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How can smart cities boost the net-zero transition? Proceedings of the 3rd OECD Roundtable on Smart Cities and Inclusive Growth (3 July 2023)

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Cities have a pivotal role to play in achieving net-zero emissions by 2050. Smart city solutions can help enable and accelerate the net-zero transition by curtailing energy use, accelerating the shift from fossil fuels to renewable energy, improving resource efficiency, reducing transport demand, and fostering necessary behavioural change. This paper summarises the proceedings of the 3rd OECD Roundtable on Smart Cities and Inclusive Growth (3 July 2023). It provides examples of smart city initiatives that can help reach net-zero emissions and explores the barriers to and risks of scaling up smart city solutions, as well as the enabling factors that can help overcome these barriers and risks. Finally, it proposes ways to strengthen the net-zero objective in the OECD Smart City Measurement Framework.

JEL codes: R11, O18, O30, O32, Q50, Q54, Q55
Keywords: urban development, smart cities, net-zero transition, climate, governance, measurement

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The preparation of the Roundtable and the subsequent proceedings was co-ordinated by Hyunjoon Cho with a team composed of Andrés Fuentes Hutfilter, Caroline Gentet-Raskopf, Rene Hohmann, Anaïs Rault and Camille Viros, under the supervision of Aziza Akhmouch, Head of the Cities, Urban Policies and Sustainable Development (CITY) Division, and Rudiger Ahrend, Head of the Economic Analysis, Data and Statistics (EDS) Division, with contributions from Soo-Jin Kim, Deputy Head of the CITY Division.

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Executive summary

This paper summarises the proceedings of the 3rd OECD Roundtable on Smart Cities and Inclusive Growth, which took place on 3 July 2023 at the OECD Headquarters in Paris.

Key messages

- With current greenhouse gas (GHG) emissions trajectories, global warming is likely to reach 1.5°C as early as 2030, with a growing risk of crossing climate system "tipping points" that could cause abrupt and irreversible changes to the environment and societies. To meet the objectives of the Paris Agreement and limit global warming to 1.5°C, the International Panel on Climate Change (IPCC) highlights that rapid reductions in GHG emissions are needed, with global net-zero emissions being reached in the early 2050s. Many OECD countries have recognised they need to reach net-zero greenhouse gas emissions by 2050, but actions to do so are urgently required. Smart city solutions can help enable and accelerate the net-zero transition by, among many others, curtailing energy use, accelerating the shift from fossil fuels to renewable energy, improving resource efficiency, reducing transport demand, and fostering necessary behavioural change.
- Key areas where smart city solutions have been widely applied and can contribute to advancing climate objectives include:
  - **Flexible and smart power grids:** Smart grid solutions that integrate generation plants, grids, demand-side responses and energy storage can provide the required flexibility to integrate intermittent renewable energy sources into power grids.
  - **In the building sector through improved energy efficiency:** BEMS (Building Energy Management System) is a wide-spread computer-based control solution that can help optimise energy consumption in buildings and reduce greenhouse gas emissions. The IEA estimates that efficiency gains from digitalisation and smart controls will help reduce emissions by around 350 $MtCO_2$ in 2050, equivalent to about 1% of today's global energy-related CO_2 emissions.
  - **In the building and transport sector through behavioural changes:** Solutions such as smart metering and ride sharing, often combined with digital apps, provide the necessary information to help reduce energy consumption or transport demand. It is estimated that they have the potential to deliver around 8% of global GHG emission reductions by 2050.
  - **Digital tools to foster the transition towards a circular economy:** Cities around the world that have adopted digitally-enhanced resource efficiency and waste management solutions (e.g., digital bottle return machines in Denmark and Germany, pay-as-you-throw waste programmes in Prague) have reaped several benefits, including reduced emissions, more cost-effective service delivery and better-quality services.
  - **Digital tools to support and inform urban policy making:** Digital twins and emission maps, as done in Stuttgart, Torino and Seoul for example, can help policy makers evaluate

urban planning programmes or strategies through virtual simulation, perform real-time calculations of environmental indicators and adjust their net-zero policy accordingly.

- While smart city initiatives have great potential to meet net-zero objectives, their uptake sometimes remains constrained by a lack of digital infrastructure, scarce funding, an absence of standardisation and integrated systems, complex and divergent interests, and insufficient capacities in subnational government. In addition to such barriers, other related risks include data security and privacy concerns, widening inequalities, and negative environmental impacts of digitalisation, mostly because of the production of digital terminals, that need to be carefully considered and managed.
- Subnational governments – in collaboration with other levels of government – can implement several steps to create an enabling environment that leverages smart city initiatives more effectively for net-zero objectives:
  - Establish a comprehensive smart city strategy that aligns with net-zero objectives
  - Secure financial means by diversifying sources of funding, ranging from traditional grants and loans from national governments to private investment and other sources such as land-based finance tools or green bonds and carbon financing
  - Build capacity to design and implement smart city initiatives for net-zero objectives in subnational governments
  - Replicate successful cases, tailored to specificities of each individual city
  - Support climate smart innovation and entrepreneurship, for example through incubation centres and innovation hubs
  - Enhance smart city data governance by setting up frameworks to safeguard transparency around data collection, storage and use as well as to promote data sharing and interoperability
  - Join forces with national governments and promote co-operation between levels of government and between policy sectors, as well as partnerships with the private sector, citizens, other cities and stakeholders
- New indicators have been identified to strengthen net-zero objectives in the three pillars of the OECD Smart City Measurement Framework:
  - **Pillar 1 (Smart city dimensions):** Input indicators have been added to the framework across several dimensions where smart city tools can help reduce greenhouse gas emissions, including mobility, housing and built environment, energy, water and waste.
  - **Pillar 2 (Stakeholder engagement):** Indicators have been added to measure stakeholder engagement efforts and outcomes, as well as communication capacity.
  - **Pillar 3 (Smart city performance):** New outcome indicators by sector (such as transport, energy, buildings, circular economy and waste management, biodiversity and land) and co-benefits of climate action have been added, which could help assess how close cities are from their net-zero goals.

Next steps

- In addition to national sources of data, the massive amount of data generated by digitalisation (e.g., satellite images, mobile devices) and the data generated at city level from the growing number of sensors and various service use platforms could be further leveraged. National statistical offices, international organisations, private organisations and academics also have an important role to play to harness this increasing amount of data and to make them comparable across jurisdictions.

- Pilot applications of the OECD Smart City Measurement Framework in interested countries and cities could be explored, in co-operation with other relevant organisations. Some degree of customisation of the framework to the specificities of pilot countries or cities could also help account for different local contexts or different starting points.
- Developing a digital platform for the OECD Smart City Measurement Framework with regular updates for pilot cities/countries could also be considered. This would help visualise the collected data in a user-friendly way, allow decision-makers, investors and citizens to assess how the city is performing and taking action, and track progress over time whenever data series are available.

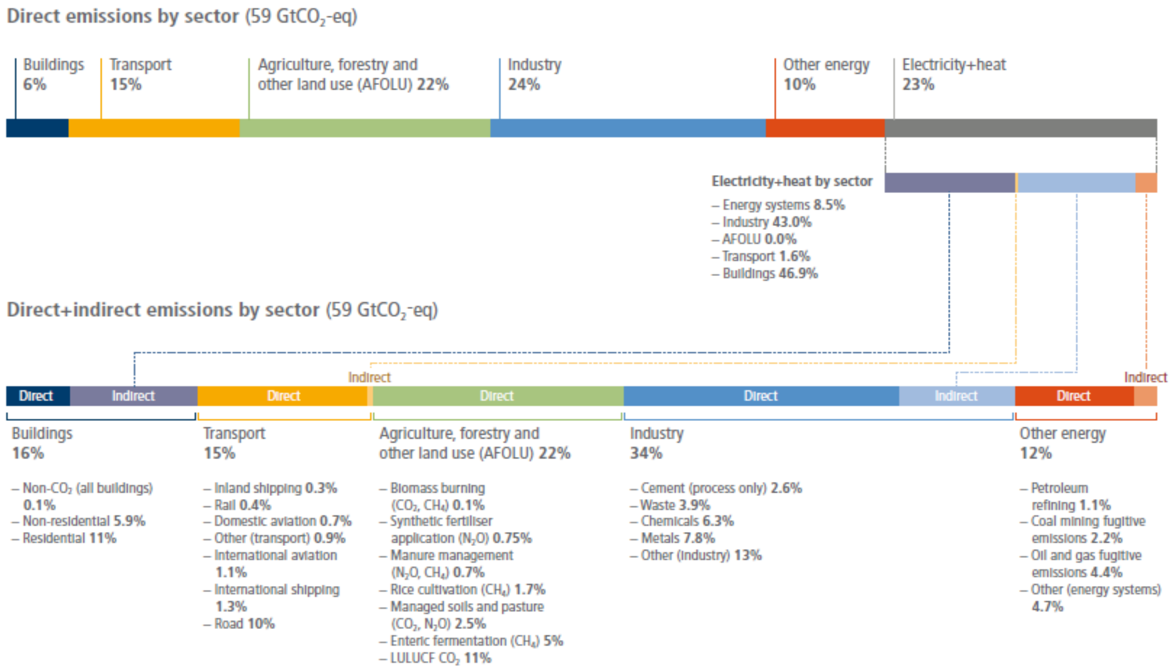
1 How can smart city initiatives boost the net-zero transition?

Cities are key for climate action

Cities have a pivotal role to play in achieving climate neutrality by 2050. According to the Intergovernmental Panel on Climate Change (IPCC), urban areas account for about 70% of global greenhouse gas (GHG) emissions worldwide – a substantial increase from 56% in 2000 (IPCC, 2022[1]).

With regard to the breakdown of overall greenhouse gas emissions by sector, out of the 59 Gt GHG emissions worldwide in 2019, one third came from the energy transformation sector, which includes electricity generation. Most energy use requires electrification to achieve decarbonisation. CO_2 emissions should be reduced to zero particularly quickly in power generation, with coal-fired electricity to be phased out in developed countries by 2030 (OECD, 2021[2]). Besides the energy transformation sector, the remainder of emissions came from the industrial sector (24%), agriculture, forestry and other land use (AFOLU) (22%), transport (15%) and buildings (6%). When emissions from electricity and heat generation are counted in, the share of buildings increases to 16% (Figure 1.1).

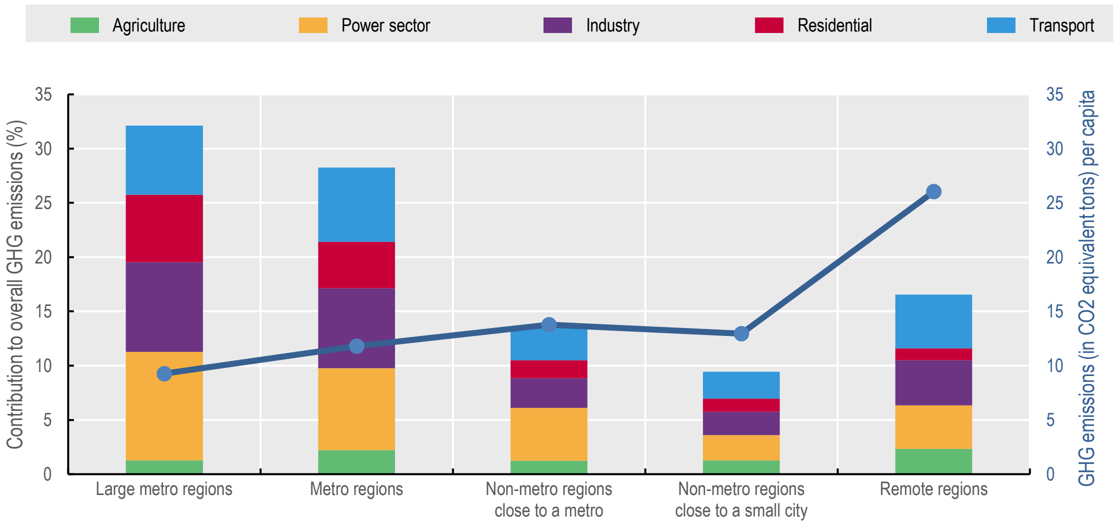
Figure 1.1. Total anthropogenic direct and indirect GHG emissions in 2019 by sector



Source: IPCC AR6 WG III report (IPCC, 2022[1]).

Considering the global trend of urbanisation, with the proportion of people living in cities, towns and semi-dense areas as the global population expected to increase to 79.4% by 2050 from 76.5% in 2015 (OECD/European Commission, 2020[3]), reducing GHG emissions in cities is a must for the net-zero transition. In OECD countries, urban regions are the biggest contributors to total direct GHG emissions (OECD, 2021[2]), with metropolitan regions accounting for around 60% of direct emissions (Figure 1.2), although metropolitan regions also have the lowest GHG emissions per capita. .

Figure 1.2. Contribution to GHG emissions (bars) and GHG emissions per capita (line) by type of region, 2018



Note: OECD countries, Romania and Bulgaria. Greenhouse gas emissions excluding emissions from land use and land use change.
Source: (OECD, 2021[2]).

That being said, cities consume many emissions intensive goods and services that may be produced outside their boundaries, meaning that on a per-capita basis consumption-based emissions of cities are much higher than production-based equivalents. Cities, and in particular higher-income cities, therefore, have significant potential to reduce emissions through demand side measures including through behavioural changes that transform consumption habits (OECD, 2021[2]), such as through reducing food waste (OECD, 2020[4]) (Marta and Deconinck, 2022[5]) (OECD, 2020[4]).

In low and middle-income countries, growing urbanisation is also a key driver of growth in energy demand and emissions, often in part fuelled by workers flowing to jobs in more energy-intensive industries in cities, and driving in turn higher demand in housing and transport. Well-planned urbanisation consistent with achieving climate neutrality is therefore critical not just to lock in energy-saving lifestyles, but also to boost well-being, for example, through lower air pollution and shorter travel times.

