unified communications

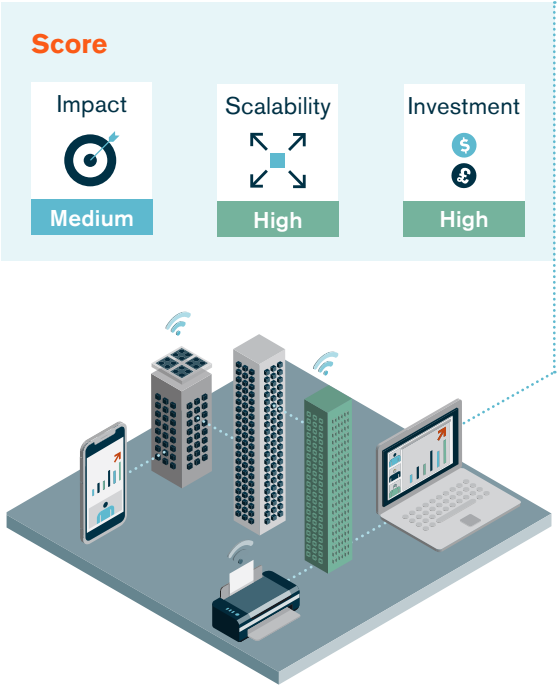
Unified communications⁶⁹ includes the equipment, software and services used to provide multiple communication channels within and between companies, such as voice, video, personal and team messaging, voicemail, and content sharing, accessed via a single integrated user interface over multiple devices including PCs, laptops or mobile phones.

Unified communications can help reduce carbon emissions by enabling Work From Home (WFH) or remote, mobile working more generally. However, although WFH reduces emissions from travelling to work, it may increase building emissions if homes have to be heated or cooled more than usual. One area where unified communications could have significant impact is on reducing business-related air travel.⁷⁰

During the Covid-19 pandemic, unified communications enabled millions of people to work and study from home. In the US, for example, 44% of employees worked from home full time, up from 17% pre-pandemic.⁷¹ The use of unified communications post-pandemic and a hybrid working model could continue to have a positive impact on emissions, as well as quality of life.

WFH has the additional benefits of saving people commuting costs and time.

There is less public-sector funding available for unified communications in general, but government policies implemented during the pandemic saw a shift towards WFH, which should encourage investment.



Osborne Clarke view



Communication is essential for successful collaboration in a hybrid working environment, but not everyone who is working from home has sufficient connectivity and some struggle with technology. One size doesn't fit all in preparing for the new normal and there are many legal considerations for employers, including reviewing employment contracts to ensure they are adequate for a hybrid working environment; transitioning to "green HR"; redesigning job specifications, redefining roles and compensation strategies; restructuring the business to accommodate new roles and transitioning to new technologies, markets and regulations.



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Osborne Clarke view



Unified communications is fast becoming the preferred communications solution for businesses in the UK. It not only provides a wide range of interconnected communications and data services, but is seen as being more agile than solutions provided by traditional telcos. As unified communication tends to be provided over existing infrastructure, it is quick and easy to set up. The only thing holding it back in some jurisdictions will be the regulatory regime. The lack of public funding available for it will not hold back its growth and development.



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Smart grids/smart meters

A smart grid uses technology to enhance the communication, automation and connectivity of various components of the power network. Smart grids rely on smart meters to collect data on energy use and help power plants better predict and respond to periods of peak demand.⁷²

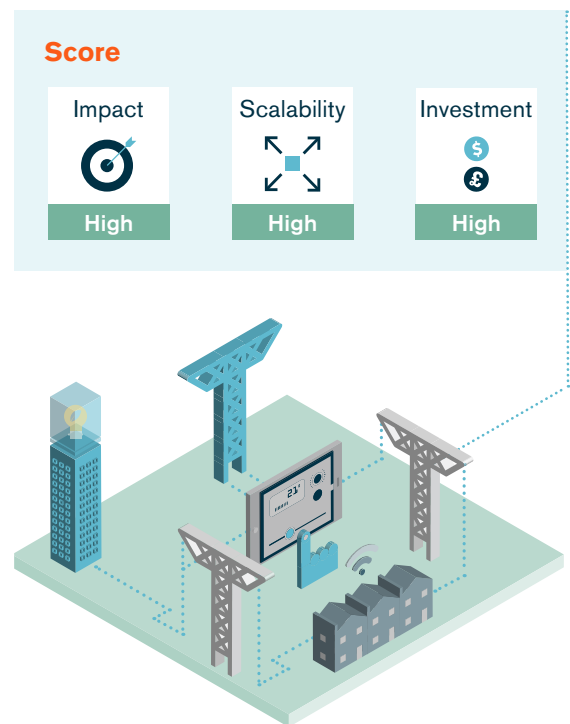
Some estimate that smart grids and smart meters could cut energy and CO₂ emissions by 12%.⁷³

Smart grids also offer more efficient transmission of electricity and faster restoration of electricity after power disturbances. They reduce operation and management costs for utilities, and can be used to smooth out peaks in demand, both of which could feed into lower power costs for consumers. They can also increase integration of large-scale renewable energy systems, which reduces the overall CO₂ emissions of the electricity grid.⁷⁴

Smart grid and smart meter technology is widely available to purchase and has attracted a lot of private investment, totalling US\$3bn (€2.6bn) with 470 investors in 2021.⁷⁵

Public policies in many countries have helped drive demand. For example, the EU set a target to replace at least 80% of electricity meters with smart meters by 2020.⁷⁶ In many countries the cost has been borne by national electricity bodies.

