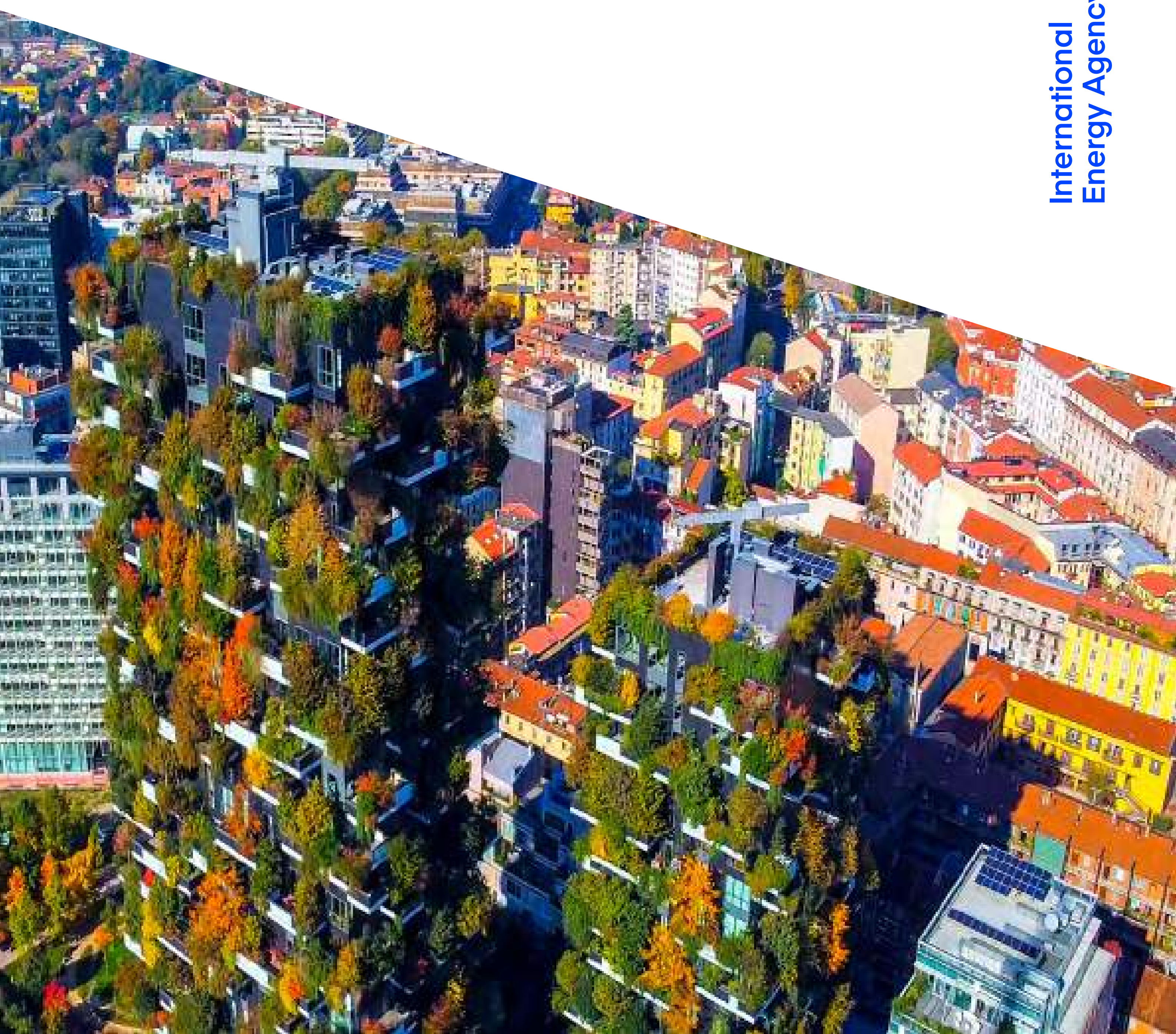
Empowering Cities for a Net Zero Future:

Unlocking resilient, smart, sustainable urban energy systems

International Energy Agency



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Abstract

Climate action in cities is essential for achieving ambitious net-zero emissions goals. Cities account for more than 50% of the global population, 80% of global GDP, two-thirds of global energy consumption and more than 70% of annual global carbon emissions. These factors are expected to grow significantly in the coming decades: it is anticipated that by 2050 more than 70% of the world's population will live in cities, resulting in massive growth in demand for urban energy infrastructure.

Smart cities represent an important opportunity to reduce energy consumption while meeting service demand, improving grid stability and improving the quality of life for all. Next-generation energy systems leverage big data and digital technologies to collect and analyse data in real time and manage city services more efficiently. These solutions are transforming the energy landscape by creating new synergies to reduce emissions, improve energy efficiency and enhance resilience.

Local governments are in a unique position to deliver on the net-zero emissions agenda. In this report we illustrate the wide range of opportunities, challenges and policy solutions that can help city-level governments capture the significant value in efficient and smart digital energy systems, no matter their unique context. Our focus is on ways national governments can help cities overcome barriers to progress and accelerate clean energy transitions using digitalisation.

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Executive summary

Cities are key to a net-zero emissions future where affordable and sustainable energy is accessible to all

More than 50% of the world's population currently lives in cities, and that figure is expected to increase to almost 70% by 2050. Cities generate around 70% of global carbon dioxide (CO_2) emissions. As societies recover from the Covid-19 pandemic, CO_2 rates are rebounding rapidly. The increase in global energy-related CO_2 in 2021 is expected to be the second-largest in recorded history. Cities are a global economic engine, responsible for 80% of global GDP, and represent a major opportunity to accelerate progress towards ambitious climate goals.

These factors make the decarbonisation of cities a global priority and of special significance to achieving national commitments and objectives.

Digitalisation is driving sustainable energy transitions

Today's constantly evolving technology landscape creates new sources of rich data on air quality, energy consumption, geospatial information and traffic patterns, and new tools to manage that data. They can help cities make smarter, better-informed decisions, especially on issues relating to sustainable urban planning and operations. Synthesising these new streams of information can help improve the operation and efficiency of energy systems and address challenges of equity and reliability, assuming that concerns over data access, privacy and security can be effectively managed. Digital solutions and systems can be particularly powerful in cities, where the high-density environment creates economies of scale, minimising the need for new infrastructure and creating new opportunities. Digitalisation can also help de-risk and encourage private investment in clean energy projects, creating new business opportunities and revenue streams, enabling innovative financing mechanisms and improving risk perception.

Increasing generation from distributed renewables, reducing the use of fossil fuel resources, and the electrification of transport and heating all require a broad portfolio of flexibility options, posing new challenges but also creating new opportunities for the management of energy infrastructure. National and local governments, together, are well placed to implement a broad range of innovative policy, financing and technological solutions that will support inclusive, flexible and resilient net-zero energy transitions in cities.

Digitalisation and smart controls can reduce emissions from buildings by 350 Mt CO_2 by 2050

Digital solutions in buildings, such as smart sensors and controls for thermostats and lighting, can help consumers use energy more efficiently and unleash behavioural and lifestyle changes that lead to sustainable energy use. Countries cannot meet their climate targets without optimising building energy efficiency and energy demand; city-level action is imperative. Buildings equipped with new technologies can provide flexibility to support power system decarbonisation, security and resilience.

Urban transport accounts for 4 billion tonnes of CO_2-eq, more than 40% of the transport sector's total emissions

Digital technologies are transforming the mobility landscape by improving energy efficiency, facilitating shifts to active and shared transport modes, improving the convenience and reliability of public transport and more. The electrification of transport and proliferation of electric vehicles (EVs) could enable greater integration of variable renewables via flexibility services such as smart charging and vehicle-to-grid (V2G) services. Time-of-use strategies can shift around 60% of the power generation capacity needed to charge EVs away from peak loading.