According to estimates from the Coalition for Urban Transitions (CUT), which use their own definitions and methodologies, direct GHG emissions from cities could be reduced by almost 90% using technically feasible, widely available mitigation measures by 2050: 58% of these would come from the buildings sector, 21% from the transport sector, and the remaining 21% from the material efficiency (16%) and the waste (5%) sectors.

To achieve a 90% reduction in greenhouse gas emissions, the net-zero transition involves the massive replacement of fossil fuels with emission-free energy sources, largely with electrification as well as reduction of energy demand. The share of electricity in total energy use will need to increase from the current 20% to 50% by 2050 according to the IEA net-zero Emission (NZE) scenario (IEA, 2022[6])(Box 1.1).

Decarbonisation of electricity accounts for 7.12 $GtCO_2$-eq, or almost half (46%) of the total potential GHG emission reductions and energy efficiency improvements. The potential for reducing GHG emissions thanks to electrification is particularly high in the building sector, estimated at 2.91 $GtCO_2$-eq, or 18.7%. In addition, behavioural changes in the transport sector, such as a shift away from motorised modes or reduced or shared motorised travel demand, are expected to reduce GHG emissions by 1.29 $GtCO_2$-eq, or 7% (CUT, 2019[7]).

Box 1.1. Sector pathways under the Net-Zero Emissions Scenario (IEA)

The Net-Zero Emissions by 2050 Scenario (NZE) shows a pathway for the global energy sector to achieve net-zero CO2 emissions by 2050, with advanced economies reaching net-zero emissions ahead of others. This scenario also meets key energy-related United Nations Sustainable Development Goals (SDGs), in particular by achieving universal energy access by 2030 and major improvements in air quality. It is consistent with limiting the global temperature rise to 1.5 °C.

Fossil fuel use falls drastically in the NZE, and no new oil and natural gas fields should be exploited beyond those that have already been approved for development. No new coal mines or mine extensions are required. Low emissions fuels – biogases, hydrogen and hydrogen-based fuels – are expected to see rapid growth, accounting for almost 20% of global final energy in 2050, compared with 1% in 2020. More than 500 Mt of low-carbon hydrogen is expected to be produced in 2050, of which about 60% through electrolysis, which will account for 20% of global electricity production in 2050. Liquid biofuels will provide 45% of global aviation fuel in 2050.

Power generation sector

Electricity demand grows rapidly in the NZE, rising to 40% from today to 2030 and more than two-and-a-half-times to 2050, while emissions from generation fall to net-zero in aggregate in advanced economies by 2035 and globally by 2040. Renewables drive the transformation, up from 29% of generation in 2020 to 60% in 2030 and nearly 90% in 2050. From 2030 to 2050, 600 GW of solar PV and 340 GW of wind are added each year. The least-efficient coal plants are phased out by 2030 and all unabated coal by **2040**. Investment in electricity grids triples to 2030 and remains elevated until 2050.

Building sector

Emissions drop by 40% by 2030 and by more than 95% by 2050. By 2030, around 20% of the existing building stock worldwide is retrofitted and all new buildings comply with zero-carbon-ready building standards. Over 80% of the appliances sold are the most efficient models available by 2025 in advanced economies and by the mid-2030s worldwide. There are no new fossil fuel boilers sold from 2025, except where they are compatible with hydrogen, and sales of heat pumps soar. By 2050, electricity provides 66% of energy use in buildings (33% in 2020). Natural gas use for heating drops by 98% in the period to 2050.

Transportation sector

Emissions drop by 20% to 2030 and 90% to 2050. The initial focus is on increasing the operational and technical efficiency of transport systems, modal shifts, and the electrification of road transport. By 2030, electric cars account for over 60% of car sales (4.6% in 2020) and fuel cell or electric vehicles are 30% of heavy truck sales (less than 0.1% in 2020). By 2035, nearly all cars sold globally are electric, and by 2050 nearly all heavy trucks sold are fuel cell or electric. Low-emissions fuels and behavioural changes help to reduce emissions in long-distance transport, but aviation and shipping remain challenging and account for 330 Mt CO_2 emissions in 2050.

Source: Net Zero by 2050 – A Roadmap for the Global Energy Sector (IEA, 2021[8]).

In this context, many cities around the globe have set net-zero objectives. In fact, some cities are targeting more ambitious net-zero GHG emissions targets than their national governments (e.g., Bristol has a target of net-zero by 2030, compared with 2050 for the United Kingdom). However, cities vary in the scope of emissions they include in their net-zero targets. The recommendations from the High-level expert group of the United Nations for net-zero pledges by non-state actors (United Nations, 2022[9]) provide guidance in this respect. Recommendations are directed to subnational governments, including cities, as well as to businesses. Relevant recommendations for cities are summarised in Box 1.2. They reflect the need to incorporate indirect emissions in decarbonisation efforts, as well as to publicly disclose action plans. Moreover, reaching net-zero emissions should not be based on the purchase of emission reductions elsewhere (voluntary carbon credits), but should be reached on account of reducing emissions locally. In addition, high-income countries also need to support emission reductions elsewhere.

Box 1.2. Recommendations for net-zero pledges by non-state actors from the High-level expert group of the United Nations

1. **Announce a public net-zero pledge** which contains intermediary targets (2025, 2030, 2035) and is in line with the IPCC targets to limit warming to 1.5°C. Any actor with the capacity to move faster should do so. Targets should include absolute emission reductions.
2. **Targets must include direct and indirect emissions** in the value chains of goods and services produced and consumed in cities.
3. **Purchases of voluntary carbon credits should not count towards own intermediate reduction targets.** They should count towards permanent emission reductions only for residual own emissions or for emission reductions beyond their net-zero pathways. They must use high-quality carbon credits.
4. **Create and publicly disclose a transition plan,** which sets out actions that will be undertaken to meet all targets and shows how governance and incentives will be structured and capital expenditure, research and development, skills and human resources aligned for a just transition. Transition plans should be updated every year.
5. **Phase out fossil fuels and scale up renewable energy**. The transition away from fossil fuels must be matched by a fully funded transition towards renewable energy.
6. **Increase transparency and accountability** by reporting GHG data, net-zero targets, plans and progress in a standardised, open format and via a public platform.
7. **Invest in just transition efforts**. For example, the transition away from fossil fuels must be just to all the affected communities, workers and consumers.
8. **Regulators should develop and accelerate regulation** and standards in areas including net-zero pledges, transition plans and disclosure.

Source: United Nations (United Nations, 2022[9]).

Despite the magnitude of the climate emergency, climate action is far behind what is needed for Paris-consistent emission reductions. System-wide transformations of unprecedented breadth and speed are required. Smart city solutions have an important potential to contribute to GHG emission reduction, but it is essential to scale them up to achieve the necessary level of transformations. In order to scale up smart city solutions in a short period of time, it is necessary to assess the effectiveness and potential of smart city solutions and carefully review the constraints and trade-offs that may prevent their scaling up. Leading cities that have participated in global initiatives such as United for Smart Sustainable Cities (U4SSC), Horizon Europe and C40 are testing a range of innovative smart city solutions as key measures to achieve net-zero GHG emissions (Box 1.3). As highlighted by the IMD (International Institute for Management Development) during the 3rd OECD Roundtable on Smart Cities and Inclusive Growth, smart cities are ideal testbeds for innovative solutions to reach net-zero objectives. Solutions with positive results in the pilot phase can inspire other cities and quickly spread through large-scale investments.

The rest of this chapter and the next chapter will investigate key sectors and strategies in cities to achieve net-zero objectives, discuss related smart city solutions, as well as examine their potential and limitations.

Box 1.3. Examples of global initiatives for smart cities and the net-zero transition

Among several global initiatives for smart cities or carbon neutrality, some initiatives that span both topics and are particularly representative and active are briefly presented below.

U4SSC

The U4SSC is a UN initiative co-ordinated by the International Telecommunication Union (ITU), the United Nations Economic Commission for Europe (UNECE) and UN-Habitat, and supported by 16 other UN bodies. It helps promote the development of policies and strategies that encourage the use of digital technologies to facilitate digital transformation and ease the transition to smart sustainable cities. The U4SSC serves as a global platform for information exchange and partnership building to guide cities and communities in achieving the UN Sustainable Development Goals.

Horizon Europe: 100 Climate-Neutral and Smart Cities

"100 Climate-Neutral and Smart Cities" is one of five Horizon Europe funding programmes for research and innovation, with a budget of EUR 95.5 billion (2021-2027). The Cities Mission aims to deliver 100 climate-neutral and smart cities by 2030 and to ensure that these cities act as experimentation and innovation hubs to enable all European cities to follow suit by 2050. Among 377 cities that submitted an expression of interest, 100 cities were selected from 27 EU countries, with 12 additional cities from countries associated with, or with the potential of being associated to, Horizon Europe. The selected cities are developing Climate City Contracts, which will include an overall plan for climate neutrality across different sectors such as energy, buildings, waste management and transport, together with related investment plans. This process will involve citizens, research organisations and the private sector.

C40 Cities Climate Leadership Group

C40 is a network of mayors of nearly 100 world leading cities collaborating to deliver the urgent, inclusive action needed to confront the climate crisis. About 97 cities (26 in Southeast and East Asia and Oceania, 18 in Europe, 17 in North America, 13 in Africa, 12 in Latin America, 10 in South and West Asia) are participating in the initiative. C40 promotes exchanges of knowledge and sharing of best practice to help cities respond to the climate challenges and accelerate their climate actions, avoid mistakes and delays and implement fairer and more impactful climate actions to meet the Paris Agreement goals. C40 also supports groups of cities, within one country or region, to implement high-impact policies and projects through regionally tailored programmes. These programmes offer mayoral engagement, technical support, peer-to-peer engagement and capacity building.

Source : U4SSC: https ://u4ssc.itu.int/about/, EU 100 Climate-Neutral and Smart Cities: https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en, C40: https://www.c40.org/about-c40/ .

Key smart city solutions with significant potential to advance net-zero objectives

Smart city solutions can be enablers or accelerators for the transformations needed to reach net-zero GHG emissions. In particular, smart city solutions are essential to decarbonise electricity, improve energy and resource efficiency, and transform emission-intensive consumption habits. For example, smart grids[1] are fundamental to make the most of renewable energy. Building energy management systems (BEMS) and smart mobility solutions can help reduce energy demand. Digital tools can facilitate the shared use, reuse and recycling of goods and components, by combining digital apps and collection systems and thereby reducing unsustainable and energy-intensive raw materials processing. In this regard, key areas for smart city solutions that are currently widely applied and tested across cities in OECD countries include the following:

- **Improving the flexibility of power grids such as peak energy savings and integrating renewable energy sources:** The share of electricity in total energy use will be about 2.5 times higher, reaching 50% by 2050 in the IEA Net-Zero Emission (NZE) scenario (IEA, 2021[8]), largely provided by time-variant ("intermittent") renewable energy. In this context, it is essential to secure flexibility of energy use to efficiently expand electricity infrastructure, taking advantage of low-cost renewables production. Smart grid solutions integrating generation plants, grids, energy storage, and demand response programmes[2] that encourage electricity users to adapt their demand to time-variant renewables profile through financial incentive can provide the required flexibility. The IEA estimates that using digital technology to adjust energy demand to the time profile of renewable energy through demand response programmes could reduce the curtailment of variable renewable energy systems by more than 25% by 2030 (IEA, 2023[10]).
- **Improving energy efficiency in the building sector:** While energy efficiency improvement will primarily come from building envelope retrofitting, digitalisation can help complement it. BEMS (Building Energy Management System)[3] is a proven and wide-spread solution that can optimise building energy consumption and reduce GHG emissions significantly, combined with building automation and renewable energy generation technologies. Many cities such as Seoul, London, and Copenhagen are mandating or adopting BEMS in their public building stock of a given size or more, and BEMS is being widely used in newly constructed zero-energy buildings. The IEA estimates that efficiency gains from digitalisation and smart controls will help reduce emissions by around 350 $MtCO_2$ in 2050 (IEA, 2021[8]).
- **Promoting behavioural changes in the building and transport sector:** Solutions such as smart metering and ride sharing can stimulate behavioural changes that reduce GHG emissions by providing people with the necessary information on energy and water consumption or available travel modes. Their overall potential for GHG emission reductions is reported to be around 8% of the 2050 total global GHG emission reductions (IEA, 2021[8]).
  - In the building sector, smart metering provides real-time energy consumption data to households and building owners, inducing them to save energy. Governments or energy suppliers can also use the information to develop policies such as peak electricity demand

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[1] The IEA defines smart grids as ''electricity networks that use digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users."

[2] The IEA defines demand response as "demand response refers to balancing the demand on power grids by encouraging customers to shift electricity demand to times when electricity is more plentiful or other demand is lower, typically through prices or monetary incentives."'

[3] BEMS is an ICT solution for managing energy sources by means of integration of the energy systems and monitoring networks to design a cost-effective computer-based control system installed in buildings that monitors and controls the building's mechanical and electrical equipment (Miguel et al., 2016[62]).

management and energy saving. To leverage this potential to induce a behavioural change, it is important to provide consumers with real-time usage information in a user-friendly manner, for example through apps or digital displays. Smart metering can also provide operational insights before establishing BEMS combined with other energy use control devices.

- In the transport sector, MaaS (Mobility as a Service) is a “distribution model for mobility services that uses shared data and a digital interface to efficiently source and manage transport-related services into a seamless offer tailored to individual preferences” (ITF, 2023[11]). Ride sharing can help reduce travel demand by replacing individual cars with common mobility (e.g., shared cars, bikes and scooters). Digital platform-based ride sharing contributes to reducing individual car use, making transport service more responsive to demand in real time (ITF, 2015[12]). A smart traffic surveillance system can also support stronger policy interventions to decrease the use of high emission vehicles, such as the introduction of Ultra Low Emission Zones (ULEZ) in London (UK) and low emission zone in Barcelona (Spain).