India is rolling out one of the world's largest electricity smart metering programmes⁷⁷ to help improve the efficiency and revenues of distribution utilities. All capital and operating expenditure is paid for by India's Energy Efficiency Services Ltd (EESL) under the Ministry of Power.^{78,79}



Smart grids can increase integration of large-scale renewable energy systems, which reduces the overall CO₂ emissions of the electricity grid.

Osborne Clarke view from India*



Despite narrowing the gap between demand and supply of power in India, most Indian distribution companies are still making significant losses. In part, this is due to transmission losses and poor recovery efficiencies. To overcome these issues, India has embarked on an ambitious smart grid and smart meter journey, with completion projected in the next decade.

The Smart Meter National Programme (SMNP) plans to replace 250m conventional meters with smart meters that will allow consumers to track how much power they use, when they use it and its cost. Real-time pricing will allow consumers to save money by using less power when electricity is most expensive. Web-based monitoring systems will also help to enhance revenues and inform power sector reforms.

This programme is being implemented by Energy Efficiency Services Ltd (EESL), a joint venture between public sector undertakings (PSUs). All capital and operating expenditure will be met by EESL. Under the programme, EESL has already replaced around 1.3m meters and has procured a further 15m.



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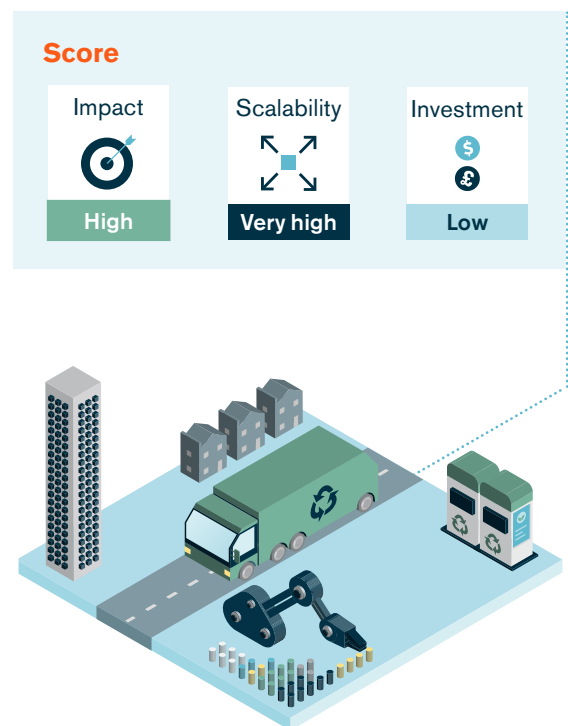
Waste robotics

Waste robotics uses Artificial Intelligence (AI) to sort recyclables, including, for example, dismantling used phones and electronic equipment.

Because waste robotics automates the recycling process and reduces the margin for error, this could cut the amount of waste sent to landfill by up to 75%.⁸⁰ This means more items can be recycled or reused in the circular economy, avoiding emissions from producing virgin materials and new products.⁸¹

Better waste management – including disposal, recycling, composting and treatment – could cut 10-15% of greenhouse gas emissions globally.⁸²

This technology is available to deploy at recycling centres around the world⁸³ but more public and private investment is needed to develop and roll out this technology. Private investment totals US\$108m (€93m) from fewer than 100 investors as of 2021.⁸⁴



Osborne Clarke view

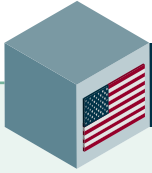


It is important to understand that machine learning itself is an energy-intensive technology. It relies on the scale and power of modern computing infrastructure to develop its insights and, in general terms, vast quantities of data to improve them. Any responsible decision to deploy AI will therefore comprise a delicate balancing act that should prove that the demonstrable benefits of a particular use case outweigh the embodied carbon generated by its development and operation.

Clearly, AI is not the proverbial silver bullet and will not solve climate change in itself – it is only a tool. That said, there are many contributions that AI can make to address the decarbonisation challenge. Depending on its use, it can have a tremendous indirect impact on environmentally protective solutions, from distilling vast quantities of data into actionable insights on deforestation and climate change on a grand scale to more prosaically providing energy-efficient algorithms to optimise domestic heating. Given the breadth of ways in which AI can positively support the delivery of decarbonisation initiatives, it would be a tragedy if a lack of sustainable vision in its deployment ultimately undermined those advantages.