National policy makers can accelerate urban energy transitions by following six high-level recommendations

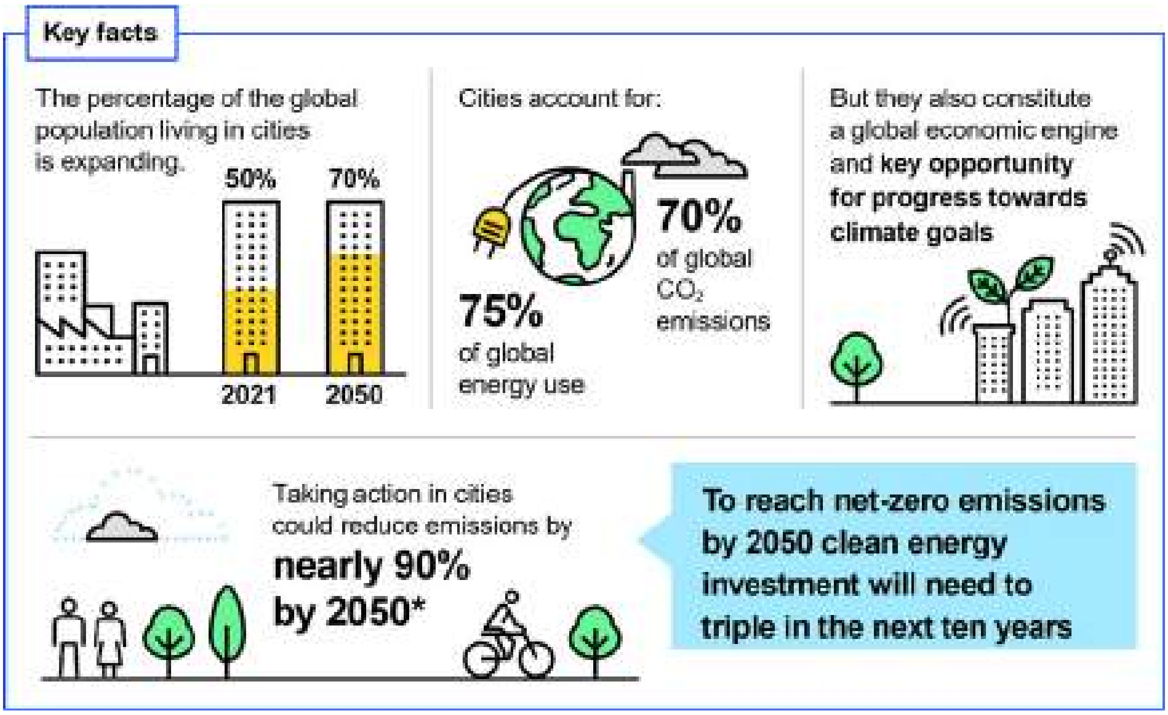
National, regional and local governments, as well as citizen-led initiatives, have an important role to play in incentivising and accelerating digitally enabled urban energy transitions. They can provide financial incentives, resources, policy tools and learning opportunities to help cities fund and implement their smart city initiatives. It is important that national and local activities are co-ordinated to make the best use of resources and that national efforts focus on tasks that cannot be done at a more local level. Our analysis for this report has led us to develop six high-level recommendations for national policy makers:

1. Design inclusive policies and programmes with people at their core.
2. Build capacity across digitalisation and energy.
3. Ensure timely, robust, transparent access to data.
4. Ensure the availability of finance and promote financial innovation.

5. Promote the development and uptake of international standards and benchmarks.
6. Create opportunities for sharing and learning.

Local governments are in a unique position to deliver on the net-zero agenda. Strengthening co-operation between local, regional and national governments can help meet shared objectives while advancing progress on equitable energy transitions. This report illustrates the wide range of opportunities, challenges and policy solutions that can help different levels of government capture the significant value of efficient, smart, digital energy systems, no matter their unique context.

Introduction



*Notes: Taking action in cities could reduce emissions by nearly 90% by 2050, compared to Coalition for Urban Transition's 2050 business-as-usual reference scenario.

A more sustainable future that limits the effects of climate change requires stronger commitment from governments to accelerate clean energy transitions. Global energy-related CO_2 emissions are set to surge by 1.5 billion tonnes in 2021 – the second-largest increase in recorded history – reversing most of the decline in emissions in 2020 caused by the Covid-19 pandemic. There is an imperative to act without further delay to keep net-zero emissions by 2050 within reach.

As of 23 April 2021, 44 countries and the European Union have pledged to meet a net-zero emissions target; in total they account for around 70% of global CO_2 emissions and GDP. Worldwide, over 10 000 cities and local governments representing more than 900 million people have committed to combat climate change under the Global Covenant of Mayors for Climate & Energy. By 2030, Global Covenant cities and local governments could account for an annual emissions reduction of 2.3 billion tonnes of CO_2.

Cities are also looking towards COP26 in Glasgow as a critical milestone in their climate journeys. As of May 2021, 708 cities have joined UNFCCC's "Race to

Zero" campaign ahead of COP26. Cities joining the campaign have pledged to reach net-zero emissions by 2050 and start implementing projects to achieve their targets by 2022.

Cities and regions that pledged for some form of net zero targets

Source: Adapted from Data-Driven EnviroLab & NewClimate Institute. (2020). Accelerating Net Zero: Exploring Cities, Regions, and Companies' Pledges to Decarbonise.

According to the IEA Net-Zero Emissions Scenario, in order to reach net-zero emissions by 2050, annual clean energy investment worldwide would need to more than triple in the next ten years to over USD 4 trillion, requiring drastic transformation. This could see public EV charging infrastructure increase from 1.3 million to 40 million units by 2030, deep retrofit rates more than double by 2030, and solar PV capacity rise twenty-fold by 2050. Meanwhile, electricity demand in emerging economies is expected to grow in parallel with economic development over the coming years. As living conditions improve and extreme weather events become more frequent, so demand for energy-consuming appliances will increase, especially air conditioners. This demand will be especially high in cities. About 90% of the urban population growth expected by 2050 occurs in Asia and Africa. Hence, improving the efficiency, security and flexibility of urban energy systems will be critical to preventing growth in carbon emissions. This requires a deep transformation of the electricity sector enabled by digitalisation.

Covid-19 crisis

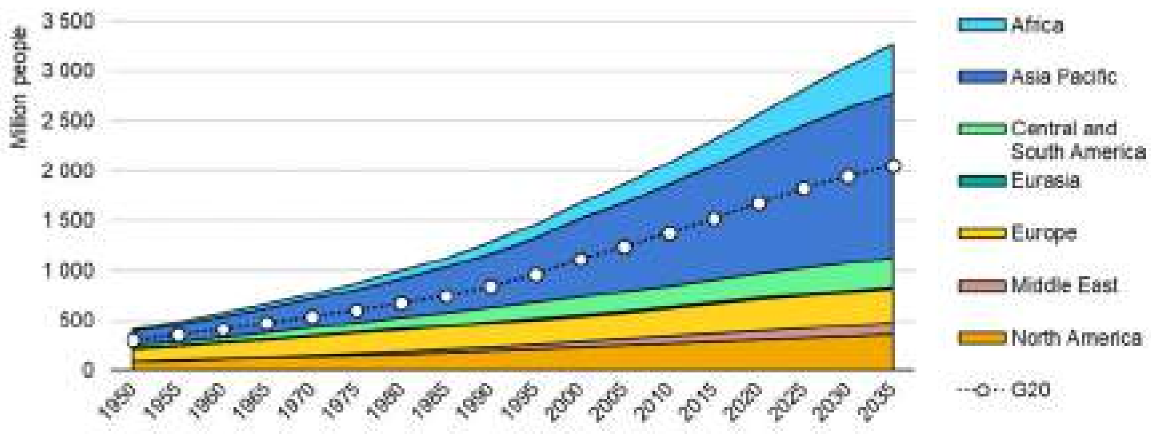
The Covid-19 pandemic has resulted in dramatic behavioural changes and often exacerbated existing vulnerabilities. Cities have suffered, with many businesses shuttered and the urban lower income populations severely affected. Working patterns have changed, with many office workers working from home, and reliance on digital technologies to deliver public services has increased. At the same time, city finances have taken a hit due to decreasing revenues and increasing expenditure, which could lead to subnational government deficits and increased debt.