- **Digital tools to foster the transition towards a circular economy:** Cities around the world that have adopted digitally-enhanced resource efficiency and waste management solutions have already seen many benefits, including reduced costs, improved environment and quality services and better life quality.
- **Supporting and informing policy making through digital tools (e.g., digital twins[4] and GHG emission maps):** Digital tools can provide policy makers with the necessary information for mapping local potential, identifying the benefits and impacts, of policy measures before implementation, and monitoring their performance. Digital twin technologies are now widely used to solve urban planning problems, notably through simulations. Digital tools are also essential to help cities adopt nature-based solutions, scale up renewable energy and improve their buildings' energy efficiency. Considering that 75% of the buildings to be built by 2050 do not yet exist in developing countries, the importance of planned urbanisation is gaining more attention in the design, construction and management of new cities and towns. (IPCC, 2022[1]).

Energy sector

As C40 highlighted during the Roundtable, achieving decarbonisation in the energy sector will depend on two key factors: electrifying energy consumption, and effectively aligning electricity demand with intermittent renewable supply. There is a growing need for increased flexibility in electricity consumption patterns. Smart grid enables efficient redistribution of peak demand over time and space [5]. It is one of the most important smart city solutions in achieving carbon neutrality with a large-scale electrification of energy use. It can also help develop resilient local power supply strategies that can continue to operate in case of power disruptions due to climate change impacts. Digital solutions can help to that end, by incorporating data on natural hazards, climate-related risks, and critical infrastructure systems. For example, resilient power technologies such as solar plus battery storage can protect critical facilities such as hospitals from power outages (IEA, 2021[13]) (Hotchkiss and Dane, 2019[14]). Smart grids coupled with local on-site electricity production, notably solar rooftops, flexible energy use, including through storage, can contribute to resilience and alleviate the pressure for building additional electricity infrastructure, including generation, transmission and distribution capacity. Moreover, developing the clean energy sector can help create local

[4] Digital twins are a virtual replica of the real world, invented in industries for manufacturing automobiles and machines.

[5] The IEA defined smart grid as ''an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users.” It comprises distributed energy resources (DER), smart metering, virtual power plants,

employment. For instance, local production and installation of smart solutions such as rooftop PVs and BEMS will result in the creation of manufacturing jobs and employment opportunities (IEA, 2023[15]).

Smart grids are the basis for various flexibility solutions across sectors, including zero and plus energy buildings integrated into the smart grid, notably through heat pumps and bilateral EV charging (including Vehicle to Grid or V2G). Flexibility enhances the power grid's resilience and allows users to save cost by consuming electricity when it is cheapest, making optimal use of low-cost renewable energy. Examples of cities that have implemented such solutions include:

- London (UK), as explained during the Roundtable by C40, has set an ambitious goal to achieve carbon neutrality by 2030. According to the findings of the 24/7 Carbon-Free Energy Pilot for London, introducing flexible technologies into buildings such as electric heat pumps, smart controls, battery & thermal storage, EV vehicle to grid and EV smart charging has the potential to yield significant carbon savings and system-wide benefits. It enables the use of electricity when the grid has low carbon intensity, and the ability to use less electricity as well as stored energy when the grid carbon intensity is high.
- Yokohama (Japan) has introduced a large-scale regional energy management system. The Yokohama Smart City Project (YSCP), implemented across 4000 sites, has developed 37 MW of PV, 2300 charging EV sites, and reduced CO_2 emissions by 29%, since the start of the project in 2010.
- Copenhagen (Denmark), alongside the city-owned Copenhagen Utilities (HOFOR), has installed a centralised energy monitoring system (EMS) to match demand to renewable energy production in around 3 500 municipal owned buildings. Following this project, Copenhagen has investigated the potential for flexible energy demand with an implementation test to assess the business and CO2 reduction opportunities for both flexible district heating and electricity demand by reducing energy consumption in buildings to balance out peak production for district heating and electricity that is often based on fossil fuels. This project has shown that flexible use of power for municipal ventilation systems, through the use of artificial intelligence and digital platforms, can help create balance in the electricity system, which helps support the use of green energy and enables the reduction of CO2 emissions from individual energy plants. This new project has been carried out in 28 buildings with 163 ventilation systems and in co-operation with a private company and the city's electricity supplier, which compensates the building owner for the flexibility reserved and activated. Calculations indicate that the investment in this technology is financially profitable for the municipality and can lead to a reduction of up ca. 50 - 100 tons CO2. Copenhagen is now seeking to scale this up into private buildings through a partnership with Google.
- Shanghai is in the process of installing 100 000 intelligent charging stations to gather data on vehicle locations and driving patterns. These smart chargers will facilitate the advancement of vehicle-to-grid integration and the establishment of innovative standards such as a "plug&charge" application, enabling users to access various charging networks. Similarly, San Diego (US)'s "Power Your Drive Program" promotes the proliferation of intelligent chargers at workplaces and residences for vehicle-to-grid integration, resulting in a network of 3 040 charging points.

Microgrid solutions are emerging as a critical element of urban energy systems. They combine renewable distributed generation with energy storage, load management and smart systems on a small local scale and can serve as a backup in case of electricity outage. Platforms for flexibility, such as network operation centres that merge demand response, smart metering and other smart grid capabilities, can also be considered to promote integrated utility management across sectors (IEA, 2021[13]).

- Virtual power plants are networks of renewable electricity sources combined with storage systems that work together to provide clean energy and grid services while also meeting customers' energy needs. Such plants are increasingly being deployed across the world, with most to date in Europe, Australia, and the United States. For instance, in Hawaii (US), the Kauai Island Utility Cooperative functions as a non-profit entity responsible for generating and distributing power within the community. They employ a digital platform called SmartHub to oversee electricity distribution, track bill payments, and report any service disruptions.

- The city of Ghent in Belgium set up Buurzame Stroom (neighbourhood power) with the goal of maximising the potential for locally generated clean energy through a collaborative and participatory approach. Partners include Ghent University and two energy co-operatives, EnerGent and Ecopower, which play the role of aggregators. The pilot enables households to better control their electricity consumption by using smart meters and open data applications to better understand electricity prices and manage their energy use. This, in turn, increases their energy efficiency and helps adapting their energy demand to the variability of renewable energies. The project aims to make solar PV more affordable for low-income households, whilst optimising energy production at the local level by better matching supply and demand and creating a sense of community through deep community participation (IEA, 2021[13])].
- Some of Germany's local utilities are deploying blockchain technology to enable new business models such as peer-to-peer electricity trading that can also reduce transmission and distribution costs. With peer-to-peer trading, consumers deal directly with local producers, eliminating the need for intermediaries and long-distance transport. These kinds of municipal utilities expand the public value of energy digitalisation to individuals, communities, and regional economies (IEA, 2021[13]) Up to now, however, this has only been possible to a limited extent, with a maximum distance, in order to allow short-distance exchanges without using up too much local distribution network capacity.

Building sector

Buildings are responsible for 28% of global energy-related CO_2 emissions, without including emissions from construction activity and the production of building materials (IEA, 2021[13]). In 2020, only 5% of new buildings were zero-carbon-ready (i.e. highly energy efficient buildings, using renewable energy directly or an energy supply fully decarbonised by 2050, such as electricity or district heat) (IEA, 2022[16]). There is a need to reduce energy consumption in buildings, and smart solutions can help to that end. The potential of optimising energy efficiency in buildings can contribute up to 55% of the required GHG emissions reduction by 2030 (C40 and McKinsey, 2017[17]).

Beyond reducing and decarbonising energy use in buildings, digitalisation in buildings can help improve data collection and life-cycle analysis; support more efficient design; optimise and avoid over-engineering and extend the useful life of buildings, according to the GlobalABC Roadmap for Buildings and Construction 2020-2050 (IEA, 2020[18]).

Energy efficiency management in buildings

Many cities are mandating their public buildings to be retrofitted with smart city solutions, applying them to BEMS to lower energy use. Cities are also developing specific programmes to use digital tools to improve the energy efficiency of private buildings. Examples discussed at the Roundtable include:

- The city of Logan in Australia has subsidised the installation of a Switch Automation Platform, a digital platform that is connected to the existing Building Management Systems (BMS) of its Hyperdome Shopping Centre. The Switch Platform collects near real-time data, providing operational insights to save electricity. During its first year of implementation, the BMS with the switch platform saved 12.6% of the total energy cost through the optimisation and reduction of peak demand by 7.7% without compromising customer comfort (U4SSC, 2019[19]).
- In the Netherlands, the Dutch Green Building Council (DGBC), an independent network organisation representing the building sector, has introduced a set of indicators that it developed

to measure progress towards net-zero emissions in buildings. The net-zero Paris Proof definition aims to reduce 60% of energy use in buildings: two-thirds coming from energy efficiency and on-site renewables, and one-third from renewable supply. For that purpose, the DGBC has developed a performance-based building energy performance monitoring scheme, which allows local authorities to enforce energy savings thanks to energy metering and therefore monitor climate goals of the building sector.

- In Stockholm (Sweden), the district heating operator, Stockholm Exergi, has introduced the Open District Heating service. This innovative initiative uses excess heat from sources such as data centres and commercial buildings, which can then be marketed through the platform. This approach has resulted in the recovery and use of 113 GWh of heat, in 2018, which is equivalent to heating 31 000 homes per year. In Helsingborg, a remarkable 96% of the heat supply is sourced from renewable options.
- In 2016, New York (US) launched the Load Management (LM) Program to work with city buildings to find no-cost or low-cost operational energy saving solutions. LM provides real-time data visualisation, data analysis and hands-on training for building operators. It is estimated that in Fiscal Year 2019, the Load Management team achieved a 10% energy savings, which implies about 3 700 tons of CO_2 avoided, and 1 million taxpayer dollars saved.[6]

Smart street lighting can reduce electricity use by up to 80% and provide more lighting hours with less power by adjusting output as needed (Colclough, 2021[20]). Most public lighting is concentrated in cities, where it can account for up to 65% of municipal electricity budgets (IEA, 2021[13]).

Today, around 320 million streetlighting poles are in use globally, but fewer than 3% of these are smart. Combined with other equipment such as sensors and cameras, poles can also be used to monitor traffic, weather, noise, and air pollution and enhance public safety or Wi-Fi connectivity (IEA, 2021[13]). Examples of cities in OECD countries that have adopted smart streetlighting include:

- In Chicago (US), 85% of streetlights have been replaced with smart lights, resulting in energy savings of up to 75%. This programme is expected to save USD 100 million in electricity costs over the first ten years.
- Similarly, Milan (Italy) has implemented 136 000 smart lights, leading to a 50% decrease in energy consumption corresponding to an annual reduction of 23 000 tonnes of CO_2 emissions and savings of EUR 10 million.
- Bratislava (Slovak Republic) has initiated an ambitious project aimed at enhancing its existing street lighting system. The objective is to transition to a fully smart light-emitting diode (LED) public lighting infrastructure within five years, targeting completion by 2025. This transition is anticipated to yield substantial energy savings, estimated at over 40% in total energy consumption (IEA, 2021[13]).

Transport sector

The transport sector represents 23% of energy-related CO2 emissions, of which 40% of these emissions come from urban transport. Congestion makes commuters lose on average 8 days per year, with an economic cost estimated at 4% of national GDP. Smart mobility solutions can deliver benefits in various forms (ITF, 2020[21]): e.g. decreased and better quality travel time, safety improvements, more efficient use of capacity, lower travel costs, better health, more public space for green areas, more equitable accessibility outcomes, better monitoring to ensure efficient policy-making and transport planning, as well as reduced environmental impacts. For example, it is estimated that 6.5 million people worldwide suffer

[6] https://www.nyc.gov/site/dcas/agencies/load-management.page

from chronic high sleep disturbance and 22 million people from prolonged high levels of annoyance due to noise pollution from transport (EEA, 2020[22]).

Smart transport sector solutions can help make these benefits a reality. Smart transport systems include a wide range of technologies, from shared mobility applications to smart traffic management systems.

- **Smart traffic management:** Eliminating congestion hotspots can reduce air pollution by 75% (IEA, 2021[13]). It can also increase bus service speeds by 30% (ITF, 2020[21]). For example, in London (UK), smart traffic management systems have reduced congestion by 8% between 2014 and 2018 (OECD, 2019[23]). Information collected from road sensors, radars and cameras has been used to actively manage traffic by adapting speed limits and allow for a dynamic use of hard-shoulders as a running lane on a temporary or permanent basis. Motorists are informed of variable speed limits and about whether hard-shoulder or other lanes are open. Smart roads construction costs are on average 40% lower than traditional widening schemes, have environmental benefits and reduce travel time (ITF, 2019[24]). In Seoul (Korea), it is estimated that smart traffic management has increased traffic speed by 30% on average (ITF, 2020[21]).
- **Mobility as a service (MaaS):** MaaS is a promising technology to allow for an integrated delivery of intermodal trips. Thanks to a unique platform that uses mobility data, users are able to plan, book and pay their trip using different modes of transportation (e.g., public transportation, ride-sharing, car rentals, etc.). MaaS could help develop the use of more sustainable modes of transportation (ITF, 2023[11]).
- **Ride sharing:** Digital-based ride sharing can help lower CO_2 emissions, as well as reduce traffic congestion, free up urban space and improve connectivity and accessibility (Box 1.4). Individual private cars are replaced by shared taxis or minibuses. These services are modelled to be available on-demand and close to the user. Supply and demand for the ride are co-ordinated by digital platforms to optimise the routing (ITF, 2018[25]).

Box 1.4. Ride-sharing: The case of Dublin metropolitan area

Modelling made for the metropolitan area of Dublin, Ireland, has showed that the number of cars, traffic, CO_2 emissions and congestion could be reduced by up to 98%, 38%, 31% and 37% respectively, if all private cars were replaced by shared options. Similar results have been obtained in Lyon (France), Auckland (Australia), Helsinki (Finland) and Lisbon (Portugal).