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Case study

San Francisco

San Francisco's primary refuse service provider, Recology, has automated part of its sorting line with AI-programmed industrial robots to sort plastics.⁸⁵ It also uses robotic sorters to perform quality control at its construction and demolition recovery facility, including identifying plasterboard and recyclable wood.⁸⁶ The company serves more than 880,000 residential and 110,000 commercial customers in California, Oregon, and Washington.⁸⁷

San Francisco has pledged to reduce the amount of solid municipal waste disposed of in landfill or by incineration by at least 50% by 2030, compared to 2015, and to increase the diversion rate away from landfill and incineration to at least 70% by 2030.⁸⁸

According to the City of San Francisco, "Recology, our primary refuse provider, rolled out smaller trash and larger recycling bins to residents throughout the city. The new bin configuration resulted in a 7% decrease in trash, a 10% increase in recycling and a 1% increase in composting."⁸⁹

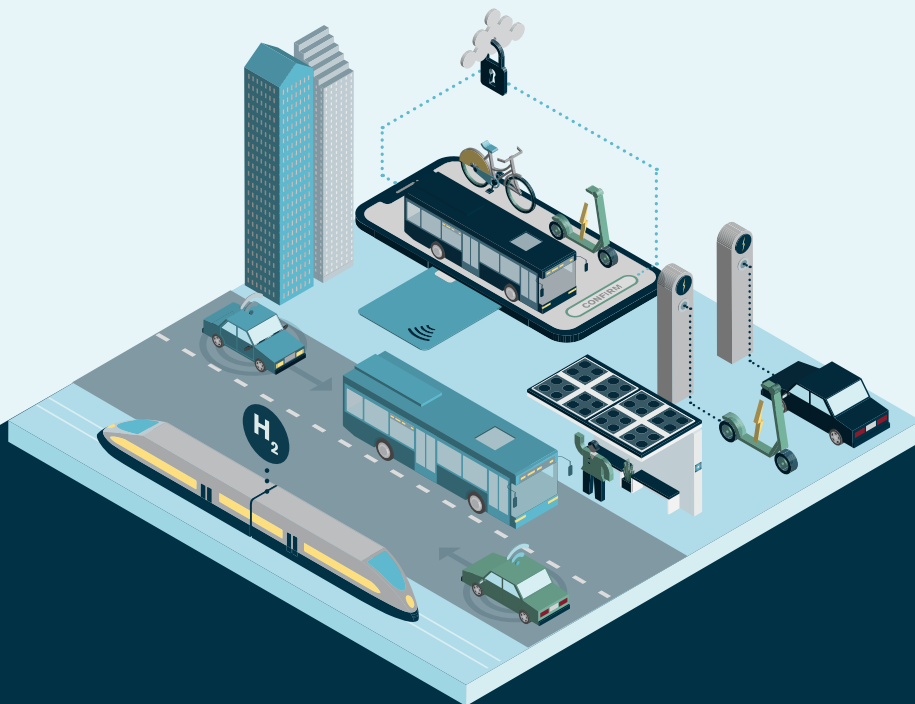




Transport technologies

From large sprawling mega-cities to small towns, transport systems play a key role in the functioning of urban life.

Transport accounts for one-fifth of global CO₂ emissions and in high-income countries, it can be the largest segment of an individual's carbon footprint.⁹⁰



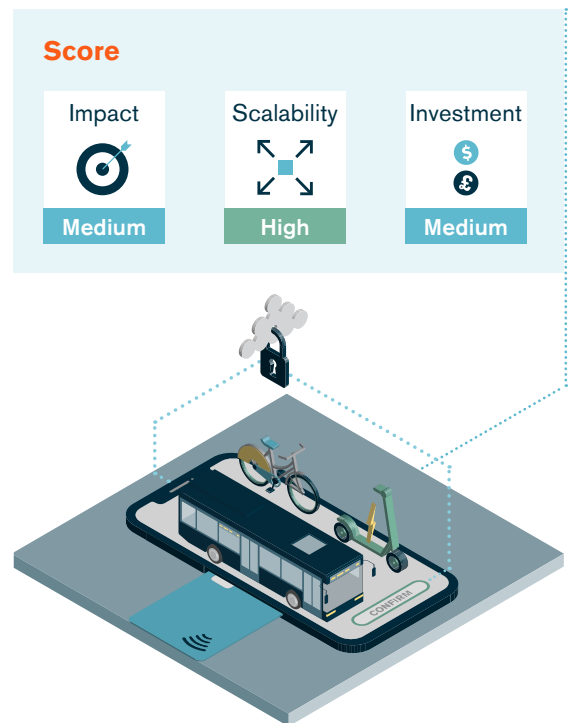
Mobility as a Service (MaaS)

Using a phone or web app, MaaS integrates traditional public transport with private mobility options (potentially including taxis or car hire, as well as newer mobility services such as ride-sharing or e-scooters), allowing users to travel door-to-door with a single interface. If people use personal cars less as a result, this could reduce city emissions.