Recovery efforts could provide opportunities to incentivise some of the climate-positive measures that have become more normalised during the crisis and to further accelerate the process of digitalisation.

Cities' central role in clean energy transitions

The proportion of the global population living in urban areas is expected to increase to over 68% by 2050. The rate of change in urbanisation globally is greatest in lower-income countries, where youth populations are growing and economic opportunities are becoming increasingly centralised.

People living in cities with more than 300 000 inhabitants, G20 countries, 1950-2035



Source: Adapted from UN (2018), Population of Urban Agglomerations with 300,000 Inhabitants or More in 2018, by country, 1950-2035, https://population.un.org/wup/Download/, made available under a Creative Commons licence CC BY 3.0 IGO: http://creativecommons.org/licenses/by/3.0/igo/.

Cities are responsible for nearly 75% of global energy consumption and 70% of global CO_2 emissions. However, cities are also a global economic engine, responsible for 80% of global GDP, and represent a key opportunity to accelerate progress toward ambitious climate goals. Taking action in cities could reduce emissions from urban buildings, materials, transport and waste by nearly 90% by 2050, compared to Coalition for Urban Transition's 2050 business-as-usual reference scenario.

Investing in city-level action can provide the greatest carbon mitigation return on investment and accelerate inclusive clean energy transitions. Making best use of existing technologies and assets and drawing upon the latest innovations in partnership with the private sector can enable more distributed, integrated and multi-directional urban energy systems. This, in turn, will reduce energy demand, improve grid stability, create household energy savings and more.

For instance, the capital costs of providing infrastructure in sub-Saharan Africa is USD 325 per person in dense urban areas as compared to USD 2 387 per person in remote rural areas. Climate-positive investment made in the 2020s roughly equivalent to 2% of GDP (USD 1.83 trillion annually) offers savings of USD 2.8 trillion in 2030 and USD 6.98 trillion in 2050. It would support 87 million jobs in 2030 (mainly from buildings efficiency) and 45 million in 2050 (mainly from transport).

City and smart city definitions

City definitions

The definition of what constitutes a city varies around the world. The OECD defines cities as high-density areas (1 500 inhabitants/km^2 or 50% built-up) with at least 50 000 inhabitants. Metropolitan areas (functional urban areas) consider cities together with their surrounding commuting zones.

Most of the world's largest cities are made up of more than one urban unit. However, the majority of comparative statistics on cities and metropolitan areas are based on data that mask these disparities in units. In addition, in many cases metropolitan areas are not the predominant legal entity. Different designations have different implications for policy and planning. A clear example is the metropolitan area of Mexico City (almost 21.8 million people in 2020), which extends over the territories of 76 municipalities consolidated into 15 jurisdictional planning units.

The delineation of what constitutes a city can significantly affect the relationship between energy use in outer industrial areas and in urban areas. In recent years, for instance, local authorities in European cities have been calling for an approach to net-zero emissions that takes into consideration the interplay between city districts and their surrounding areas. This can pave the way for more integrated approaches where, for instance, district heating and cooling networks using waste heat and renewable energy sources located in peri-urban areas are considered as part of the overall solution for buildings with net-zero emissions.

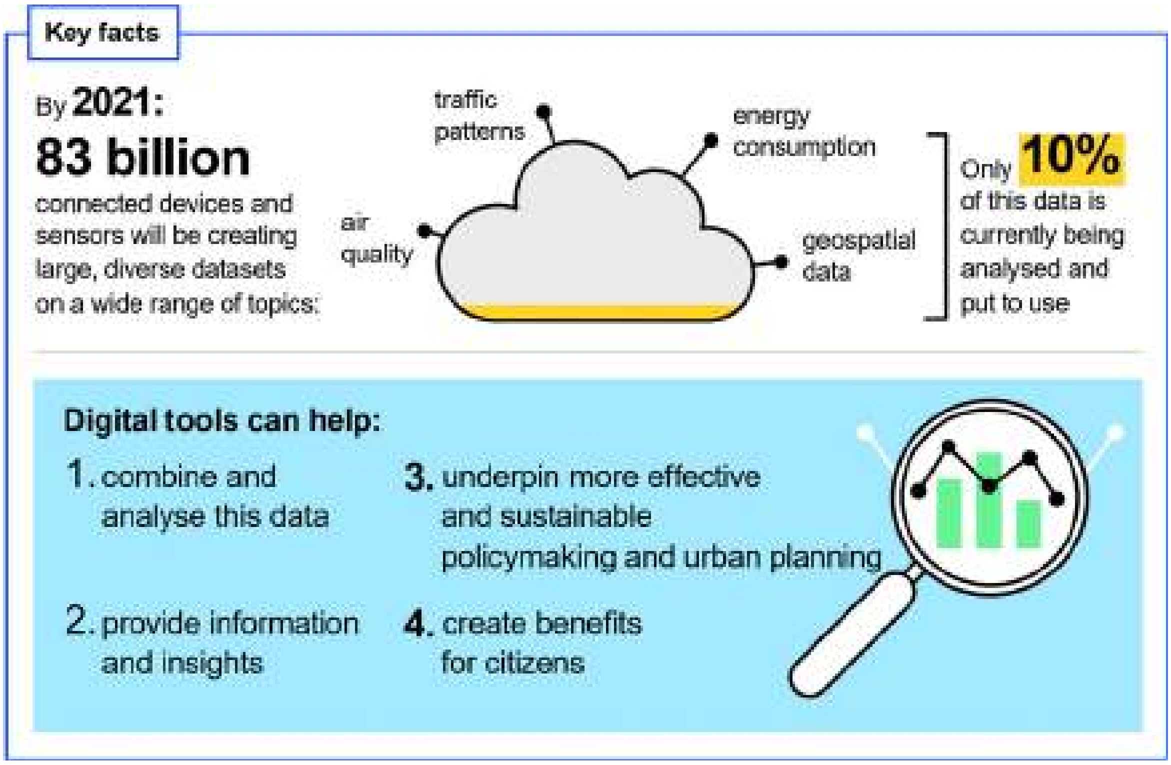
Smart city definitions

The term smart city was coined less than two decades ago and was used to refer to the application of information and communications technology (ICT) and information processing capabilities to improve urban planning, design and operations. Subsequently, the concept of smart cities has expanded to include governance, access and inclusivity, economic and social innovation, and sustainability. To date there is no unified definition. The OECD defines smart cities as “cities that leverage digitalisation and engage stakeholders to improve people’s well-being and build more inclusive, sustainable and resilient societies”.

This OECD definition underlines that digitalisation and digital innovation are not an end in itself, but rather aim to improve people’s lives to achieve greater inclusion, sustainability and resilience.

The smart attribute not only focuses on digital technologies; it also encompasses sociotechnical approaches that combine technological, social, financial and governmental interventions. A number of leading initiatives centre on either smart cities or sustainable cities, but purposely connecting the two frameworks can create smart solutions to accelerate the achievement of urban and national sustainability goals.