Ride-sharing is a low-cost mode of transportation. It was estimated that shared minibus services would cost less than the price of a public transport ticket, thus limiting the need for subsidies. Other co-benefits include lower urban pollution and more space for slow mobility.

Ride-sharing can be a popular mode of transportation. Results from a survey suggest that 20% of car drivers would be willing to switch to shared rides in Dublin. However, even if only 20% of private car trips were replaced by shared modes, shared services could still be provided at a sufficiently low cost.

Finally, ride-sharing also reduces the cost of electrifying transport. Indeed, reducing the number of cars and using the latter more intensively would take advantage of electric vehicles' lower operating costs, while limiting electricity demand, material use for batteries and car production. It would also boost technology diffusion thanks to more frequent car renewals.

Source: (ITF, 2018[25])

- **Smart parking/charging:** Cities are actively adopting IT technologies to provide parking and charging station data to drivers. Despite concerns about potentially increasing private car use, this initiative could contribute to reducing GHG emissions by reducing unnecessary driving. Many cities are making public and private parking space information open to the public. For example, in Berlin (Germany), radar sensors detect empty parking spaces to allow users to identify free parking places. Mobile applications can also help users to plan routes with available charging points, thus helping to reduce anxiety, a barrier to EV adoption (IEA, 2023[26])

In order to make smart transport solutions inclusive, it is important to reduce inequalities of access to smart solutions. The cost of technologies, access to data and digital skills are barriers that need to be overcome to make smart solutions available for all (IEA, 2021[13]).

The circular economy and waste management

Many cities have put the circular economy at the forefront of their climate neutrality strategy. For example, London (UK) is pursuing circularity in order to aspire to become a zero-carbon city by 2050. In Joensuu (Finland), the city is planning circular economy actions to be carbon-neutral by 2025. The circular economy implies a systemic shift, whereby services are provided, making efficient use of primary materials and optimising their reuse; economic activities are planned and carried out in a way to close, slow and narrow loops across value chains; and infrastructure is designed and built to avoid linear lock-in to avoid material waste. Therefore, the transition towards a circular economy has the potential to reduce environmental pressures and risks of raw material supply shocks (OECD, 2020[4]).

Smart city solutions can help avoid waste, reducing energy-intensive materials use, and recycling, by combining digitalisation and other technologies. For example:

- **Plastic bottle and can deposit-return system:** As highlighted during the Roundtable, the city of Tallinn (Estonia) is promoting reusable packaging in collaboration with the private sector, combined with the regulation banning single use plastic from public events in Tallinn from June 2023. Private reusable packaging companies collect a fee and a deposit when selling food in their reusable containers and return the deposit when the containers are returned. The experiment has allowed to save almost 20 tons of plastic waste during the youth festival attended by 100 000 people in 2023 (OECD, 2023[27]). In Denmark and Germany, digital bottle return machines are effectively supporting a strong and systematic implementation of bottle and can recycling. A certain amount of deposit is charged on each plastic, glass bottle and aluminium can when purchasing, and is given back when returning. This improves the purity of the recycled material flows that can replace higher-value raw materials, avoiding a larger share of emissions. In Denmark, producers do not have to pay for Dansk Retursystem to take care of collecting their beverage packaging.
- **Smart waste management:** The city of Prague (Czech Republic) has introduced a “Pay-as-you-throw” system within its zero-waste plan of Smart Prague 2030. The system combines sensors, identification technology and internet connectivity, which, when attached to waste and recycling containers, help implement pay-as-you-throw waste programmes and optimise municipal waste collection (Smart Prague, 2019[28]). In Korea, Sejong has been running its “Pay-as-you-throw Clean-net”, a vast waste vacuum-suction underground network serving its 300 000 citizens without garbage trucks since its inauguration in 2013. During the Roundtable, Amazon Web Services has showed that the city of Harrisonburg (US) was able to cut 230 000 pounds of CO_2 emissions, save 61 minutes per collection operation and USD 194 000 with the help of cloud-based real-time waste collection monitoring and a route optimisation system.
- **Second-hand goods trading apps:** In many countries, people are using digital trading platforms for all second-hand goods including cars. Those platforms developed by the private sector are not only commercially successful but are another excellent example of using digital technology to promote the reuse of second-hand goods, thereby reducing GHG emissions.

Digital tools to inform policies and to promote behavioural changes

Digital tools can provide policy makers with useful information for diagnosing the current status, mapping local potential. Thereby they can help in identifying the benefits and impacts of policy measures before their implementation, and in monitoring their performances. These tools can be particularly relevant to help dense urban areas use their scarce land and resources more efficiently (IEA, 2021[13]). Considering that 75% of the buildings to be built by 2050 do not yet exist in developing countries, their importance in urban planning is gaining more attention (Almendral, 2014[29]). How new cities and towns are designed, constructed, managed, and powered will lock -in behaviour, lifestyles, and future urban GHG emissions (IPCC, 2022[1]). Digital tools are also essential to help existing cities adopt nature-based solutions, scale up the use of renewable energy and improve the energy efficiency of their buildings.

- **Digital twin (digital simulations):** A digital twin is a virtual replica of the real world, initially invented in industries for manufacturing automobiles and machines. Digital twin technologies are now widely used to solve urban planning challenges, including by allowing a more transparent basis of communication for participatory processes with the public. One of the key features of digital twins is simulation. For example, simulation based on heat island effects and wind path analysis can help cities identify the best sites for nature-based solutions such as urban forests or fountains and simulate the expected results. Creating local cool islands can help reduce demand for air conditioning and therefore energy consumption in cities. It has been estimated that a 20% increase in green space can provide heat island reduction benefits by reducing local surface temperature peaks by 2°C (Emmanuel and Loconsole, 2015[30]). Another example is the analysis of renewable energy generation potential such as solar power. Using GIS, the IEA has estimated that the globally available rooftop PV potential is over 9000 GW. Many cities are also using digital twin simulation in formulating their renewable energy generation investment plan (IEA, 2021[13]):
    - The Stuttgart Metro region (Germany) is using digital twins to implement smart city solutions to map current and planned land-use features, using socio-economic data to study demographic and economic trends, and to model mobility and climate features. This allows to develop scenarios for different development strategies.
    - New York City (US) has assessed all public buildings above 1000 gross square metres for solar readiness. It identified nearly 55 MW of rooftop solar potential that could contribute to achieving its goal of installing 100 MW of solar PV on city-owned buildings by 2025. Energy companies are also adopting digital twin simulation to develop their investment plans. The LA100 study, conducted for Los Angeles (US) by the National Renewable Energy Laboratory, has projected a cost-efficient option avoiding between USD 472 million and USD 1.55 billion in distribution network investments based on its simulation (IEA, 2021[13]).
    - Virtual Singapore, presented during the Roundtable, is a digital twin modelled using GIS data that replicate the city’s infrastructure, transport systems and buildings. It is updated with dynamic real-time data. Stakeholders use it to support their decision-making and to simulate situations of emergencies to optimise evacuation routes (Singapore Land Authority, 2023[31]).
- **Mapping:** As highlighted during the Roundtable, mapping can also help plan carbon-neutral cities, both at national and local level.
    - The Netherlands has developed open data systems on local energy infrastructure and building energy and water consumption, to support the local authorities’ energy transition efforts related with infrastructure optimisation and visualisation of consumption.
    - The city of Torino (Italy) has combined the urban heat island map, the urban sequestration map, and the land surface temperature map to expand carbon storage, to mitigate heat island effect and to improve air quality.

- In London (UK), New York (US) and Seoul (Korea), different types of building energy monitoring systems enable city officials and researchers to regularly check buildings' energy performance, helping focus on policy targets with the highest potential.
- As presented during the Roundtable, taking one step further based on its building energy monitoring system, Seoul (Korea) has been piloting GHG emission cap regulation since 2021 for its 582 000 buildings, i.e. about 92% of total registered buildings. By establishing a monitoring system and categorising buildings by their use with relevant benchmarks for standard energy consumption, city officials can get more accurate and timely granular information to enforce the GHG emission caps.
- Korea is also developing a nation-wide carbon emission spatial map that uses spatial analysis to better understand the characteristics of GHG emissions in cities and regions by grid level and visualises the cities' GHG emission activities and the ability of surroundings carbon sinks. The map provides more granular data at city level compared to the national GHG emission inventory by thematic sector (such as energy, building, and industry). The carbon spatial map is updated annually.
- Demand for heating and cooling can be mapped, combining weather with demand data, to identify where efficiency interventions are needed. For example, the Hotmaps GIS toolbox is an open-source platform of heating and cooling demand in European countries. For example, pilot tests conducted in Geneva (Switzerland) and Bistrita (Romania) have demonstrated the ability to save heat demand by 30-40% by retrofitting 70% of the cities' buildings (Hotmaps Project, 2023[32]) (IEA, 2021[13]).

- **Digital apps for behavioural change:** Antwerp (Belgium) engages residents in the creation of initiatives to stimulate behavioural change. The project uses a range of digitally enabled innovations (e.g., sensors, measurement systems, apps and rewards via a digital currency) for behavioural nudging to stimulate change in the use of electricity, heat and water, as well as to promote materials reuse and waste reduction.

2 Barriers and enabling factors for smart cities to meet their net-zero objectives

As discussed in Chapter 1, many different smart city initiatives can help cities meet their net-zero objectives. Nonetheless, their uptake has sometimes remained limited so far, which limits their potential to reduce GHG emissions. For example, although it is estimated that smart streetlighting can reduce electricity use by up to 80% by adjusting light according to ambient light levels and weather, only 3% of the world's 320 million street lighting poles are smart (IEA, 2021[13]). There is no one-size-fits-all smart city model, and some smart city initiatives that are successful in one place cannot necessarily be transferred to a different local and national context. However, policies to put in place the right enabling factors can help accelerate the transition to smart and climate-neutral cities. This chapter first explores the barriers to scaling up smart city solutions towards net-zero objectives, then the risks brought by smart cities, and finally the enabling factors that can help overcome these barriers and risks.

Barriers to scaling up smart city solutions towards net-zero objectives

Broadening and scaling up the use of smart city solutions towards net-zero objectives can face several bottlenecks, including:

- **A lack of adequate digital infrastructure:** Without the right infrastructure, it is challenging for cities to implement smart city initiatives that can help reach net-zero objectives. For example, a lack of smart grid infrastructure to monitor and manage energy use can prevent the implementation of advanced energy management systems that could contribute to the net-zero transition. Insufficient data and communication infrastructure can also hamper the efficient operation of smart systems, while connectivity issues can hinder data transmission, real-time monitoring and co-ordination between various smart city components.
- **A lack of funding:** At the roots of the lack of infrastructure may lie a lack of funding. Difficulties in securing finance or funding are often a significant barrier to scaling up smart city initiatives. This is the case in the Asia-Pacific region, for example, as highlighted by the UN Economic and Social Commission for Asia and the Pacific (UNESCAP) during the Roundtable. The high upfront costs associated with implementing the right infrastructure and technologies can deter cities and other stakeholders from pursuing ambitious projects. Budget constraints and uncertainties about the return on investment can make it challenging to secure the necessary funding for large-scale deployment of smart city solutions. During the Roundtable, the EU mentioned that 68% of the 377 cities that submitted an expression of interest (EoI) to the EU's Climate-Neutral and Smart Cities Mission identified the lack of funding and financing schemes as a barrier. The Korea Research Institute of Human Settlements (KRIHS) also highlighted that when the support from the national government ends, many smart city pilot projects may stop because of the difficulty to sustain funding over time.

- **A lack of standardisation and integrated systems:** This can create several barriers such as data silos and inefficiencies, hampering effective data sharing, analysis and decision-making; incompatibility and interoperability challenges, hindering the capacity to leverage synergies across different smart city sectors; and limited replicability of successful smart city practices, as different organisations use different data formats, systems and protocols. It is currently estimated that 90% of the data generated from these sources are not analysed (IEA, 2021[13]) . As highlighted by the UNESCAP, the lack of interoperability can lead to fragmented service delivery.
- **Complex interests:** Scaling up smart city solutions often involves multiple stakeholders. For example, the discrepancy between the cost bearer and the beneficiary is a common and critical obstacle to the retrofitting of buildings with smart city solutions. For smart solutions that have a long payback period of more than 10 years, this is a particularly acute challenge. Reaching an agreement that aligns the interests of various owners of collective buildings is also a time-consuming process that requires persistent persuasion and consultation over a long period of time, often spanning several years. UNESCAP also highlighted the need for inducive policy frameworks that create the conditions for the private sector to invest in cities of all sizes – including small and intermediate.
- **Insufficient capacities in subnational governments:** Many local governments lack the necessary capacity and skills that are necessary for collecting, storing and analysing the data available (OECD, 2019[23]), particularly in small local governments (OECD, 2023[33]). In some countries, there is also a lack of smart city architects and experts or professionals who can design and co-ordinate smart city development. During the Roundtable, the EU underlined that 47% and 45% of the 377 cities that submitted an EoI to the Climate-Neutral and Smart Cities Mission mentioned the fragmentation of responsibilities and insufficient administrative and/or operational capacity as a barrier, respectively. UNESCAP highlighted that many small-sized cities face institutional barriers to implementing smart city solutions to meet net-zero objectives. For example, it is often difficult for small and midsized cities to access capital markets or enter into public-private partnerships (PPPs). In this respect, Seoul (Korea) pointed out that further devolution is needed for local governments to enact regulatory ordinances according to the Constitution of Korea.