MaaS has the potential to offer substantial additional benefits beyond carbon-emissions reduction⁹¹. Public authorities can better understand mobility patterns, and travellers benefit from an enhanced travel experience without owning a private vehicle.

However, the system has potential security risks and significant logistical and technical challenges with development and implementation.

Public authorities can better understand mobility patterns, and travellers benefit from an enhanced travel experience without owning a private vehicle.



Osborne Clarke view



Next to the funding and operational challenges, MaaS raises complex legal issues. One must ensure market players, in particular mobility service providers, enjoy equal access and fair usage conditions with respect to the data sharing platform. A web of contracts will govern the relationships with operators, data sources and business users. Obviously, the protection of end users is another key consideration, and MaaS

operators will need to navigate several regulatory layers. Given the potential privacy concerns, data protection rules will have a significant impact and will bear on the ability to pool data, track users and monitor their utilisation, as well as share outputs for other purposes, including achieving goals of public interest, such as a better management of public transportation networks.



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In some cities, there is also a risk it will result in a spiralling number of vehicles and make cities more car dependent, says Peter Newman, coordinating lead author for transport in the Intergovernmental Panel on Climate Change (IPCC)'s sixth assessment report (AR6) and professor at Curtin University's Sustainability Policy Institute in Bentley, Perth.

The technology is available to purchase across all cities in the study, with relatively low costs and opportunities to leverage existing transport infrastructure. However, it has only been rolled out in a handful of cities globally, and there is limited data on how many people actually use the service.⁹²

Private investment is high – US\$2.3bn (€2bn). But MaaS has not yet received substantial government funding compared to other technologies in the study.

Two exceptions include the UK, which has committed £90m (US\$123m/€106m) to trial transport technologies, and the US, which allocated US\$3.5m (€3m) in June 2020 for the Mobility for All Pilot Programme Grants, which covered projects in 16 states to address mobility issues for vulnerable passengers.⁹³ EU-funded MyCorridor – a €3.5m (\$4m)⁹⁴ research project – aimed for a minimum 15% shift from private car to shared transport solutions in its pilot cities.⁹⁵

Osborne Clarke view



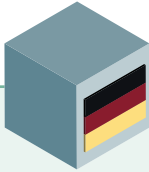
Italy has announced the "Mobility as a Service for Italy" plan, launched in the context of the National Recovery and Resilience Plan. It is aimed at innovating transport services in Italian cities through the creation, in partnership with private entrepreneurs, of a digital platform for the management of mobility needs, efficiently selecting and combining intermodal means of transport. The current phase of the "MaaS for Italy"

plan covers the selection of three pilot projects, sponsored by large municipalities, with completion expected within 2021. Satellite projects, linked to the pilot projects, are expected in the near future.



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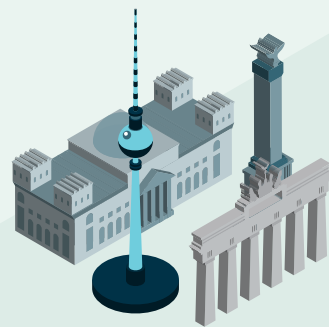
Case study

Berlin⁹⁶

Berlin's public transport operator, BVG, launched the Jelbi mobility service in 2019,⁹⁷ a smartphone app that aims to wean people off their cars and encourage them to use public and sharing transport to help reduce emissions.

Jelbi connects existing car-sharing and bike-sharing companies, public transport, and taxis. Sebastian Wolf, Jelbi project lead at BVG, told Cities Today,⁹⁸ *"Our competitor is the privately owned car, not other private forms of mobility."*

Users can plan and book their journey, comparing prices and expected travel times. The Jelbi service also installed mobility hubs in neighbourhoods and next to subway stations, where users can find shared-use cars, bicycles and scooters.



Osborne Clarke view



The implementation of MaaS platforms brings to light the issue of associated payment solutions. The aim? To guarantee the best paperless/cashless experience for the user. Several approaches facilitating the dematerialised management of cash flows can be envisaged but they need a review of the functionalities of MaaS platforms in the light of European regulation of payment services. Why? Because collecting funds on behalf of third parties is in most cases a regulated activity.

In France, since the adoption of the 2019 mobility orientation law offering employees a comprehensive mobility package paid for by employers, several transport and smart ticketing players have positioned themselves to offer companies specific payment instruments. This way, they can be used by their employees for the consumption of mobility packages.