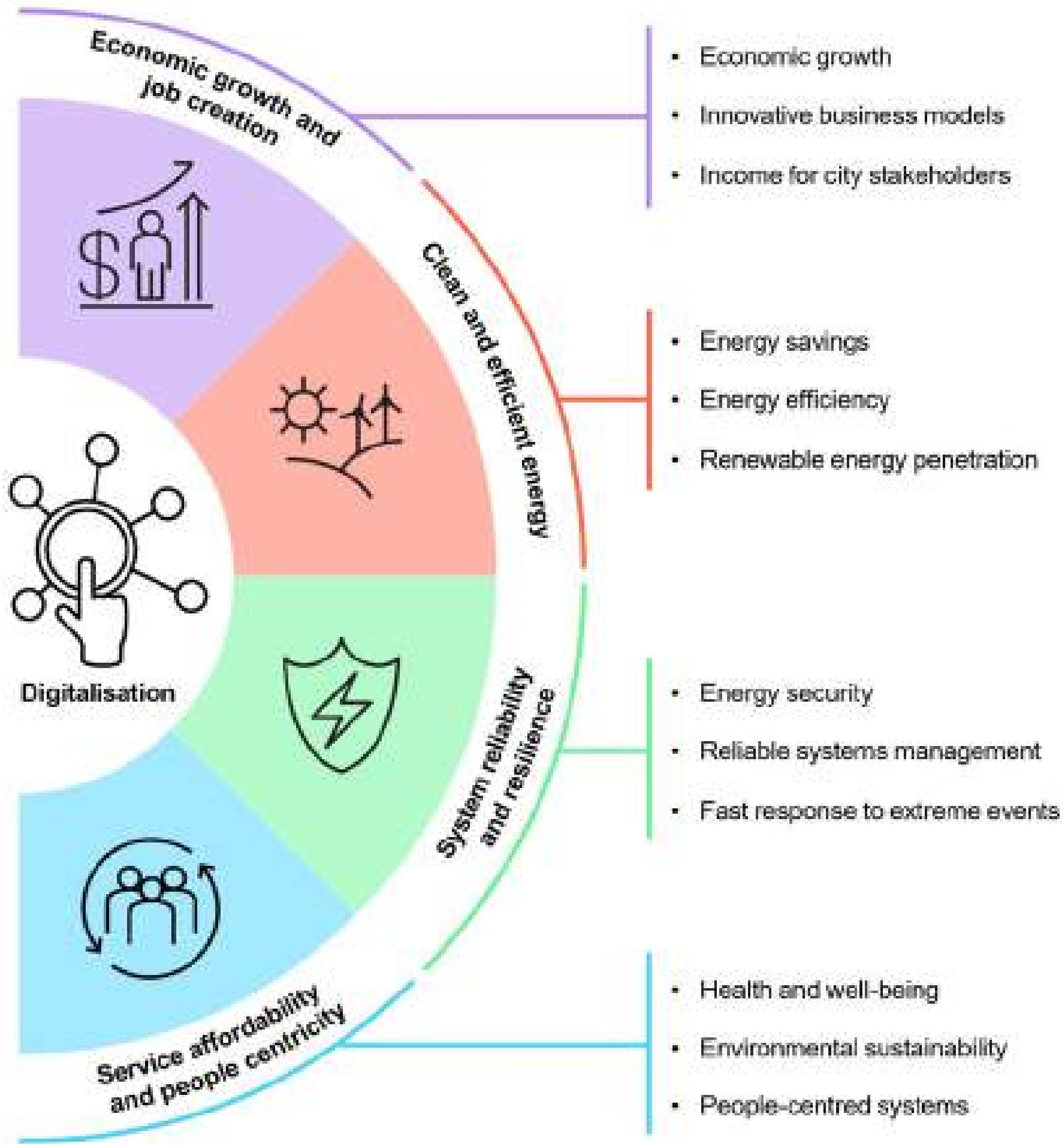
The digitalisation opportunity



By 2024 an anticipated [83 billion connected devices] and sensors will be creating large, diverse datasets on a wide range of topics, such as air quality, energy consumption, geospatial data and traffic patterns. Digital tools can further help combine and analyse this data to provide information and insights that can underpin more effective and sustainable policy making and urban planning, and create benefits for citizens.

Digital technologies are powerful tools for improving the sustainability and resilience of energy systems. Integrating smart digital solutions into energy systems can provide a wide range of benefits, including enhanced energy efficiency. In buildings, for instance, digitalisation enables the analysis of data from various sources (e.g. heating, ventilation, air conditioning, motion sensors, weather) to create real-time insights and forecasts that can be used to optimise energy use while maximising comfort. Digitalisation can also contribute to electricity system efficiency by allowing a network operator to manage smart appliances, for example by briefly pausing or cycling down their operation to help balance the network.

Multiple benefits of digitally enabled transitions to net-zero emissions



Energy efficiency is a no-regret option to cost-effectively achieve multiple benefits. Energy efficiency through digitalisation is especially powerful in a dense urban context. The density of activity in cities creates economies of scale and scope with a high potential for actions that together have a significant impact. By increasing the connectivity of buildings, appliances, equipment and transport systems, digitalisation provides a wealth of opportunities beyond those possible when urban energy end uses remain disconnected. It can reduce resource demand and improve flexibility to respond to changes in the system in real time.

Energy efficiency investments can improve the cost-efficiency of transmission and distribution networks and help reduce the demand strain on distributed renewable resources, such as rooftop solar panels.

Digitalisation is also having and will continue to have a far-reaching impact on employment, including shifts in job categories and skills requirements. While there is a risk that digitalisation could worsen divides between social groups and between the formal and informal economy, in combination with the right policies digitalisation can instead be a leveller and improve access to services and opportunities for all groups. Moreover, digital financial tools can facilitate wider access to services, enable businesses to become more robust and grow, and promote the shift to formal economic activity.

About the report

In this report we explore the role that cities and digitalisation can play in accelerating progress toward a net-zero emissions world. Our focus is on ways national governments can help cities overcome barriers and accelerate clean energy transitions based on digitalisation.

In "The role of cities toward net-zero emissions" we examine how cities' advantages and characteristics can shape net-zero transitions, focusing on how they can specifically influence energy systems.

In "Cross-sector opportunities for smarter sustainable cities" we review the opportunities that digital tools open up to help accelerate clean energy transitions, with a focus on urban planning and integrated approaches.

In "Sector-specific opportunities for smarter sustainable cities" we bring together the range of opportunities that cities can consider in different sectors, considering their associated benefits and providing implementation examples.

In "Challenges and risks" we explore the challenges that need to be tackled and the role of national governments in addressing them and supporting cities.

In "Recommendations" we outline six high-level recommendations mainly targeted at national policy makers, but also relevant for other stakeholders such as city authorities and organisations supporting local-level implementation.

The role of cities toward net-zero emissions

Cities' advantages in net-zero transitions vary greatly from one city to another, but they all have significant power to transform national ambition into action on the ground. The converging megatrends of energy decentralisation and digital solutions put cities at the centre of energy transitions. This chapter outlines the key opportunities, characteristics and drivers.

Key city characteristics

Cities benefit from economies of scale, but are seeing peak energy demand increase

Cities generate agglomeration economies due to the spatial concentration of socio-economic activities, which creates benefits for companies and people. Agglomeration economies create economies of scale, reducing the costs of infrastructure and production of goods and services. In addition, the concentration of people sharing their knowledge is a critical driver of innovation and economic growth in urban ecosystems. These distinct features position cities at the heart of clean energy transitions.