Risks brought about by smart city tools

The implementation of smart city initiatives entails a broad range of risks that need to be carefully considered and managed. These include:

- **Data security and privacy concerns:** While data offers a remarkable asset and opportunity for cities, it also entails data management, security, integrity and privacy concerns (OECD, 2023[33]). Smart cities capture and collect an increasing amount of information about their citizens. This creates challenges in terms of who accesses and owns the data, for how long and for what purpose. It also generates concerns about surveillance, security and privacy among citizens, which can undermine the efficiency of smart cities and trust in public authorities. This is particularly at stake if public authorities are using the data to monitor the population, or if companies do so to conduct more targeted advertising. For example, smart metering infrastructure in smart grids can be used to monitor the living habits or working hours of inhabitants (IEEE, 2022[34]).
- **Risk of system disruptions:** As smart cities rely heavily on technology infrastructure and data systems, any disruptions, such as cyber-attacks or system failures, can have significant consequences that go beyond digital security. Such disruptions can imply the shut-down of vital services such as electricity or water (Trapenberg Frick et al., 2021[35]), as well as significant economic losses. For example, a cyber-attack on the city of Atlanta (US) in 2018 cost taxpayers USD 17 million (Sneed, 2019[36]). In Florida (United States), a hacker managed to gain access into

the water treatment system of the city of Oldsmar, threatening to poison the water (Vera, Lynch and Carrega, 2021[37]).

- **Widening of inequalities:** If the needs of all population groups are not considered, smart city initiatives may inadvertently widen the digital divide between people who have access to technologies and digital skills, and people who are not equipped with the technologies or with the knowledge and skills to use them and find themselves left behind (OECD, 2021[38]). Authorities need to take into account the requirements of segments of the population that cannot afford to purchase smart technologies. Authorities also need to recognise that not all segments of society will benefit equally from all smart technologies made available, for example people with certain disabilities may not be physically able to enjoy access to smart-cycling infrastructures, or simply people who would choose to be digitally marginal (Lee, Woods and Kong, 2020[39]). Moreover, the sharing of data by public-owned entities can reinforce existing urban inequalities. For instance, smart technologies could give access to maps that are created with the mapper's subjective perception of a neighbourhood (e.g., "unsafe") (Lee, Woods and Kong, 2020[39]). The use of such labels is "highly speculative in orientation" (Leszczynski, 2016[40]) and could have a significant impact on the neighbourhood's image and therefore its economic and societal dynamism.
- **Environmental impacts:** The increase in the use of smart city tools can paradoxically lead to higher carbon emissions. Estimates show that the digital industry, including the running of data centres and the production of digital terminals, is responsible for 3.7% of total greenhouse gas emissions and 4.2% of global energy consumption (Sénat, 2020[41]). The manufacture of digital terminals (e.g. smartphones, tablets, etc.), represents 70% of its carbon footprint in France (Sénat, 2020[41])), while data centres and data transmission networks account for around 0.9% of energy-related greenhouse gas emissions (IEA, 2022[42]). More generally, technologies that have been introduced to increase the productivity of resources can in fact lead to increased demand for these resources ("rebound effects") that diminish the benefits for the environment (IPCC, 2022[1]). For example, in the United States, during the second half of the 20th century, energy efficiency gains tripled to about 340 GJ/capita thanks to more efficient technologies (Smil, 2000[43]), which induced a 24% increase in energy demand (Bentzen, 2004[44]), absorbing part of the efficiency gains. Unintended rebound effects can also be observed in the transport sector where improved mobility attracts more private cars and passengers. The magnitude of the rebound effect may even exceed the initial greenhouse gas emission savings ("backfire effect"). Rebound effects can also be indirect: if a resource is used more efficiently, its price decreases and therefore allows consumers to buy more goods in other markets. These risks may also result from using smart city tools. For example, smart technologies can make it easier to choose higher home ambient temperatures in winter or lower temperatures in summer, which in turn result in higher energy demand. Furthermore, although 5G networks, which offer great opportunities for smart cities, are expected to be more energy efficient than 4G networks, the overall energy and emissions impacts of 5G are still uncertain, given that 5G's higher speed and bandwidth could also lead to an increase in the number of devices using the network and in the volume of data (IEA, 2022[42]). To reduce the carbon footprint of digital terminals, it is necessary to limit the renewal of digital devices, including for example by promoting circular economy models. Several steps can be taken to reduce the environmental impact of data centres, such as implementing energy efficiency improvement measures, encouraging the use of renewable energy, investing in innovative cooling techniques or heat recovery networks, or procuring equipment that consumes less than older devices. Furthermore, energy and environmental rebound effects should be included in environmental impact assessment (Van den Bergh, 2011[45]) . Ultimately, policies need to limit the supply of environmentally harmful resources and orient income gains from increased productivity towards protecting natural resources.

Enabling factors for smart cities to meet net-zero objectives

Subnational governments, with the help of other levels of government, can implement several steps to create an enabling environment to help cities leverage smart city initiatives more effectively for their net-zero objectives:

- **Establish a comprehensive smart city strategy that aligns with net-zero objectives**: Smart city strategies should set net-zero objectives as a guiding framework. Designing such a strategy upfront, from its pilot to scale-up stage, rather than as an afterthought, can ensure policy coherence between smart city objectives and environmental objectives. For example, the Vienna Smart City Strategy (Austria) recognises that smart city goals and the Sustainable Development Goals are closely interlinked, and it defines action that can contribute to reaching both. UNESCAP highlighted during the Roundtable that any smart city strategy should be “civic-minded”, with the objective to contribute to more liveable and affordable communities. It also pointed out that a national framework of smart city solutions that encompasses a whole ecosystem can help attract private sector investment. In Rio de Janeiro (Brazil), the smart city strategy is fully integrated into the broader strategy of the city to promote a smart, sustainable and resilient city that aims to improve the quality of life of current Rio citizens and future generations. The Chair of the OECD Working Party on Urban Policy stressed that cities are not smart if they are not sustainable and do not address climate change. During the Roundtable, the IMD also underlined that long-term action should be guided by a steady vision and strategy, and not be overshadowed by shorter-term emergencies. European Metropolitan Transport Authorities (EMTA) emphasised that a comprehensive smart city strategy should come with a strong and clear political vision to realise the expected outcome of a transition to net-zero.
- **Foster collaboration and partnerships with a wide range of stakeholders:** Engaging and seeking partnerships with various stakeholders, including with the private sector, academia and citizens, is central to the efficient and effective implementation of a smart city strategy towards net-zero objectives.
    - **With the private sector:** Public-private partnerships (PPP) can help improve the delivery of smart city services by using the resources and expertise of the private sector in implementing smart city solutions. During the Roundtable, C40 emphasised the co-operation and communication with market players to seek mutual benefits and potential areas for collaboration. In Europe, the private sector is recognised as a key partner to provide innovative solutions that can help reach net-zero objectives in the 100+ cities of the EU mission for 100 climate-neutral and smart cities by 2030. The European Digital SME Alliance also highlighted that SMEs are key local partners who can provide technology solutions to cities. Partnerships between governments and the private sector are also key to ensure data security and data protection for citizens. The OECD Recommendation of the Council on Enhancing Access to and Sharing of Data recommends that competition-neutral data-sharing partnerships, including Public-Private Partnerships, should be encouraged where data sharing across and between public and private sectors can create additional value for society (OECD, 2021[46]). In Europe, about 100 technology SMEs responded to a call to join a European excellence group focusing on smart communities – the Focus Group Smart Communities (Alliance, n.d.[47]). Together they have developed a manifesto on the sustainable local digital transformation, calling especially upon local administrations to think about procurement strategically and locally, as this creates jobs locally, attracts skilled workforce, and prevents vendor lock-in. This can also help foster trust between local administrations, companies, the local workforce and citizens.

  - **With citizens:** Enhancing engagement with citizens in the planning, design and implementation of smart city initiatives, through public consultations, citizen engagement platforms, and other participatory processes, can foster a sense of ownership and ensure that smart city projects address people's needs and priorities. Digital tools such as online platforms and community planning tools can foster more engagement from citizens. In Europe, citizen engagement is a central part of the EU Mission for 100 climate-neutral and smart cities by 2030. The mission platform that has been developed as a core instrument of the Mission to provide cities with support and solutions to better engage their citizens. The city of Rio de Janeiro in Brazil seeks partnerships not only with private companies but also with the civil society to drive innovation and the development of smart and sustainable solutions. For example, through initiatives such as RioIdeas and RioApps, the city has collected more than 4000 ideas for different areas, and one of the winners, EasyTaxi, became the most popular taxi-hailing app. The IMD stressed during the Roundtable that citizens should be engaged from the very beginning of the design of smart city solutions for reaching net-zero objectives, taking into account first and foremost the problems they face. C40 also highlighted the importance of making sure that all stakeholders including residents "own" the process and impact of newly adopted solutions, so that they can provide useful advice and feedback.
  - **With other cities:** Co-operation between cities, including at the international level, can play a crucial role in fostering smart city initiatives for the net-zero transition, thanks to knowledge-sharing networks that go beyond municipal or even national boundaries. UNESCAP also highlighted that the development of guidelines at the level of the Asia-Pacific region can promote a community of practice that fosters knowledge sharing and collaboration between countries. In Europe, the EU mission 100 climate-neutral and smart cities by 2030 has the objective to develop synergies with other ongoing initiatives and programmes that touch upon urban development, for example the Digital Europe Programme, or the Smart City marketplace. It also fosters peer-to-peer collaboration for climate action plans by twinning a city selected for the mission with another city that is currently outside of the mission but would like to join. This twinning exercise helps these cities to learn from the experience of the pioneering cities of the mission.
- **Secure financial means to leverage smart city potential to reach net-zero objectives:** Smart cities need to rely on robust digital infrastructure, including high-speed internet connectivity, sensors, and communication networks. To build and maintain such infrastructure, subnational governments need funding. While cities can use some of their financial resources to fund such initiatives, their capacity to invest in a tight fiscal environment is limited. Cities can tap into other funding opportunities, such as grants and subsidies offered by national governments specifically targeting smart cities and sustainability projects, or loans from public national and international financial institutions (OECD, 2023[48]). To secure funding for smart city initiatives, subnational governments can also leverage private investment, either by partnering with the private sector through public-private partnerships or attracting investment for example from impact investors interested in funding innovative solutions (OECD, 2023[48]). National governments also have a key role in developing an enabling environment for cities to attract investment. They can create a regulatory environment that is conducive of private investment by adapting legal frameworks and instruments that allow private actors and financing institutions to be mobilised to diversify sources of funding (G20-OECD, 2022[49]) (OECD, 2023[48]). Other sources of funding can include the use of land-based finance instruments and harnessing the revenues from existing infrastructure assets (G20-OECD, 2022[49]). During the Roundtable, UNESCAP recommended to review existing funding mechanisms to enable cross-sector partnerships and to match businesses with the incentives and infrastructure investment. Cities can also issue green bonds or access sustainable finance mechanisms such as ESG investing (Environment, Social and Governance) to raise funds for smart

city projects (UNFCCC, 2019[50]) (C40, 2020[51]) or explore carbon financing mechanisms to generate revenue for smart city initiatives. The IEA highlighted that access to finance by cities to develop smart city solutions to reach net-zero objectives can be fostered by supporting the creation of new financial instruments, e.g., green bonds, or by developing dedicated financing vehicles. In Europe, Horizon Europe sets the foundations for the financial support and technical assistance that is provided to the cities taking part in the EU mission 100 climate-neutral and smart cities by 2030. As introduced during the Roundtable, in Germany, the Federal Funding Programme for Smart Cities currently dedicates EUR 820 million to fund 73 smart city projects from 2019 to 2029[7].

- **Build capacity in subnational governments:** Technical competencies and skills are central to design and implement smart city initiatives for net-zero objectives, as highlighted by the ITF during the Roundtable. Specific smart city teams can be established at the subnational level, with relevant expertise in urban planning, technology, data analytics, stakeholder engagement, and sustainability, for example. Capacity building opportunities for government employees involved in smart city initiatives can help enhance their technical skills and knowledge to effectively plan and implement smart city projects. Outsourcing necessary skills from specialised entities such as public utility companies and non-profit associations or delegating some technical tasks to them is also a possible solution. National governments also have a crucial role to play in supporting subnational capacity building, for example by seeking to reinforce the capacities of public officials and institutions in a systemic approach; by assessing capacity challenges at the local level on a regular basis; by distributing formal/standardised guidance documents in relevant areas such as procurement or evaluation; or by creating dedicated public agencies fostering local capacity building (OECD, 2019[52]). In Europe, the mission platform of the EU mission 100 climate-neutral and smart cities by 2030 provides support to increase the capacity of local authorities.
- **Promote scaling up and replication:** During the Roundtable, C40 emphasised the importance of setting realistic goals, which may sometimes mean starting small and then scaling up successful cases. In Germany, a co-ordination and transfer consortium gather about 10 expert organisations to share knowledge and scale up and replicate successful smart city initiatives in other cities. Any software that is being developed within the Model Projects Smart Cities (MPSC) funding programme is required to be opensource in order to help replicate smart city initiatives while tailoring them to each individual city context. The International Smart Cities Network commissioned by the German Federal Ministry for Housing, Urban Development and Building also promotes exchanges of good practices and knowledge transfers at national and local level through an international dialogue. Among the MPSC supported by the German Federal Government, the project in the region of South Westphalia "*5 für Südwestfalen*" encompasses five small- and medium-sized cities that have teamed up to develop a framework strategy together and learn from each other, with the objective to replicate this approach to other cities, depending on their own local context.
- **Support innovation and entrepreneurship:** To encourage the development and deployment of smart city solutions for net-zero by start-ups and small and medium-sized enterprises, subnational governments can create an enabling environment for innovation and entrepreneurship. For example, with the support of national governments, subnational governments can establish incubation centres and innovation hubs that focus on the net-zero transition and provide a supporting environment for start-ups, entrepreneurs and innovators. SMEs and entrepreneurs need to access resources such as finance, skills, innovation and a wider entrepreneurial ecosystem to start and develop further (OECD, 2022[53]). Governments can also offer regulatory sandboxes to facilitate the entrance of innovative and digital products and services to the market (Attrey, Lesher and Lomax, 2020[54]). UNESCAP emphasised that cities need to encourage start-ups and

[7] https://www.smart-city-dialog.de/modellprojekte.

technology firms to be more civic-minded and to create an innovative ecosystem where start-ups and entrepreneurs can co-develop solutions in cities. The European Digital SME Alliance gave the example of the city of Dún Laoghaire in Ireland which has developed into a "digital hub" that supports digital companies in their growth, thereby creating new jobs and attracting new talent to the city.