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Vehicle to grid technologies (V2G) for electric vehicles (EVs)

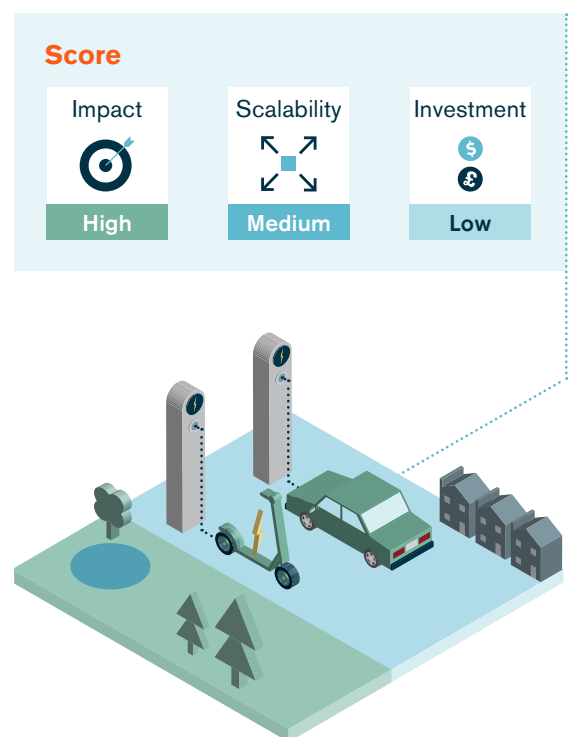
V2Gs enable EV batteries to both charge and discharge their energy into a power grid, effectively turning car batteries into storage for wider use across the energy network.

Balancing supply and demand is becoming more difficult with the increasing proportion of renewable energy generation, some forms of which cannot be controlled by suppliers but depend on weather patterns (wind, sunshine etc). In this context, storage becomes more important. If energy from a charged car battery can be fed back into the grid at times when demand for energy is high, that can support grid balancing and potentially reduce the grid's need for energy from carbon-intensive sources at peak times. The car would be charged when demand is low or when supply is higher than demand due to excess generation from renewable energy sources.

V2Gs could enable a 24% reduction in greenhouse gas emissions, while also improving the efficiency, stability and reliability of the electricity grid in cities as well as maximising renewable electricity production.

There are other potential benefits. V2G technologies could give owners of fleets of electric vehicles an additional revenue stream, incentivising them to go electric. They can receive price signals that help them decide when to charge, discharge, or use their vehicles for their business operations.⁹⁹

Some are exploring the possibility of incorporating utility vehicles with V2G technologies in emergency plans for cities. During a blackout for example, they could be used to create microgrids or to power emergency shelters.¹⁰⁰



V2G technologies could give owners of fleets of electric vehicles an additional revenue stream, incentivising them to go electric.

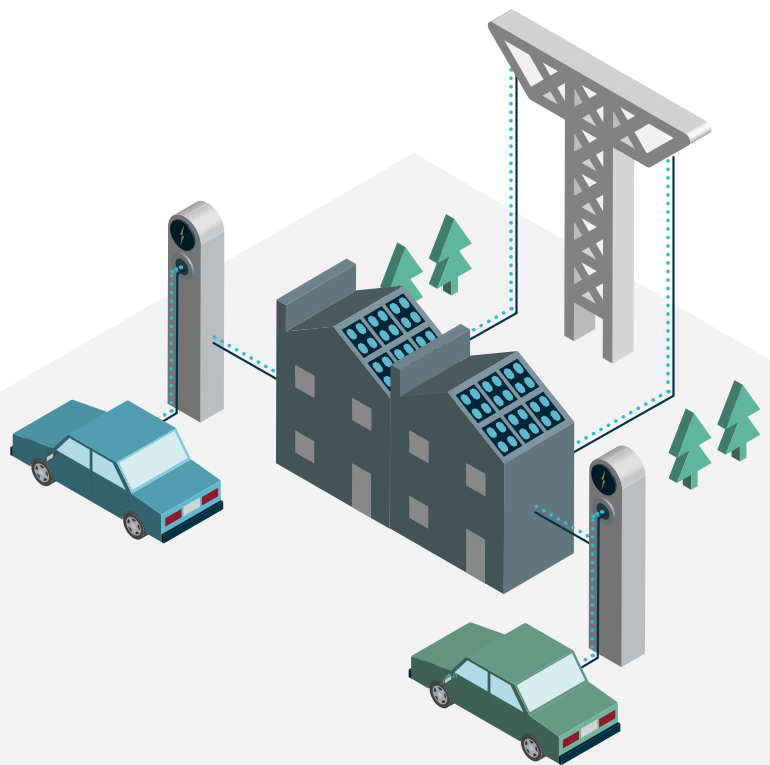
Although V2G technology is excellent in theory, it may be difficult to roll out in practice, says Promise Udekwe, Founder and CEO of elow (formerly CSN Energy). Its ability to reduce emissions still needs to be proved, as does the viability of its business model, he says.

Currently, V2G technologies are in the pilot stage for most cities in the study, with some implementation occurring in France, Spain, Korea, the UK and the US.

Only US\$35.5m (€30.6m) in private investment is earmarked for V2G technologies as of 2021, and there are very few government initiatives.

In January 2020, the Italian Ministry of Economic Development published a decree that set out criteria and methods to promote integration between EVs and the electricity grid.¹⁰¹

National grid operator Terna is trialling a pilot project in Turin¹⁰² that uses V2G technologies on EVs waiting to be delivered to the sales network. The potentially high number of vehicles stored for long periods in one place could provide an aggregated service to the network.