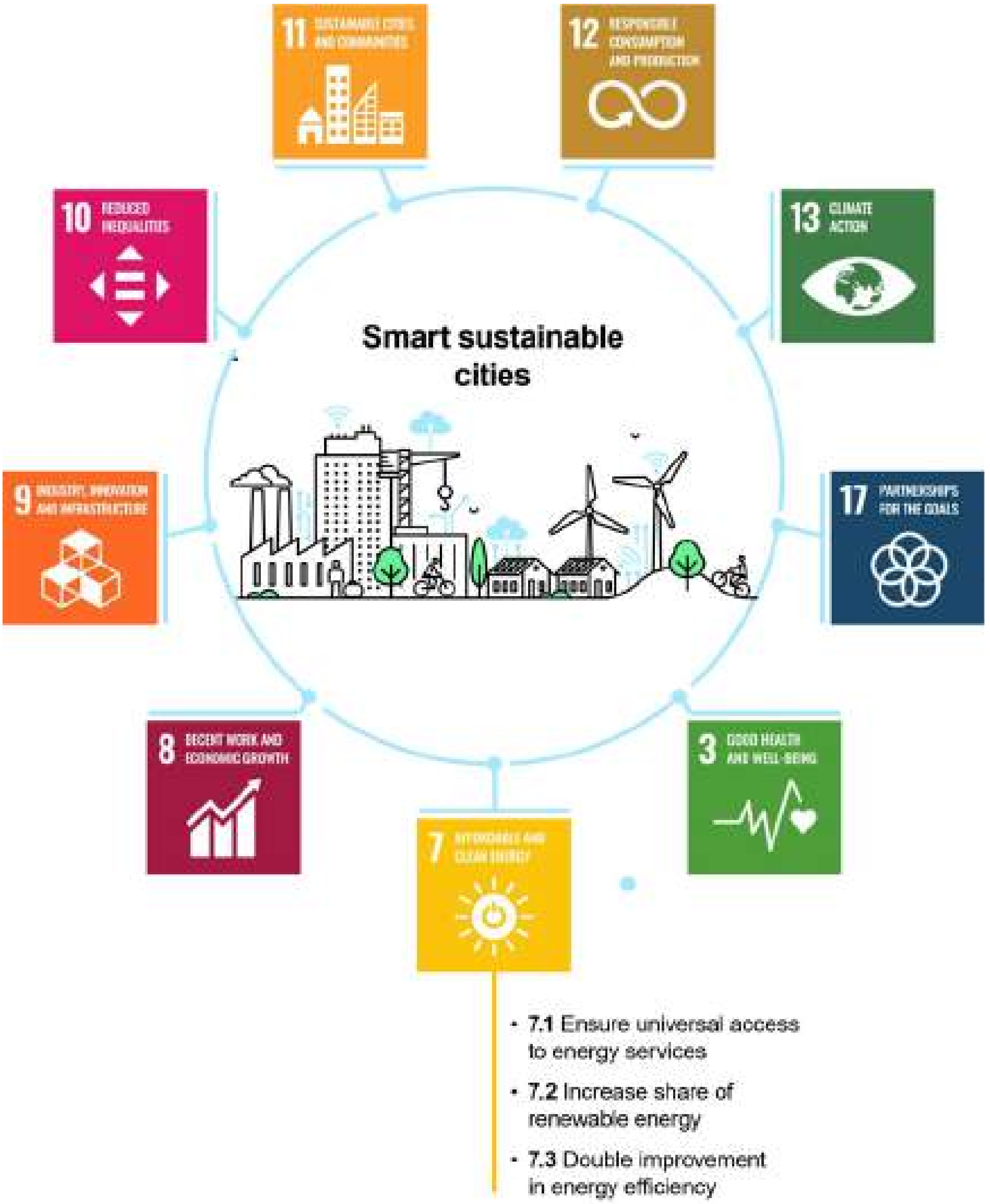
Many global cities are expanding to accommodate growing populations, especially in emerging economies, requiring the extension of energy services to new consumers. This is creating significant acceleration in energy demand growth, especially for cooling. To put this into perspective, by 2040 cooling is expected to account for 30% of peak electricity demand in ASEAN countries, mostly concentrated in urban areas, up from around 10% today. An additional 200 GW of capacity, roughly equivalent to Germany's total current electricity capacity, will be needed to meet this demand. By combining efficiency policies, digital solutions and distributed renewables, such as rooftop photovoltaics (PV), a large share of this peak demand can be mitigated. In mature cities and developed economies, energy demand is more stable, but energy consumption patterns are shifting. The electrification of transport and heating, for example, may increase urban electricity demand, while improving urban quality of life, notably air quality.

These changes in energy demand coupled with the concentration of energy consumers in one place create additional strain on energy grids, especially at times of peak demand. In cities with insecure or unreliable energy supply, this can regularly create drops in voltage, restricting consumption. Natural disasters can also cause extensive damage to energy grids, resulting in severe energy supply outages. Digital technologies can help to support energy network security and stability, especially when they improve the resilience and energy efficiency of the system, reducing overall demand and easing the strain at peak times. As countries retire fossil fuel-based energy sources to achieve their net-zero emissions targets, rapid growth in variable renewables and distributed resources will see them replace fossil-based power generation and help to alleviate traditional fuel security concerns. The transition to net-zero emissions will require a broad portfolio of policy, regulatory, technological and behavioural solutions.

Cities have a new role to play in this transition. As load centres in the power system, they used to almost exclusively consume power generated outside their urban areas. Today, with the rapid deployment of distributed energy resources, cities can meet part of their consumption themselves. They can support the integration of renewable energy both at local and national scale by providing flexibility. The term “demand-side flexibility” describes the capacity to align the energy demand of buildings and transport systems with variable renewable energy supply.

Digital solutions allow urban clean energy transitions to be accelerated and scaled up, thereby speeding progress toward the UN Sustainable Development Goals (SDGs). Digital technologies can simultaneously contribute to SDG11, Sustainable Cities and Communities, and to all three sub-targets of SDG7, Affordable and Clean Energy, as well as contributing to a range of other SDGs.

Contribution to SDGs



Source: Adapted from UN (2021), https://sdgs.un.org/goals.

Cities' characteristics shape their role in achieving net-zero emissions

Each city has distinct characteristics, environment and culture. However, cities also share common qualities that can inform our understanding of social, spatial and economic trends. While the most effective path to digitally enabled net-zero transitions will vary across different types of cities, a number of cross-cutting factors can help cities identify and learn from their peers, including:

Density – Higher population densities and compact urban forms can reduce greenhouse gas (GHG) emissions by a factor of two or more. High density does not necessarily mean high-rise, as well-designed medium-rise buildings can offer similar density benefits. Density provides significant value, especially to cities with more limited resources, as it plays a key role in reducing the energy intensity and cost of the urban infrastructure and services. The economies of scale created by density give cities greater potential to leverage active transport modes, public transport, district heating and cooling, and digital network infrastructure. Conversely, higher density may also negatively impact access to solar energy for energy production, daylight and thermal comfort, both indoors and outdoors.

Level of municipal budgets and economic profile – City budgets can determine the opportunities that are best-suited to the purpose. Cities with bigger budgets are able to invest more in innovative technologies, while resource-constrained cities are often sources of innovative business and financing models. Local industry also strongly influences city energy use and emissions. Urban areas that serve as transport and freight hubs may have significantly higher demand for transport fuels than other types of cities. Likewise, cities where the service industry predominates may require higher shares of electricity for buildings energy use.

Affluence – The affluence of residents also influences energy use and GHG emissions. Cities with a per-capita GDP of less than 10 000 USD on average use just under one-quarter of the energy of those above this threshold. In addition, affluence may also correlate with higher land values, thereby increasing the cost of renewable energy installations or public transport systems.

Informality and inequality – Socio-economic inequalities are manifest in the urbanisation patterns of many countries, particularly in fast-growing urban areas of emerging countries, often in the form of socio-spatial segregation. Poor households often have to resort to constructing self-help housing situated on the fringes of cities in zones at greatest risk of natural hazards. Another dimension of inequality in cities is informal labour, which represents a significant proportion of the urban labour force, especially in the buildings, services and construction sectors. In some regions, this share can be as high as 75% for the construction of residential buildings.

Degree of decision-making power – The autonomy, mandate and scope of responsibility of cities vary considerably. Cities with a high degree of autonomy will be able to take advantage of a broader range of opportunities, while cities with less autonomy will more heavily rely on national support to devise and implement net-zero emissions plans. Even in the latter case, the role of cities remains important as they can be strong advocates and accelerators of action towards decarbonised and digitalised energy systems, notably by championing behavioural change and the adoption of new technology solutions.