- **Enhance smart city data governance:** Digital technologies do not only support digital infrastructure and devices but also generate a vast amount of real-time data. The amount of data generated is often growing more rapidly than governments' capacity to store and process them. As the success of smart cities in reaching net-zero objectives often relies on the availability, accessibility and effective use of data, effective smart city data governance is critical, not only to improve the functioning of smart city projects but also to enhance trust in smart cities. Protecting people's data privacy and ensuring data security should be at the heart of smart city data governance, for example by setting ethics and security oversight committees, adopting ethical guidelines, and defining opt-out procedures as part of data collection (OECD, 2023[33]). Standardised rules are needed, as well as frameworks to safeguard protection and ensure transparency around data collection, storage and use and to promote data sharing and interoperability as well. During the Roundtable, Amazon Web Services emphasised that data sharing internally and externally, as well as standardisation is key to support data-driven policy making and to accelerate dissemination of innovation, highlighting the importance of standardisation initiatives such as FIWARE and the key role that Cloud computing plays to help cities become more agile, reduce costs, and accelerate data-based urban innovation. The European Digital SME Alliance pointed out that open data prevent vendor-lock-in and ensure real competition, helping to lower overall costs of smart city implementation. It also highlighted that Europe is well advanced in terms of standardisation and has invested in developing standards such as machine-to-machine (M2M) standards that are used for example in Hamburg (Germany), Ghent (Belgium) and Helsinki (Finland). These standards have created an interoperable framework where all independent companies can provide IoT solutions and are being used as inspiration in other countries such as in India and Korea. The IEA emphasised that digitalisation risks should not be neglected, and that cybersecurity frameworks and guidelines should be developed. For smart mobility solutions, ITF highlighted the importance of recognising that mobility data infrastructure that increasingly shapes real-world outcomes but is developed mostly by the private sector, is barely regulated. It emphasised that the public authorities should treat data as a foundational transport infrastructure, and this mainly with respect to three pillars: data sharing, data reporting, and machine-readable regulation (ITF, 2023[11]).

- **Join forces with national governments and promote co-operation between levels of government and different policy sectors:** National governments can play an important role in accelerating the development of smart cities, especially with the purpose of reaching net-zero objectives. They can inter *alia* create a legal framework that encourages the adoption of smart technologies and ensures data privacy and security, enhance co-ordination between levels of government, support capacity building and provide the necessary support to help cities mobilise funding (IEA, 2021[13]). National governments can also establish standards for data sharing, connectivity and interoperability, as well as help scale up successful smart city initiatives. While no standardisation can lead to non-interoperable silos, full standardisation can also hinder innovation. In the case of the early stages of the deployment of MaaS, for example, locking-in one single mobility data sharing syntax can be inefficient, as MaaS solutions are likely to evolve (ITF, 2023[11]). Importantly, national governments can establish frameworks that provides clear policy signals, such as setting emissions reduction targets, promoting renewable energy adoption, and encouraging energy-efficient buildings and transport, to provide the grounds for smart city initiatives to align with net-zero objectives. UNESCAP is implementing the Smart Cities Innovation Lab (SCIL) project that focuses on enhancing the innovation ecosystem, as well as working with other member states to develop national smart city policy recommendations. UNESCAP also stressed during the Roundtable that national smart city strategies should promote both vertical and horizontal integration. Vertical co-operation between the national and local levels helps smart city strategies support efficient urban service delivery and improved quality of life. In Europe, following the launch of the EU mission for 100 climate-neutral and smart cities by 2030, several member states have put in place some national networks to provide dedicated support to their cities to develop a smart and climate neutral strategy. Germany has established a national smart city dialogue process to set up normative guidelines defined under the Smart City Charter and within which cities and city networks can develop their smart city strategies (Bundesministerium für Wohnen, n.d.[55]). The IEA also highlighted the importance of co-ordination between various levels of government and departments and of avoiding a silo approach, as smart city initiatives need to be more integrated and cross-sectoral to maximise their impacts. The Chair of the OECD Working Party on Urban Policy emphasised that national policies can establish the enabling conditions to promote smart and sustainable cities, for example by securing shared standards for data privacy and protection, training local authorities' workforce and building appetite for smart city solutions, and seeking synergies between different smart city initiatives. The European Metropolitan Transport Authority stressed the importance of implementing the right regulation frameworks, especially in the context of urban transport, to ensure the urban mobility market is not saturated with competing fleets. The Metropolitan Government of Seoul (Korea) highlighted that devolution is needed for local governments to enact public policies. For example, without devolution, the Metropolitan Government of Seoul is unable to implement regulation to cap greenhouse gas emissions for buildings.

3 Strengthening the net-zero greenhouse gas emission objective in the OECD Smart City Measurement Framework

The 1st and 2nd OECD Roundtables on Smart Cities and Inclusive Growth (held in 2019 and in 2020) underlined the need to measure the performance of smart cities, leading to the development of the OECD Smart City Measurement Framework. As seen in Chapter 1, smart cities hold great potential to help cities reach their net-zero objectives, but the actual contribution of smart cities to climate objectives needs to be assessed to deliver policies grounded in evidence, track progress vis-à-vis these objectives, adjust them for greater effectiveness and scale them up. This chapter will recall why it is important to measure the performance of smart cities and how the OECD Smart City Measurement Framework is structured. It then proposes ways of how to strengthen the net-zero objective in this Framework and concludes with the next steps for data collection and further use.

Measuring the performance of smart cities

The simple presence of digital technologies does not mean that they automatically lead cities closer to their net-zero objectives. Properly measuring and assessing smart city performance can therefore help cities understand where they stand vis-à-vis their objectives, track progress and impact, and adjust policy interventions for greater efficiency and better results. The Key Performance Indicators (KPIs) developed by United for Smart Sustainable Cities (U4SSC) that were presented during the Roundtable aim to help cities measure their progress over time, compare their performance to that of other cities, develop informed policymaking, accelerate their digital transformation, and achieve the UN Sustainable Development Goals (SDGs). The World Smart Sustainable Cities Organization (WeGO), an international association of cities and local governments, technology solution providers, and civil society institutions committed to the transformation of cities into smart and sustainable cities, also emphasised the crucial role of time series measurement. KRIHS showed that smart city measurement can also help with the actual implementation of smart city initiatives. This has been the case in Korea where the Smart City Index is used to drive successful pilot projects such as the High Technology MaaS (mobility as a service) Pilot Project Case. Measuring the performance of smart cities can also contribute to improving government accountability vis-à-vis citizens and should be included in smart city strategies from the outset. In that sense, measuring smart city performance is critical to implement Principle 11 of the OECD Principles on Urban Policy *"Foster monitoring, evaluation and accountability of urban governance and policy outcomes"* (OECD, 2019[56]). During the Roundtable, WeGO also highlighted that indicators enable cities to set a prioritisation path, and to focus on what is important rather than on what is urgent.

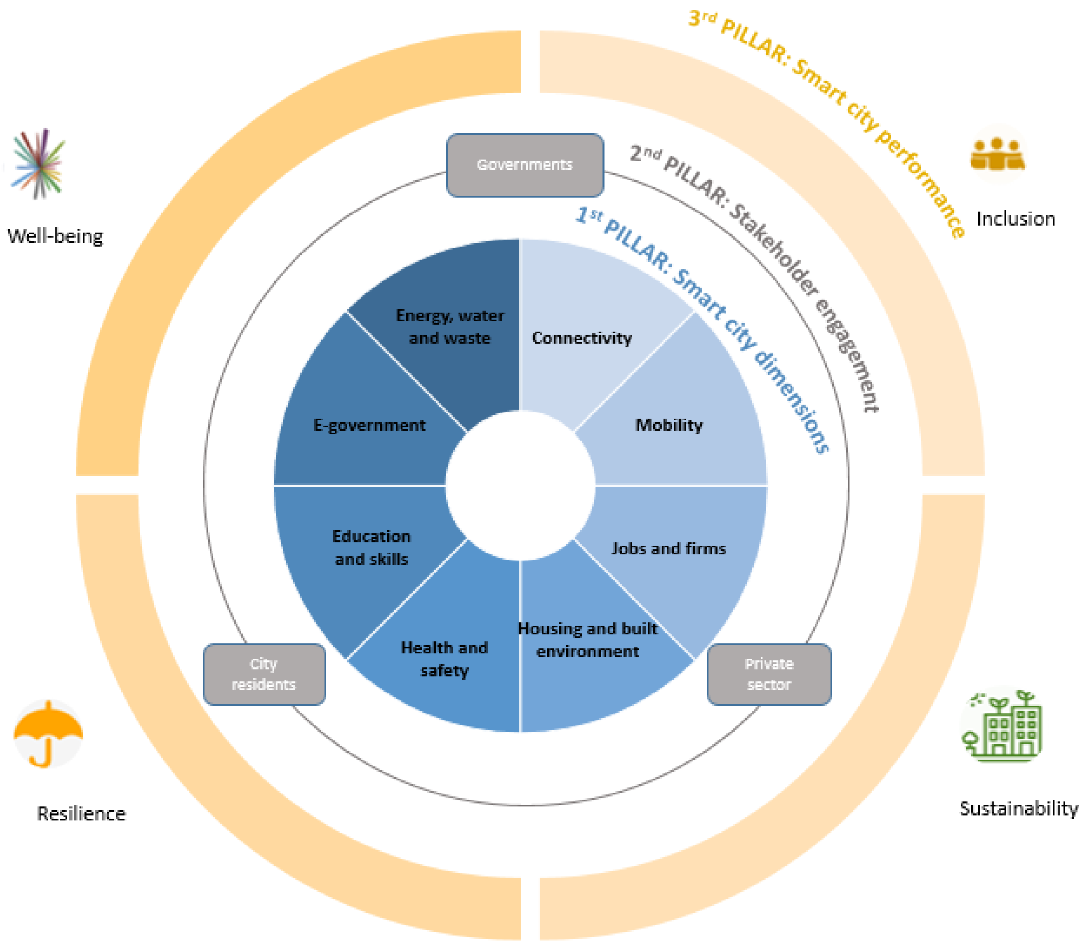
Advancing the measurement of smart city performance calls for a comprehensive, multi-dimensional and flexible framework that serves local and national strategic priorities, as well as global sustainable development objectives. The IMD also stressed during the Roundtable that metrics to measure the performance of smart cities need to be rigorous, neutral and relevant, as well as people-centric. The main principle of the IMD Smart City Index is to first identify the issues faced by citizens and administrations and translate them into relevant indicators. EMTA reinforced the importance of measurement being human-centric and to give the priority to measuring the outcomes of smart cities such as safe cycling on the street and the proportion of people feeling secure in public transport at night.

The OECD Smart City Measurement Framework aims to encompass not only the degree of digitalisation in cities, but also the level of stakeholders' engagement, and most importantly, how both contribute to improving the wellbeing of all urban residents and building inclusive, resilient and sustainable cities. The measurement framework can serve as a tool to guide local and national governments in their efforts to reshape city governance, business models and stakeholder engagement through digital innovation (OECD, 2021[38]).

To address these needs, the OECD Smart City Measurement Frameworks is built around three pillars (Figure 3.1):

- Pillar 1: Indicators of the degree of digitalisation and digital innovation at the city level, across eight dimensions (connectivity; mobility; jobs and firms; built environment; health and safety; education and skills; e-government; and energy, waste and water)
- Pillar 2: Indicators of the engagement of various stakeholders in building the smart city.
- Pillar 3: Indicators of how smart cities help achieve the four core objectives of the smart city according to the OECD's definition of smart cities, i.e., well-being, inclusiveness, sustainability and resilience.

Figure 3.1. OECD Smart City Measurement Framework



Source: OECD (2020), *Measuring smart cities' performance: Do smart cities benefit everyone?*, https://www.oecd.org/cfe/cities/Smart-citiesmeasurement-framework-scoping.pdf.

Strengthening the net-zero objective in the OECD Smart City Measurement Framework

Several smart city measurement frameworks include an implicit or explicit mention of net-zero objectives (Box 3.1). The Chair of the OECD Working Party on Territorial Indicators pointed out that smart city measurement is now a crowded space including measurement frameworks that focus on net-zero objectives.

Box 3.1. Selected examples of smart city measurement frameworks and how they incorporate net-zero objectives

The IMD Smart City Index

In 2019, the IMD (International Institute for Management Development) launched a Smart City Index to assess the economic and technological aspects of smart cities on the one hand, and their human dimensions on the other hand (quality of life, environment and inclusiveness). It gathered responses from a survey to assess how inhabitants perceive their city's application of technology around two pillars: the "Structures" pillar, referring to the existing infrastructure of the cities, and the "Technologies" pillar, describing the technological provisions and services available to the inhabitants. Each pillar is assessed over five areas: health and safety, mobility, activities, opportunities, and governance. Cities are distributed across four groups based on their Global Lab's Human Development Index (HDI) score, and within each of these groups, cities get a rating scale (IMD, 2023[57]). While net-zero objectives are not explicitly referred to in the survey, some questions in the mobility area can be linked to climate targets. These include, in the Structures pillar, "traffic congestion is not a problem" and "public transport is satisfactory", and in the Technologies pillar, "car-sharing apps have reduced congestion", "bicycle hiring has reduced congestion" and "online scheduling and ticket sales have made public transport easier to use".