Autonomous vehicles (AVs)

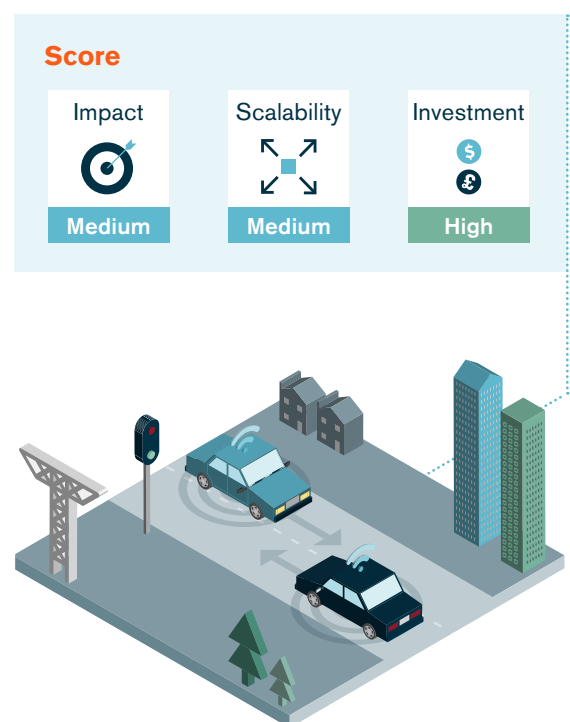
AVs rely on artificial intelligence, including machine learning systems, computer-vision algorithms, and sensor systems such as Lidar, to drive autonomously.

There is a lot of hype about the promise of AVs, and many companies and cities are investing heavily in AV technology and infrastructure. Electric AVs could have a positive impact on emissions. Not only do they rely on electric batteries, but the ‘autonomous’ element means that there is less waste in battery usage (even compared to a traditional electric vehicle). This is because more battery power will be consumed when driving quickly, braking or re-accelerating excessively which does not happen in an autonomous vehicle.¹⁰³ That said, given that AVs are not fully operational, there is conflicting evidence and not yet enough data on whether they would increase or decrease emissions in the long term,¹⁰⁴ and would only work as a decarbonisation technology if they were rolled out as *electric* autonomous vehicles. They also have other benefits, including improved accessibility, mobility and driving efficiency while reducing traffic congestion and accidents.¹⁰⁵

Fully self-driving cars are not yet available but automation is being implemented in stages and continuing to improve.¹⁰⁶

AVs are one of the most investable technologies in this report. Companies include Tesla, Uber, Amazon and Microsoft. More than 3,165 individual investors have invested a cumulative US\$87bn (€75bn) worldwide, according to Crunchbase. The main driving force, however, is private profit rather than environmental sustainability.

Some cities are following suit. For example, in July 2021, the Seoul Metropolitan government created an ordinance to provide administrative and financial support for testing the operation of AVs in designated areas. The government plans to invest ₩1.1trn (US\$932m) in AVs between 2021 and 2027.¹⁰⁷



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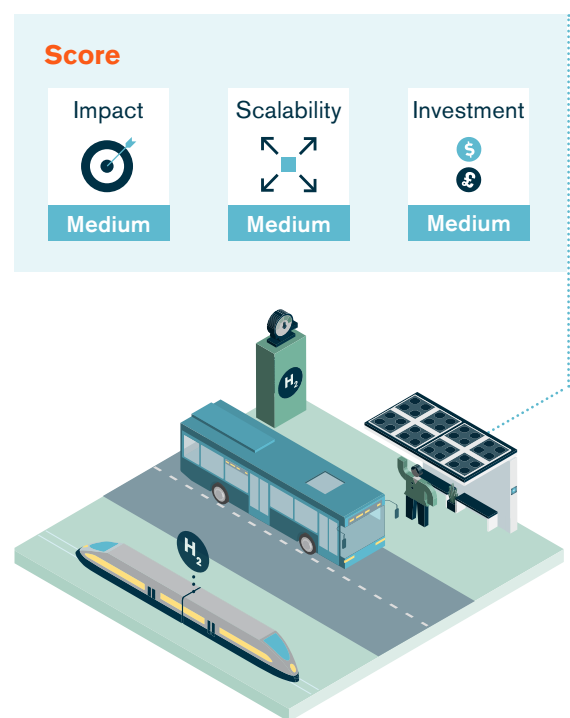
Hydrogen vehicles

A hydrogen vehicle is powered by hydrogen fuel, which can be generated from renewable resources such as solar and wind – green hydrogen – as well as fossil fuels.

Hydrogen vehicles are better suited to long-haul routes compared to standard battery-powered EVs. This is because batteries for heavy road freight would need to be large and heavy. Even when produced using fossil fuels, hydrogen vehicles are estimated to reduce greenhouse gases by 30% compared with their conventional gasoline counterparts.¹⁰⁸

While the total amount of private investment for hydrogen transport is high (US\$2.4bn as of 2021), the number of individual investors is below 100 as of 2021. This discrepancy suggests that concerns about cost could be preventing private investment on a wider scale. Hydrogen transport also relies on the production of green hydrogen to meet its full decarbonisation potential. This is currently in short supply and its production needs to be scaled up.