Maturity level and development – Cities also vary in the age of their built environment, the need for new urban development and the pace of urbanisation. Mature and static cities with old building stocks will find greater opportunities in retrofits and optimising the use of existing infrastructure. Meanwhile, developing or emerging cities will have more opportunities to integrate net-zero solutions in new buildings and development plans.

Urban form – The nature of the built environment is an important determinant of urban energy demand, encompassing its overall physical characteristics, such as shape, size, density, functionality, street networks and public spaces. Likewise, at the building scale, factors like compactness, height and orientation influence energy demand in buildings and local renewable energy potential.

Status of infrastructure – Cities with ageing infrastructure will find opportunities for the modernisation and optimisation of existing assets, while cities in the process of developing new infrastructure can leverage digital technologies as part of commissioning and development. In particular, the age of transport infrastructure can significantly affect energy use. For example, legacy highway systems can be linked to vehicle congestion and inefficient freight logistics.

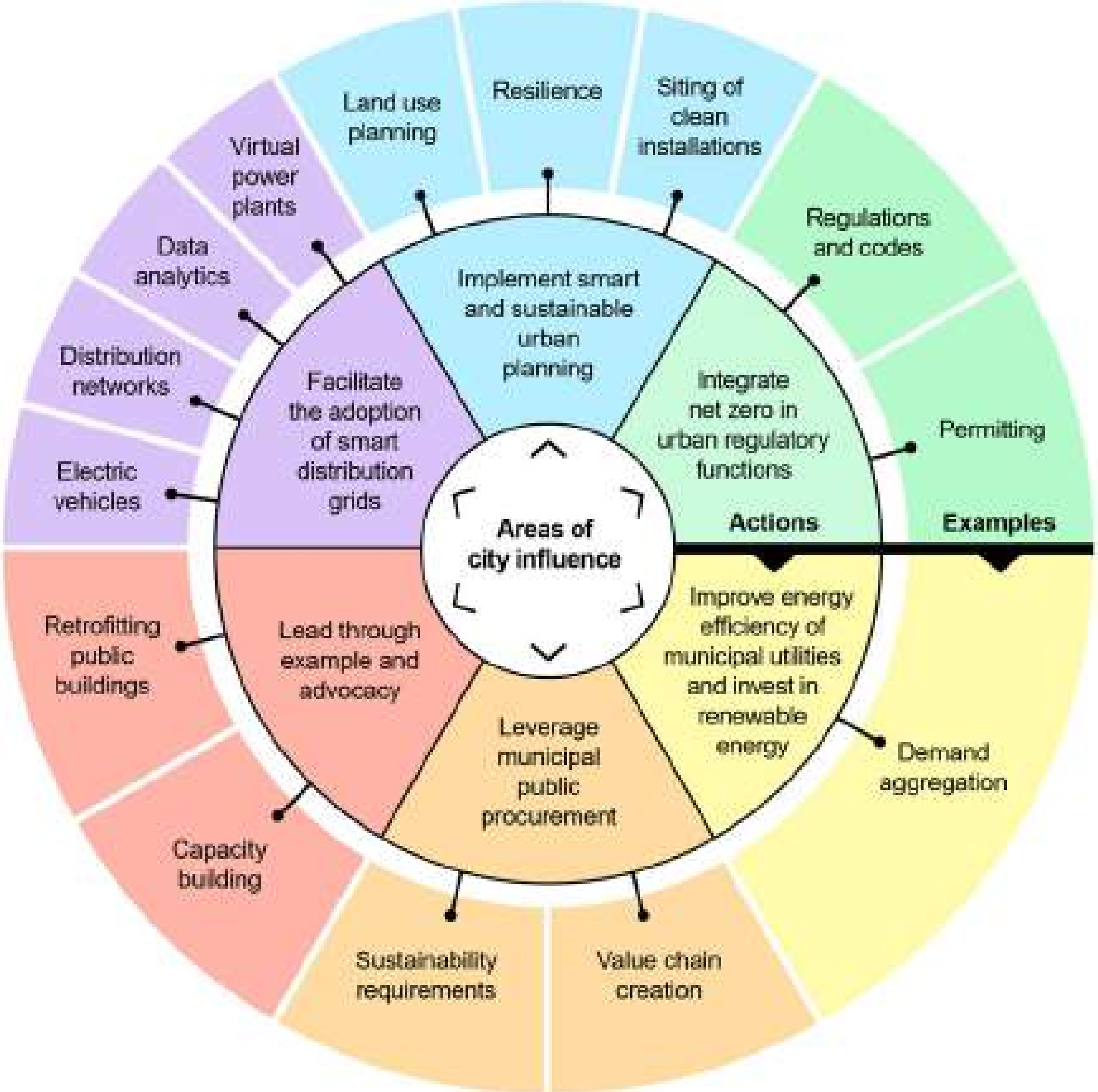
Geography and climate – Geographic factors, like topography, availability of renewable energy resources, patterns of renewable resources, risk of natural disaster and prevailing temperatures, can affect city energy demand. A high availability of renewables will necessitate more focus on demand-side flexibility, while cities with less availability of renewables will need to focus even more on reducing demand and decarbonising energy supply.

Connectivity – Cities that have access to highly interconnected power grids may have less imperative to focus on new and distributed forms of flexibility.

Meanwhile, cities with low or unreliable access to energy services may find opportunities in autonomous and off-grid solutions. Cities with advanced communication networks and extensive access to them will have more opportunities for digitally enabled net-zero solutions than cities still in the process of developing communication networks and infrastructure.

The urban influence on energy systems

How cities can influence local energy systems



Cities' complex networks of infrastructure (water supply, transport, electricity, heat, waste, etc.) are governed by multiple and often overlapping areas of policymaking. In this context, a growing number of cities are using their climate plans and targets to align various policy spheres and stakeholders behind common goals and induce structural change at the urban planning level. Cities can be change agents in clean energy transitions by playing an active role in local energy planning aided by new digital solutions.

Cities benefit from implementing smart and sustainable urban planning

Through their core functions of spatial and urban planning, local governments shape the sustainability trajectory of their cities. Planning decisions on land use and urban layout have impacts lasting for decades and even centuries. A number of crucial levers shape the urban form and can influence climate mitigation and adaptation, including urban design and nature-based solutions.

From a land use perspective, by fostering land use change via rezoning, development control and green zoning, cities can protect and restore vital ecosystems and use nature-based solutions to build urban resilience. The URBAN GreenUP project has developed a digital tool to assist authorities, urban planners and citizens identify the nature-based solutions that best fit a city's needs. Cities can also make public land available for clean energy infrastructure. As land use planners, local authorities can guide urban development plans to encourage smart, sustainable energy solutions. In Germany, more than two-thirds of municipal utility companies use the roof surfaces of public buildings to locate their installations.

One of the core functions of city governments is to protect their residents from natural hazards and extreme climate-related events. Digital solutions have considerably enhanced the accuracy and granularity of land use plans by incorporating data on natural hazards, climate-related risks, critical infrastructure systems and facilities that address community utility needs such as hospitals and emergency shelters.

Cities are increasingly developing resilient power strategies to ensure that critical public and private facilities can operate in the event of power disruption. Resilient power technologies, such as solar plus battery storage, are now available to protect critical facilities from power outages. Distributed solar generation with energy storage can be used to create embedded microgrids when combined with load management and smart systems, disconnecting from the main grid through "adaptive islanding" in the event of major disruption and continuing to supply the critical loads despite the loss of the main energy feeder. These microgrid solutions can also help with faster system restoration following disturbances, and are emerging as a major element of urban energy system resilience.[1]

Expanding on their planning function, cities can also make use of geographical information systems (GIS) to map renewable energy potential at the city level and identify best options for siting distribution network infrastructure. Through its Clean Energy Program, the New York City government aims to expand solar PV and other distributed energy resources across its portfolio of buildings, with the goal of installing 100 MW of solar PV on city-owned buildings by 2025. To this end, the city assessed all public buildings greater than 1 000 gross square metres for solar readiness and identified nearly 55 MW of rooftop solar potential.