The U4SSC Key Performance Indicators

The United for Smart Sustainable Cities (U4SSC) is a global UN initiative co-ordinated by ITU, UNECE and UN-Habitat. It has developed the U4SSC Key Performance Indicators (KPIs) to help cities evaluate the role and contribution of ICTs and digital technologies to smartness and sustainability, and provide them with the tools for self-assessment with the objective of achieving the UN SDGs (ITU, 2021[58]). The KPIs are structured around three main dimensions: Economy, Environment, and Society and Culture. In the Environment dimension, several indicators are directly related to net-zero objectives. These include: greenhouse gas emissions per capita (tons eCO_2/capita) using the United Nations Greenhouse Gas Inventory Data; green areas (hectares/100 000 inhabitants) using municipal data, aerial surveys and GIS data; renewable energy consumption (percentage) using data provided by local utility providers; electricity consumption (kWh/year/capita) using data collected from local electricity utilities; residential thermal energy consumption per capita (Gj/year/capita) using data collected from local utilities; public building energy consumption (ekWh/m2/year) using data collected from municipal facilities departments and local utilities (ITU, 2017[59]).

Source: IMD (2023), *Smart City Index Report 2023*, https://www.imd.org/wp-content/uploads/2023/04/smartcityindex-2023-v7.pdf and ITU (2021), *Key performance indicators: A key element for cities wishing to achieve the Sustainable Development Goals*, https://www.itu.int/en/ITU-T/ssc/united/Documents/U4SSC%20Publications/KPIs-for-SSC-concept-note-General-June2020.pdf.

Climate considerations are already at the core of the OECD Smart City Measurement Framework, especially in Pillar 1 (Smart city dimensions) and Pillar 3 (Smart city performance) (see list of indicators that were discussed during the 2nd OECD Roundtable on Smart Cities and Inclusive Growth in Annex B).

This section discusses how to further strengthen climate considerations in the measurement framework by suggesting some new indicators that were discussed during the 3rd OECD Roundtable on Smart Cities and Inclusive Growth. These indicators are not meant to be exhaustive, and cities and countries are not expected to use all of them. Indicators are rather meant as a guiding tool for national and local governments, and could be adjusted according to different policy contexts and available data.

Pillar 1: Smart city dimensions

In **Pillar 1 (Smart city dimensions)**, smart city initiatives can help reach climate objectives in several dimensions of urban life, such as mobility, housing and the built environment, and energy, water and waste. Several indicators already identified for these dimensions relate to smart city tools that can help decrease greenhouse gas emissions. For example, in the mobility dimension, as seen in Chapter 1, shared mobility applications (such as ride sharing applications) and smart traffic management systems can help reduce congestion and therefore greenhouse gas emissions, while real-time information equipment for public transport can improve the convenience and reliability of public transport and induce greater use of public transport modes. In terms of housing and the built environment, building energy management systems (BEMS) can help monitor and control energy needs. Urban planning technologies such as digital twin modelling can help identify priority areas for rooftop PVs, urban forests and fountains, or building retrofit. Smart electricity metering can also help households reduce their electricity consumption. In the energy dimension, smart streetlighting and smart grids can help reduce energy consumption and reach net-zero targets (Table 3.1).

Table 3.1. Suggested candidate indicators for Pillar 1: Smart city dimensions

Dimensions	Indicators
Connectivity	% households equipped with (high-speed) internet Wireless broadband coverage % low-income households equipped with (high-speed) internet / digital terminals % households with elderly people equipped with (high-speed) internet / digital terminals % of Public Wi-Fi-hotspots/km2
Mobility and accessibility	% public transport providing real-time information number of users of sharing economy transportation per 100 000 population % electric bikes/vehicles smart (V2G or real-time information available) charging station % traffic monitoring: length of major streets monitored by ICT % smart intersection control % public parking spaces providing real-time availability information % public parking spaces equipped with e-payment systems
Jobs and firms	% job seekers who have access to e-career centres % firms using digitally-based eco-innovations (e.g., carbon footprint testing technologies or the tracing of sustainable materials in supply chains)

Housing and built environment	% buildings equipped with BEMS % buildings with heat pumps or access to emission-free district heating % households with smart electricity meters % households equipped with BEMS % households equipped with smart water meters % buildings equipped with smart solar system % use of smart city tools (e.g. digital twins) by municipality to identify priority areas (rooftop PVs, urban forests and fountains, building retrofit, etc.) % firms equipped with smart electricity meters % firms equipped with BEMS % firms equipped with smart solar systems
Health and safety	number of air pollution sensors to measure air pollution/km2 % population with online access to their unified health file % medical appointments that can be booked online % population with the choice between online or face-to-face medical appointments % population equipped with real-time alert systems (air, water, diseases, etc.)
Education and skills	% children who have access to e-learning platforms number of digital learning devices available per 1 000 primary school students
E-government	% city services available online % households using city services available online open data portal (number of online accessible datasets) privacy and data security frameworks in place
Energy, water and waste	% curtailment of renewable electricity generation % smart streetlights % demand response penetration % drinking water under water quality monitoring by real-time water quality monitoring station % coverage of smart water leak detector % coverage of smart waste systems zero-emission consistent energy storage by time (battery, heat storage, hydrogen)

Source: Elaboration from OECD (2020[60]), *Measuring smart cities' performance: Do smart cities benefit everyone?*, https://www.oecd.org/cfe/cities/Smart-cities-measurement-framework-scoping.pdf.

Pillar 2: Stakeholder engagement

As shown during the 2nd OECD Roundtable on Smart Cities and Inclusive Growth, **stakeholder engagement (Pillar 2)** is central to shaping smart cities, with key stakeholders including the city/local government, other level of governments, the city's residents, NGOs, knowledge institutions, and the private sector. As seen in Chapter 2, engaging and seeking partnerships with various stakeholders is key to the efficient and effective implementation of a smart city strategy, especially to foster the net-zero transition. As the transition to net zero requires economies and societies to go through major adjustments, this can be best supported through co-ordinated action between all stakeholders. The consideration of the net-zero transition can be strengthened throughout all steps taken in engaging stakeholders: from basic communication and stakeholders' feedback to the full coproduction, co-delivery and co-evaluation of smart city solutions for net-zero. This can be done for example through communication campaign activities, the creation of a dedicated website, or through workshops and roundtables. Cities could assess the number of those activities (e.g., the number of workshops organised, the number of participants in workshops, the number of clicks on the information website, etc.) to measure the level of stakeholder engagement. In addition to such input indicators, cities could also consider the number of participating private sector entities, and the ratio of private sector funding in certain R&D initiatives or smart city projects depending on their local contexts. During the Roundtable, EMTA proposed to measure the "smartness" of contracts between cities and service providers, i.e., how digitalised these contracts are (Table 3.2).

Table 3.2. Suggested candidate indicators for Pillar 2: Stakeholder engagement

Dimensions	Indicators
Engagement efforts	number of communication activities (e.g., the number of workshops organised, the number of participants in workshops, etc.) number of people reached (participants)
Clarity of goals, transparency & accountability	availability of a master plan with clear goals and specific timelines
Capacity & information (Open data portal)	dedicated websites or platforms to communicate with stakeholders number of clicks on the information website
Engagement outcomes	number of participating private sector entities or % of participation of target group % private sector funding in certain net zero related R&D initiatives or smart city projects % people (stakeholders) supporting (aware of) net-zero related SC projects

Source: Elaboration from OECD (2020[60]), Measuring smart cities' performance: Do smart cities benefit everyone?, https://www.oecd.org/cfe/cities/Smart-cities-measurement-framework-scoping.pdf.

Pillar 3: Smart city performance

Pillar 3 (Smart city performance) aims to measure the impact of digital technologies on well-being, inclusion, sustainability and resilience. To take better account of the net-zero objective and to follow the analysis made in Chapter 1, the sustainability objective can be subdivided into the main sectors where smart city tools can help reach climate objectives. These sectors are transport, energy, transport, buildings, circular economy and waste management, biodiversity and land, and climate action co-benefits. For each of these sectors, new indicators have been identified to strengthen the net-zero objective in the measurement framework. Suggestions of such indicators for the sustainability objective are shown in the table below (Table 3.3).

Table 3.3. Suggested candidate indicators for the sustainability objective in Pillar 3 (Smart city performance)

Smart city objective	Sectors	Indicators
Net-zero transition & climate objectives	**Energy**	energy consumption per capita (kgoe per person) GHG emissions per capita (tons of CO2 equivalent / year) direct and indirect GHG emissions from energy use in each energy use sector (transport, buildings, industry, waste, energy transformation; in tons of CO_2 equivalent)

		energy from renewable sources (%) electricity outage frequency and time
	Transport	modal share of public transport modal share of non-motorised transports realised ratio of electric cars vs. NZE target number of individual vehicles per 1000 people average time taken to access public transport platform average time taken to access key public services, jobs and amenities
	Buildings	heating energy use per square meter % renovated buildings (municipal, residential, other vs. NZE targets) realised ratio of electrification of buildings (municipal, residential, other)
	Circular economy & waste management	municipal waste rate (kilos per capita) municipal waste that is recycled (%) Commercial and industrial waste that is recycled (%) Circular material use rate (share of recycled materials in material consumption) Domestic Material Consumption (tonnes per capita)
	Biodiversity and land	green area (Hectares / 100 000 inhabitants) % green area accessibility (Number of inhabitants living within 300m from public green area bigger than 0.5ha biodiversity loss change in land consumption per capita (square metre per capita)
	Climate action co-benefits	life expectancy level of noise pollution in key points of the city exposure to PM2.5 in µg/m³ (micrograms per cubic metre) average commuting time (average hours per day) time lost in traffic jam (hours/days per year) energy bill relative to household income % people with green job % firms reporting their GHG emissions (Scope 1) % firms reporting their GHG emissions (Scope 2)

Source: Elaboration from OECD (2020[60]), *Measuring smart cities' performance: Do smart cities benefit everyone?*, https://www.oecd.org/cfe/cities/Smart-cities-measurement-framework-scoping.pdf.

Next steps for data collection and further use of the OECD Smart City Measurement Framework

Potential next steps to expand the OECD Smart City Measurement Framework include defining the sources of data that could be used for each indicator, how the data could be collected and at what scale (e.g., grids, wards, boroughs, arrondissements, etc.). While data sources exist for several indicators and could be collected easily, surveys could be designed to collect data for other indicators and fill the data gaps. In this regard, a pilot application the OECD Smart City Measurement Framework with cities and national governments could help refine it as a practical tool. The U4SSC Key Performance Indicators

(KPIs), for example, have gone through a number of iterations after testing the relevance of the KPIs for cities, and whether cities were actually able to collect the corresponding data. During the Roundtable, the Chair of the OECD Working Party for Territorial Indicators highlighted that there can be several sources to collect data but that national statistical offices remain key data sources. In addition to national sources, the huge amount of data generated by digitalisation (e.g., satellite images, mobile device data, etc.) can also be leveraged, as well as the data generated at the city level from the growing number of sensors and various platforms. To harness this increasing amount of data and make it comparable across different jurisdictions, national statistical offices, as well as private organisations and academics, have an important role to play.

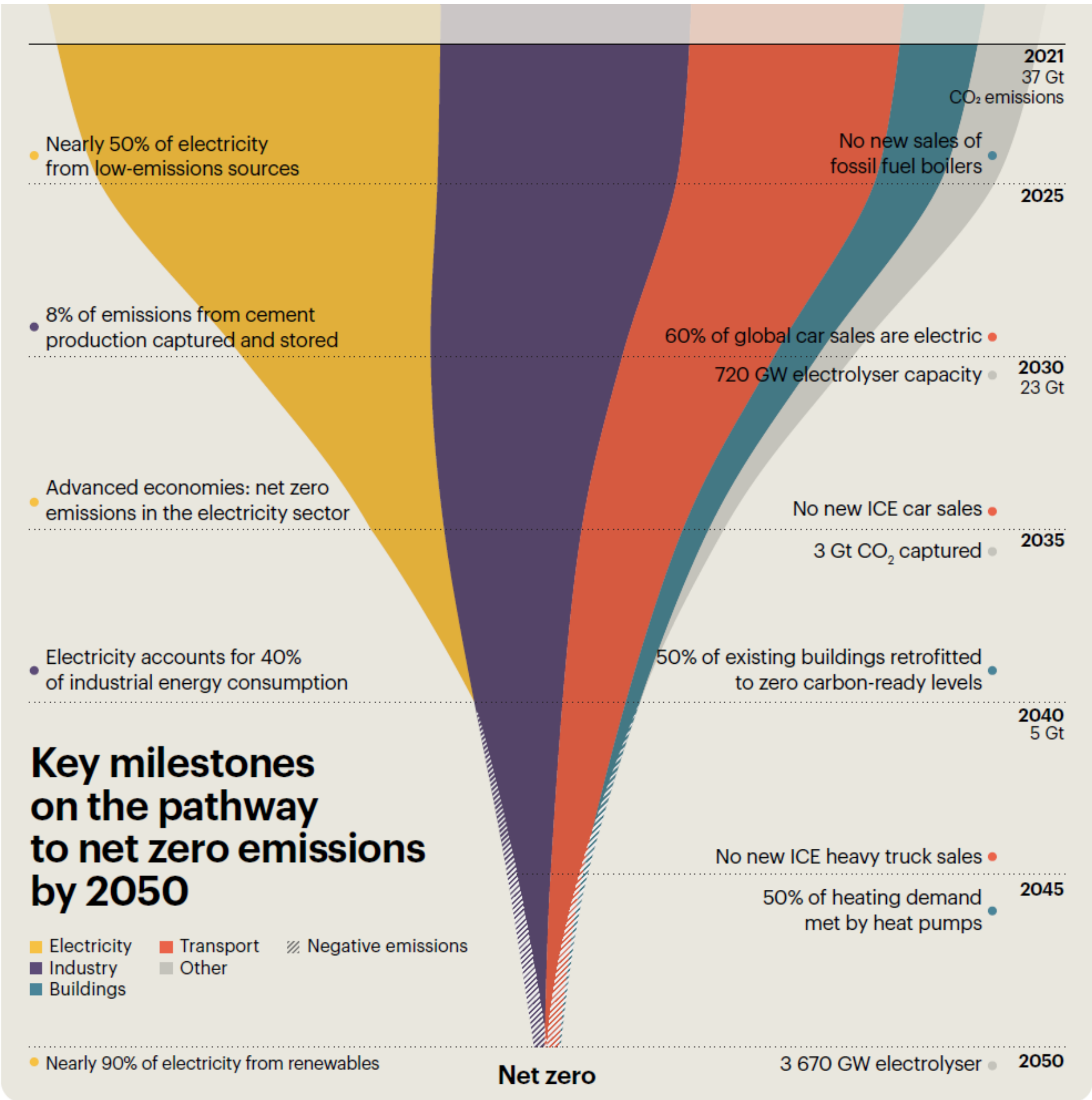
Furthermore, while some suggested indicators could be compared across cities if they are available, some degree of differentiation and customisation would be needed to account for different starting points, or different contexts. Some indicators such as realised ratio of electric cars vs NZE target can also be used as a guiding tool (e.g., benchmarks, progress rates, etc.) for cities to track the progress or to measure the impacts of their policy measures vis-à-vis their net-zero objectives.