Lower levels of private investment may be offset by city, national and regional investments. The EU-funded JIVE 2 project (Joint Initiative for Hydrogen Vehicles) aims to deploy 152 new zero-emission fuel cell buses and associated refuelling infrastructure across 14 European countries, including France, Germany, Iceland, Norway, Sweden, the Netherlands, Spain and the UK.



Osborne Clarke view

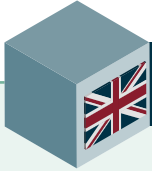


Hydrogen can play a vital role in decarbonising transport in those sectors where battery electrification is not cost effective, provided use cases that support investment models can be developed. Heavy road freight, maritime, bus and coach and those areas of the rail network where lineside electrification is not an option are all good candidates. The solutions adopted will, in the longer term, need to use green hydrogen

and depend on the creation of both infrastructure and a regulatory framework to support mass take-up. Recent studies suggest that it may be more efficient to ship hydrogen produced from renewable sources to where it is needed, although pilot projects using co-location of hydrogen production from wind and solar sources have also been successful. A focus on discrete areas using hydrogen technology – the strategic road network or "clusters" leveraging production and usage across multiple sites – appear most likely to result in investable models.



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Case study

London buses

London recently launched 20 new hydrogen-fuel-cell double-decker buses to help reduce the city's carbon footprint, curb harmful pollution, and create new jobs.

They have a range similar to conventional diesel vehicles achieving 350-400 miles (560-640 km) on a single tank of fuel, and they can be refuelled within 3-5 minutes.¹⁰⁹ From 2023, the hydrogen will be produced by electrolysis powered by a direct connection to an offshore wind farm.

The buses are funded with £6m from the government-run Transport for London, £5m from European bodies – the Fuel Cells and Hydrogen Joint Undertaking, and the Innovation and

Networks Executive Agency (INEA), an executive agency of the European Commission – and £1m from the UK's Office of Zero-Emission Vehicles.¹¹⁰

The project is helping to support or create jobs in the UK to manufacture the buses and gas cylinders, and transport the hydrogen fuel.



Conclusion

Technologies with strong potential to reduce emissions are available to scale in all the cities studied. In many cases, they can bring additional benefits – cleaner air, lower energy bills, savings on commuter costs, and job creation.

However, scaling them requires regulatory, policy and financial incentives. For example, lack of policy incentives is impacting the uptake of low-carbon cement and concrete alternatives. Conversely, national/regional targets backed by public funds have played a vital role in scaling up smart meters/grids.

The majority of technologies need substantial additional public and/or private investment to scale. Even technologies that have high impact and scalability potential receive low amounts of funding. These include low-carbon cement and concrete alternatives, waste robotics and V2G technologies.

Public funds have helped start the roll-out of hydrogen vehicles, high-efficiency heat pumps, and district heating/cooling systems. But they require much more investment to scale in the cities explored.

High-tech and “smart” solutions tend to attract the most investment or largest number of investors. These include AVs, unified communications and smart meters/grids.

Nascent, “smart” technologies like AVs and MaaS could reduce greenhouse gas emissions, but evidence can be patchy and trade-offs remain.

Technologies alone will not decarbonise cities. For example, digital twins, BAS and smart-meter technologies are useful tools that can be used to monitor energy usage and emissions, but these data need to be acted on to avoid or reduce emissions.

Dr. Richardson, Europe Director of the World Green Building Council, suggests reducing the consumption of construction materials, including concrete is as important as switching to lower-carbon cement. And improving the fabric of buildings is as important as installing high-efficiency technologies like heat pumps.

Similarly, transport vehicles will not meet their decarbonisation potential unless the hydrogen or electricity that powers them is produced from renewables or other low-carbon sources.

The most important actions national and municipal governments can take in the building and construction sector, is to encourage energy retrofits of existing buildings, and new and stronger standards in new builds. These create the environments for the use of technologies, says Dr. Rachel Huxley, Director of Knowledge and Learning at C40.

All cities in this report have announced targets to reach net zero,^{111,112} most of them by 2050.¹¹³ Many of the technologies explored in this report could play an important role in reaching this goal, but more incentives and investment are urgently needed to scale them.

Companies also need to play a part in the decarbonisation of cities, which might include support for these technologies through funding, reinvestment of corporate profits into projects incorporating these technologies, or through their procurement and purchasing decisions.