Integrating net-zero emissions into urban regulatory functions is a powerful tool

Cities can also have a powerful role in clean energy transitions by incorporating smart and clean energy solutions into regulations and codes. In the same vein, local authorities can streamline relevant permitting procedures and technical standards.

City authorities are essential stakeholders for implementing national strategy and policies, for example via building codes. Construction and buildings are typically governed by rules set in urban planning regulations. Authorities should take into consideration building energy consumption and the potential for local energy production when implementing these regulations and developing plans. Local authorities are increasingly setting out urban plans that promote zero-carbon buildings, with consideration of how urban form impacts energy demand through shape, size, density and configuration. At the building scale, compactness, height, orientation and mutual shading have a great influence on energy demand, on demand for materials and on local renewable energy potential.

For example, the city of Vancouver, Canada, now requires every residential parking space in new developments to feature Level 2 electricity outlets to charge EVs. This change addresses the challenge of accessing EV charging in multi-family residential buildings, which is usually harder than in single homes.

Municipalities can also act as local hubs for building renovation programmes, as illustrated through the example of Europe's Citizen Energy Communities. By co-ordinating these local hubs, cities can aggregate housing renovation projects

[1] Ostfeld, A., M. Whitmeyer and A. Meier (2018), *Adaptive Islanding and Self-Sufficiency of Block-Scale Microgrids*, https://www.researchgate.net/publication/325635656_Adaptive_Islanding_and_Self-Sufficiency_of_Block-Scale_Microgrids.

to secure high-quality local supply chains and support residents' decision-making. Local governments can also be powerful change agents by mandating the sustainable design and construction of social housing, as shown in Mexico through the Financial Co-operation Programme for Sustainable Housing in Mexico.

Cities, as owners and operators of municipal utilities, have significant influence

In some cases, municipalities are owners and operators of local utilities. As such, they can influence the energy mix and automatically enrol residents on low-carbon schemes with the ability to opt out. In some countries, municipal energy companies are among the most important investors in renewable energy projects. Germany has approximately 900 municipal utilities, called *Stadtwerke*. These companies often bundle energy services such as electricity distribution, public lighting and public transport, and many of them are using digitalisation to create new business models. The city of Emden's *Stadtwerke* recently founded a new company, Emden Digital, to implement its digitalisation projects. It will manage an Internet of things (IoT) open data platform, rolling out both a smart meter programme and a broadband expansion plan. Other *Stadtwerke* are deploying blockchain technology to enable new business models such as peer-to-peer electricity trading. These kinds of municipal utilities expand the public value of energy digitalisation to individuals, communities and regional economies.

Some cities that have not traditionally owned local distribution utilities are beginning to create their own so they can accelerate the energy transition. Barcelona Energia was set up in 2018 and exclusively draws its power from renewable sources, using efficient digital tools. In the span of two years, it has achieved savings of EUR 1.3 million in electricity costs and 100 000 tonnes of CO_2 emissions at the city level. Even when cities do not own local utilities, they are still large energy consumers and can require that the power they use for hospitals, schools, offices, streetlighting and public transport come from renewable sources coupled with smart and efficient technologies.

They can also act as aggregators of demand, procuring clean electricity in large quantities to cover the combined needs of residents and businesses, increasing competition, reducing risk and negotiating better rates for local residents. Some city authorities have taken a proactive role in facilitating or running community bulk-buying programmes on behalf of residents and businesses, such as Community Choice Aggregation (CCA) programmes in the United States. CCAs are "statutorily authorised retail electricity choice programs administered by municipalities", which aggregate the demand of all customers within their jurisdictional boundaries, enrolling customers on an opt-out basis, to source supply from clean energy generation suppliers. As of 2019, CCA laws covered half of the annual electricity demand in nine states, across over 1 500 municipalities and serving over 30 million Americans.

Municipalities can leverage their public procurement to pursue net-zero emissions

Public procurement, defined as "the purchase by governments and state-owned enterprises of goods, services and works", accounts for 12% of GDP on average in OECD countries, and up to 20% in many emerging and developing countries. Around two-thirds of this amount is spent at subnational level. By including sustainability requirements in their procurement practices, as well as life-cycle cost-benefit assessment, cities can activate cleaner supply chains. This can benefit the broader public and create cost savings. Public procurement is a powerful lever in mainstreaming sustainability practices and amplifying cities' purchasing power. It can lead to innovation and drive market change towards the sustainability goals of the city and at a national level. A growing number of cities are incorporating requirements and/or guidelines into public tender competitions to prioritise material efficiency and the use of low-carbon materials in municipal development projects.

In 2017, Oslo adopted a new procurement strategy with the clear objective that all purchasing decisions, amounting to EUR 3 billion annually, must contribute to the goal of carbon neutrality by 2030. The Los Angeles Department of Water and Power is the largest municipal utility in the United States, with USD 5 billion in annual operating revenues and USD 2 billion in annual spending for goods and services. To put this figure into context, in just one month (May 2018), the organisation awarded 216 new contracts worth USD 62.7 million to 134 suppliers. It has been reporting its emissions to customers through the Carbon Disclosure Project, with ambitious goals to further reduce its environmental footprint and carbon emissions

Cities are ideally placed to lead by example and through advocacy

City authorities are also powerful advocates, leading by example when building or refurbishing their own assets. They can influence the behavioural choices of citizens and businesses. Municipal authorities can also strengthen local capacity and employee skills through staff training programmes, focusing on cross-cutting skills that enable integrated city planning, including resilience planning. In recent years, among many such programmes, the Asian Development Bank, the Economic Commission for Latin America and the International Telecommunication Union (ITU) have all developed capacity-building programmes for integrated city planning.

City planners have a unique overview of the various ongoing or planned projects in their territory. They therefore have a crucial role to play in facilitating innovative clean energy projects by bringing together local stakeholders, in particular project developers and community groups. In this way, they can strike a balance between financial and public value performance measures.

Municipalities can support and take part in local energy co-operatives that bring together different city stakeholders to implement clean energy projects. A study of German and Swiss energy co-operatives showcases how private individuals, municipalities, farmers, banks, enterprises, energy utilities and other city actors facilitate the installation of renewable energy sources. The study highlights the role of municipalities in encouraging these initiatives by capitalising on political support and employing their financial capacity, public relations competence and authority on land rights.

Cities can also engage residents in awareness campaigns that aim to make cities' plans and regulations clear and understandable to the public. The latest EV policy in New Delhi, for example, was advertised through the eight-week mass campaign "Switch Delhi EV", during which younger generations were specifically targeted and encouraged to take a pledge that their next vehicle will be electric.

Smart electricity distribution can boost flexibility and transform cities

Cities have characteristics that make them ideal for power system flexibility platforms. They have less land available, and it is more expensive. This results in competing demands for land and greater need to use space efficiently. A highly interconnected, but often more constrained network also benefits from greater flexibility, creating a compelling business case for increasing electricity system flexibility in cities, particularly as the electrification of heating and transport increases.

Digitalisation enables cities to create a range of distributed energy and flexibility platforms that can support the acceleration towards net-zero emissions goals, from virtual power plants and data analytics on distribution networks, to connected EVs and integrated public transport. Having these platforms close to demand creates greater efficiencies by reducing the need to build grid infrastructure and better aligning supply and demand.