The IMD emphasised that simplification and readability are key success factors for measuring the performance of smart cities towards their net-zero objectives. Data needs to be shown in a simple way, with good visualisation tools, to allow decision-makers, investors and citizens to have an immediate view of how the city performs and take action. U4SSC and WeGo pointed out that time series are important for monitoring progress. EMTA stressed the difficulty in measuring some indicators, in particular when it comes to assessing the effect of digital technologies outcomes such as carbon emissions, pollution, etc. This would require experimental protocols that are hard to put in place.

As emphasised by the Chair of the OECD Working Party for Territorial Indicators in his concluding remarks of the Roundtable, smart cities go beyond a narrow definition of cities: they are complex ecosystems that involve many stakeholders, including municipalities and for some of them their metropolitan areas, citizens, the private sector, etc. There is therefore a need for solid governance systems that foster co-operation between the various actors. The OECD Roundtable on Smart Cities and Inclusive Growth allows all stakeholders to share best practices and learn from each other, with the goal of pushing the smart city agenda further and respond to the climate urgency.

Annex A. Net-zero emissions (NZE) Scenario (World Energy Outlook 2022, IEA)

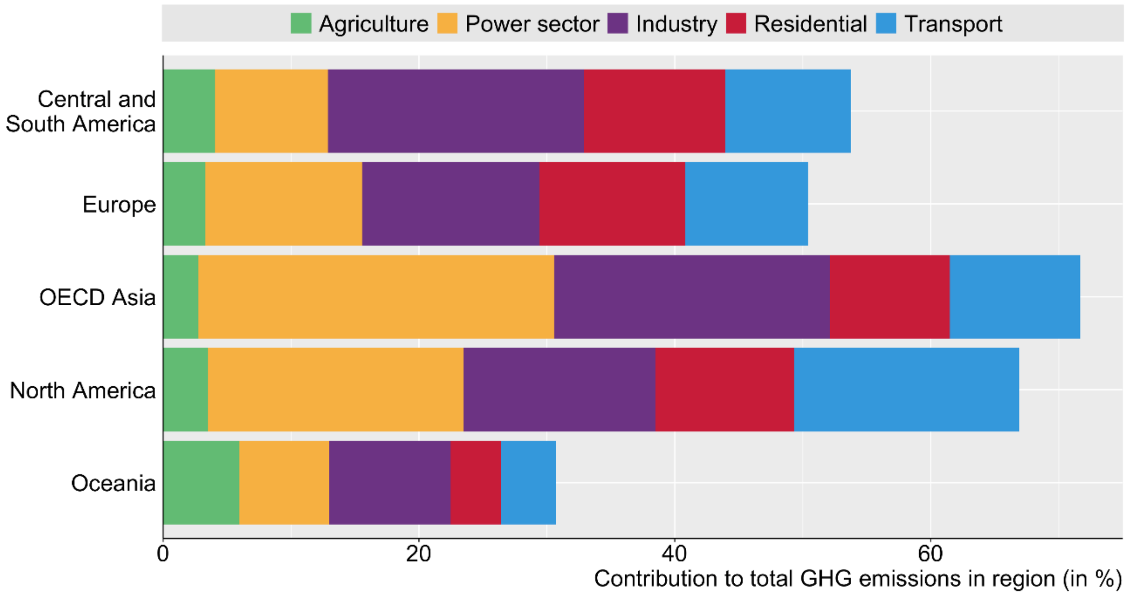
Figure A.1. Key milestones on the pathway to net zero emissions by 2050



Source: (IEA, 2022[6])

Figure A.2. Metropolitan regions contribute the most to greenhouse gas emissions in OECD Asia and North America

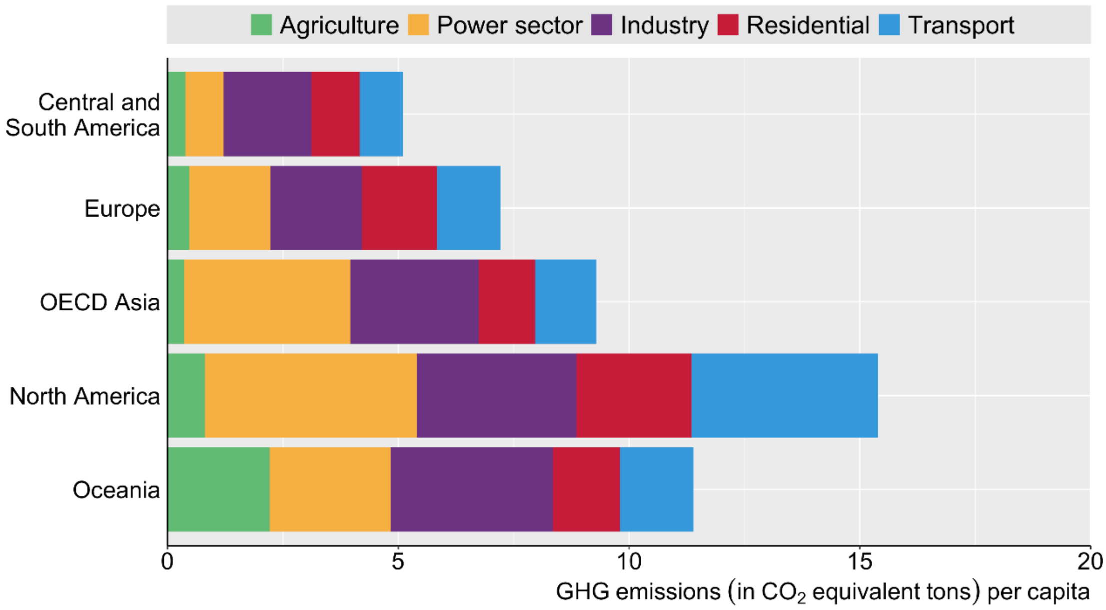
Contribution of metropolitan regions to total production based GHG emissions by macro-region, 2018



Source: (OECD, 2021[2])

Figure A.3. Per capita emissions in metropolitan regions are particularly large in North America, Australia and OECD Asia

Contribution of metropolitan regions to total production based GHG emissions by macro-region, 2018



Source: (OECD, 2021[2])

Annex B. Suggested indicators for the OECD Smart City Measurement Framework presented at the 2nd OECD Roundtable on Smart Cities and Inclusive Growth

Table B.1. Suggested indicators for smart city dimensions

Dimensions	Indicators
Connectivity	% households equipped with (high-speed) internet, wireless broadband coverage; % of households who use digital apps or platforms to connect to local community
Mobility	% of smart traffic lights; % of public transport equipped with real-time information; number of users of sharing economy transportation per 100 000 population; % of public parking spaces equipped with e-payment systems
Jobs and firms	% of job seekers who have access to e-career centres; expenditure in R&D
Housing and built environment	Open-source cadastral data; digital land-use and building permits
Health and safety	% of medical appointments conducted remotely; % of population registered with public alert systems for air and water quality; % of population with online access to their unified health file; % population equipped with real-time alert systems
Education and skills	% of children who have access to e-learning platforms; number of computers, laptops, tablets, or other digital learning devices available per 1 000 primary school students; % of adults undergoing reskilling
E-government	% of city services available online; number of municipal smart stations installed per 100 000 population; % of payments to the city that are paid electronically; high-speed connectivity in the public sector
Energy, water and waste	% of households equipped with smart energy meters; % of buildings with smart electricity meters; % of smart streetlights; % of households equipped with smart water meters; % drinking water under water quality monitoring by real-time water quality monitoring station; % of buildings equipped with smart waste systems

Source: OECD (2020[60]), *Measuring smart cities' performance: Do smart cities benefit everyone?*, https://www.oecd.org/cfe/cities/Smart-cities-measurement-framework-scoping.pdf.

Table B.2. Examples of indicators on stakeholder engagement

Dimension	Indicators
Inclusiveness and equity	Informed and transparent identification and selection of stakeholders to be involved in the engagement process
	Broad outreach to inform individuals and organisations
	Stakeholders' motivations and expectations have been clearly identified (e.g., survey)
	Equitable share of representation among categories of stakeholders (local, national and intermediate governments, academia and knowledge institutions, private sector, civil society, citizens
Clarity of goals, transparency and accountability	Clear understanding of the framework of the engagement process in terms of line authority, proposed timeline, targeted objectives, expected outcomes, etc.
	Development of a master schedule
	Consistent and appropriate communication between promoters of the engagement process and the stakeholders involved
	Dissemination of concise summaries of stakeholder meetings, including digitally
Capacity and information	Establishment of a website to educate stakeholders about how they can contribute
	Number of training sessions
	Summary reports are prepared using non-technical language and disseminated, including digitally
	Existence of mediation mechanisms
Efficiency and effectiveness	Regular monitoring throughout the engagement process
	Definition of performance measures to gauge the extent of stakeholder engagement
	Successful use of the inputs from the engagement process to achieve the desired outcomes agreed by stakeholders
	Fulfilment of the agreed-upon purpose of the engagement process
Institutionalisation, structuring and integration	Requirements for stakeholder engagement are in place within the organisation
	Charters and the rules of the game are clearly established
Adaptiveness	Outcomes of engagement processes cover short- and long-term issues
	Regular reassessment and establishment of new methods to address gaps where the engagement process is not meeting expectations

Source: OECD (2015[61]), *Stakeholder Engagement for Inclusive Water Governance*, https://dx.doi.org/10.1787/9789264231122-en.

Table B.3. Suggested indicators for smart city performance

Smart city objectives	Dimensions	Indicators
Well-being	Jobs	Employment rate (%)
		People satisfied with their job (%)
	Income	People with enough money to cover their needs (%)
	Housing	Overcrowding conditions (rooms per inhabitant)
		People satisfied with affordability of housing (%)
	Access to services	Performance of public transport network (ratio between accessibility and proximity to amenities or people)
		People satisfied with public transport (%)
		Average commuting time to place of work (minutes)
	Education	People from 25 to 64 years old with at least tertiary education (%)
	Political participation and community	Voter turnout (voters in the last national election as a % of the number of persons with voting rights)
		Social connectedness

	Health	Life expectancy at birth (years)
		People declaring good or very good health (%)
	Environmental quality	Exposure to PM2.5 in μg/m³, population weighted (micrograms per cubic metre)
	Personal safety	Percentage of population that feel safe walking alone at night around the area they live
		Transport-related mortality rates (deaths per 100 000 people)
		Percentage of population that have been assaulted or mugged in the previous 12 months
	Community	People satisfied with their city (%)
		People with someone to rely on in case of need (%)
	Life satisfaction	Satisfaction with life as a whole (from 0 to 10)
Inclusion	Economic	Gini index of disposable income (after taxes and transfers) (from 0 to 1)
		Ratio between average disposable income of top and bottom quintiles
	Gender and LGBT+	Gender gap in employment rate (male-female, percentage points)
		Female research and development personnel as a percentage of total research and development employment
		People who believe their place of residence is a good place to live for gay or lesbian people (%)
	Migrant and ethnic	Migrant gap in employment rate (native-foreign, percentage points)
		People who believe their place of residence is a good place to live for migrants (%)
		People who believe their place of residence is a good place to live for racial and ethnic minorities (%)
	Inter-generational	Children poverty rate (%)
		Elderly poverty rate (%)
		Youth unemployment rate (%)
		Young population (from 18 to 24 years old) not in education, employment or training (NEET) (%)
	Disability	Population with a disability at risk of poverty or social exclusion (%)
Sustainability	Energy	Energy consumption per capita (kgoe per person)
		Electricity consumption from renewable sources (%)
	Climate	CO_2 emissions per electricity production (in tons of CO_2 equivalent per gigawatt hours)
		People satisfied with efforts to preserve the environment (%)
	Biodiversity	Change in tree cover (percentage points)
	Material footprint	Municipal waste rate (kilos per capita)
		Municipal waste that is recycled (%)
		Number of motor road vehicles per 100 people
		Change in land consumption per capita (square metre per capita)
Resilience	Health and social	Active physicians rate (active physicians per 1 000 people)
		People with jobs that can be performed remotely (%)
		Deaths due to emergencies/ natural disasters
	Institutions	Population without access to health care (%)
		People with confidence in the national government (%)
		People with confidence in judicial system and courts (%)
		People with confidence in the local police force (%)
		People that believe corruption is spread throughout the government in the country (%)
		SME bankruptcies (%)

Source: OECD (2020[60]), *Measuring smart cities' performance: Do smart cities benefit everyone?*, https://www.oecd.org/cfe/cities/Smart-cities-measurement-framework-scoping.pdf.

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