Osborne Clarke view



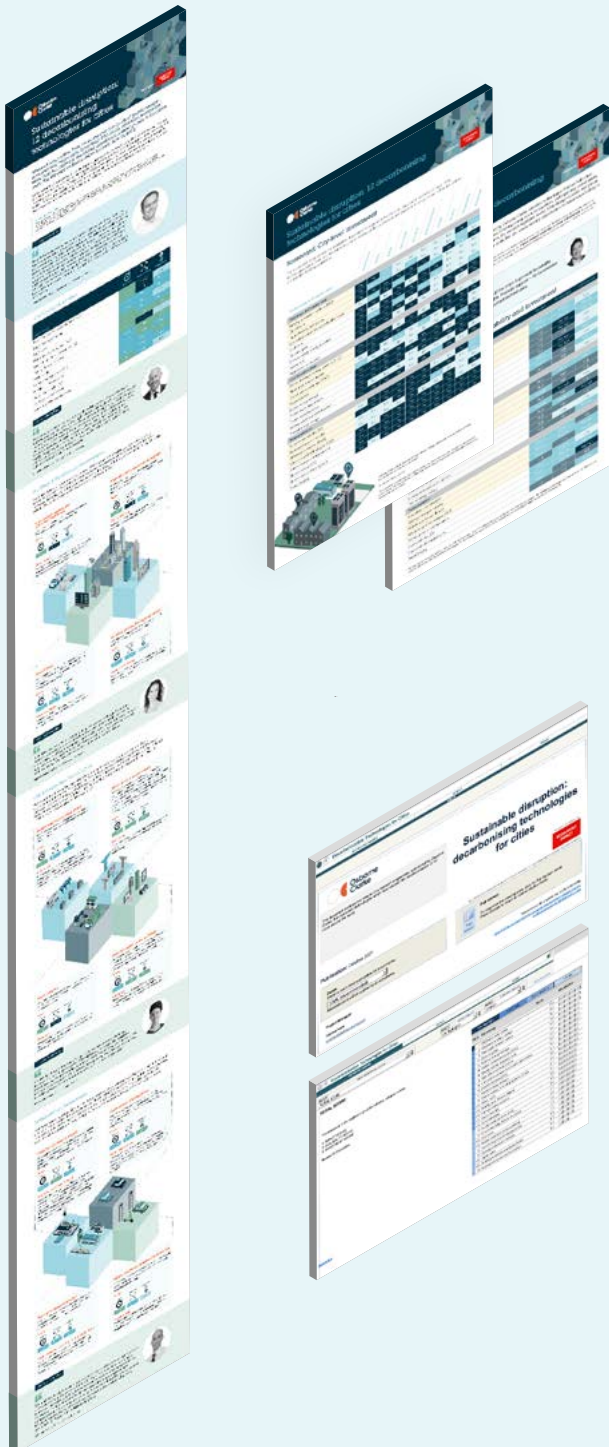
Climate protection is at the centre of the public debate. A clean, healthy and sustainable environment, which the Human Rights Council has only recently explicitly recognised as a human right, requires significant efforts to reduce greenhouse gas emissions and achieve net zero. A growing legal framework sets standards, for example, for sustainable construction, carbon pricing, tramlines for a circular economy.

More and more companies will be required to report on their impact on ESG issues or voluntarily commit to do so. Regulations such as the EU Regulation on sustainability-related disclosures in the Financial Services Sector and the EU Taxonomy Regulation aim to steer investments towards sustainable projects and companies. Customers and employees want to know and even demand that the company they deal with or work for follows a sustainable business model and conducts its business in a sustainable manner. There is an according need to deploy and use new decarbonisation technologies to meet climate change targets. Such need in turn opens up business opportunities that come with their development, deployment and use.



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Related materials



We have published various supporting materials for this report:

Infographic, summarising key findings from this research.

Scorecard, highlighting:

- The long list of technologies considered in developing this material, and details of how they scored against the assessment criteria of impact, scalability and investment
- An overview of city-level investment into the technologies

Data Workbook, containing details of the research that underpins this report.

Appendix 1 – Scorecard

26 technologies researched:

Technology and Thematic area	Impact	Scalability	Investment
Buildings and Construction			
Building automation systems (BAS)	Medium	Medium	Low
Digital twins	Medium	Medium	Medium
High-efficiency heat pumps	High	Very high	Medium
Low-carbon cement & concrete alternatives	High	Very high	Low
Cool roofs	High	High	Low
Dynamic glass	High	Very high	Medium
Environmentally friendly insulation	Medium	Very high	Low
Green roofs	Medium	High	Medium
High-performance glass	High	High	Low
City Infrastructure			
District heating & cooling systems (DHC)	High	Medium	Medium
Smart grids & smart meters	High	High	High
Unified communications (VOIP)	Medium	High	High
Waste robotics	High	Very high	Low
Battery energy storage	Medium	High	High
Distributed energy storage	High	Medium	Very high
Distributed solar power	High	High	High
Subway advanced control system	High	Low	Low
Thermal energy storage	High	High	Medium
Transportation			
Autonomous vehicles (AV)	Medium	Medium	High
Hydrogen transport vehicles	Medium	Medium	Medium
Mobility as a Service (MaaS)	Medium	High	Medium
Vehicle-to-grid technologies (V2G)	High	Medium	Low
Battery operation enhancements	Medium	Medium	Medium
Electric vehicles (EV)	Medium	Medium	Very high
Electric vehicle charging ports	Medium	High	High
Smart charging	High	High	Medium

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