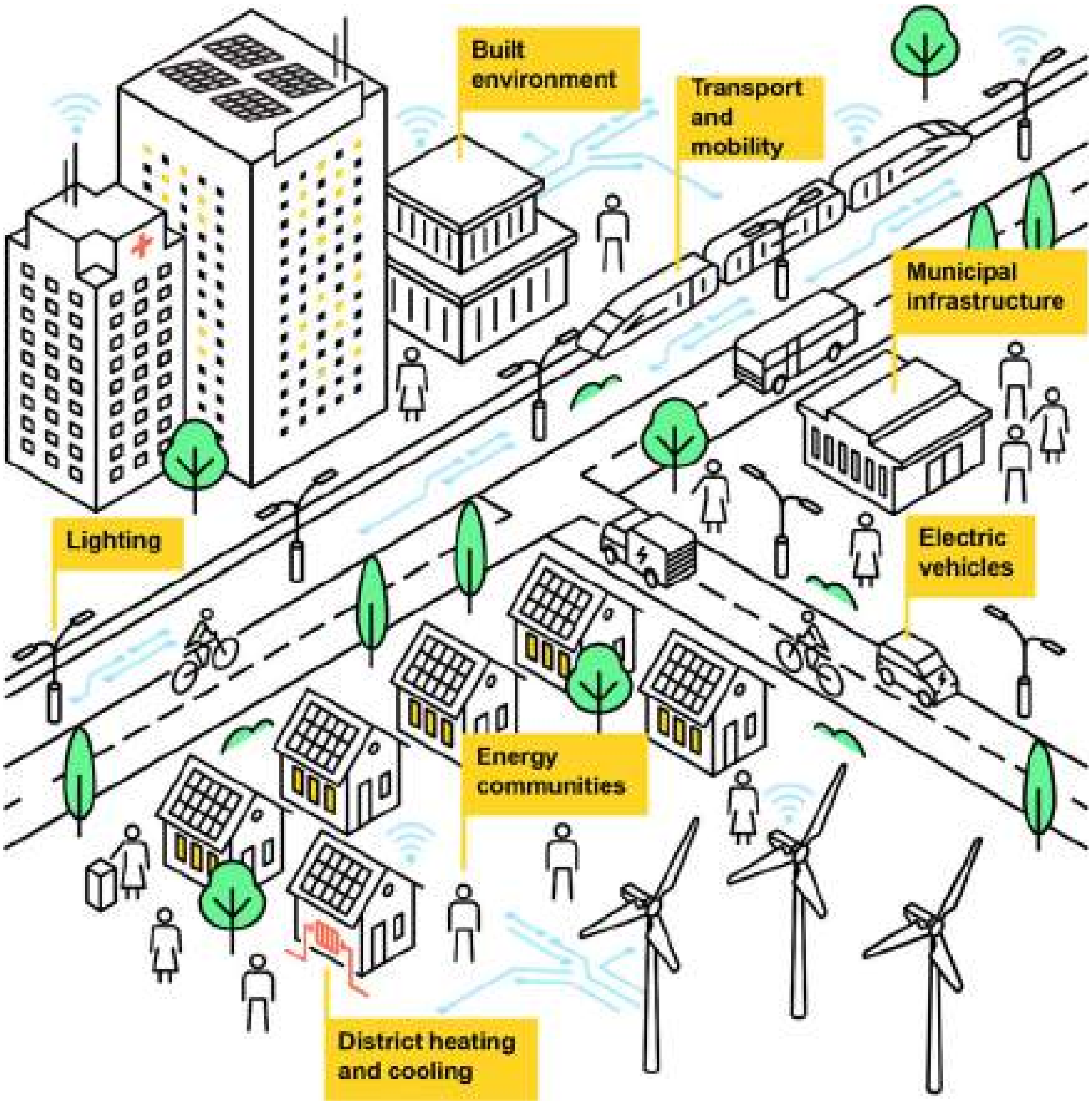
Platforms for flexibility can focus on particular solutions, such as Singapore Power's initiative to digitalise substations, or Dubai's move towards integrating neighbourhoods, where DEWA, the local utility, has launched a network operation centre that merges demand response, smart metering and other smart grid capabilities. Flexibility can also support integrated utility management across sectors. Implementing flexibility platforms at the outset of new urban developments can help to break down sectoral silos and improve efficiency across end uses. For example, a greenfield smart city in India, led by Nava Raipur Development Authority, includes a command and control centre, transport, smart grid applications and waste management.

Cities have a role in promoting smart distribution grids

Flexibility is required in all electricity systems with higher penetrations of variable renewable energy. In certain locations, specific geographical circumstances make demand-side solutions more valuable. For example, flexibility sources in London, UK, provide GBP 500 million annually in direct avoided distribution network costs and more than GBP 900 million per year in wider system savings, contributing to the GBP 16 billion in savings to the wider system per year by 2050.

A full understanding of the synergies between "smart grids" and "smart cities" is nascent, but rapidly developing. Smart grid technologies have focused mainly on transmission in the past. But increasingly, digital technologies are able to bring to the distribution and transmission networks some of the smart grid benefits of monitoring, predictive analytics, more accurate modelling and real-time balancing or load management, as well as predictive maintenance and more rapid fault identification/repair crew dispatch. In Brazil, Enel launched the Urban Futurability project in the Villa Olimpia district of São Paulo, a living lab to demonstrate the benefits of full digitalisation of an urban area in a megacity, starting with the power grid, and involving and engaging all local stakeholders. Over the coming decade, regulatory frameworks will evolve to unlock a variety of barriers, to allow not just industrial sites but also smaller loads such as vehicle fleets, homes and neighbourhoods to participate in the provision of energy and ancillary services that have been traditionally managed centrally.Although many city authorities have a limited role in energy distribution (unless they own the local utility), they can play a role in supporting the evolution of distribution networks. Cities can build an enabling environment by introducing planning policies that ensure network operators co-operate widely and adopting regulatory requirements that rule out some solutions and favour others. For instance, Paris will ban diesel-based generation from 2024. This means distribution system operators will have to rely on smarter technologies, such as batteries or flexibility contracts, to manage outages. Enedis, the main system operator in France, launched a call for tenders for flexibility in some parts of Paris, excluding diesel-based generation.

Cross-sector opportunities for smarter sustainable cities



At the city level, a complex system of infrastructure networks – such as water, transport, electricity, heat, waste and communications – comprises multiple, and in some cases overlapping areas of policymaking. Digital tools can open up opportunities for integrated and systemic solutions across these networks to help accelerate clean energy transitions. They can help visualise and identify opportunities at the intersections between systems, as well as support circularity and sustainability. Sensors and real-time demand management can provide considerable value to energy networks and urban systems. For instance, EV charging can be shifted to times when more renewable energy is available, demand response-enabled appliances can help mitigate peak demand, and real-time information on traffic conditions can reduce road congestion. Smart cities can leverage advanced big data analytics and digital technologies to collect and analyse data in real time and more efficiently manage city operations and services.

Digitalisation can be deployed across a range of systems to improve efficiency and reduce the costs of urban services, while also accelerating clean energy transitions – increasing the deployment of renewables, improving energy efficiency, and reducing fuel consumption and emissions. Connected assets and infrastructure can support more integrated urban planning practices and transform urban energy sectors, such as buildings, transport and lighting, making the value of smart, sustainable urban energy systems more than the sum of their parts.

These types of technologies can transform the energy and urban landscape by creating new synergies. However, policies, building codes, appliance standards, demand management protocols, energy prices and other carbon intensity signals will need to change to ensure that this value can be realised.

International efforts are increasingly focusing on cities and include the following initiatives:

- Global Covenant of Mayors for Climate and Energy
- C40 Cities Climate Leadership Group
- Carbon Neutral Cities Alliance
- Coalition for Urban Transitions
- ASEAN Smart Cities Network
- Inter-American Development Bank's Emerging and Sustainable Cities Initiative
- European Commission 100 Climate-Neutral Cities by 2030.

Furthermore, proposals to create an IEA Cities Technology Collaboration Programme and a possible future Mission on Innovation-Driven Urban Transitions are under discussion.

Digital technology definitions

Big data does not simply imply handling large datasets. The term refers to data sources that are continuously generated and too large and diverse to be processed by conventional means, requiring advanced digital intelligence and analytics.

The **Internet of things (IoT)** is a system of physical devices connected over the Internet and exchanging data streams. These devices include sensors and actuators embedded in appliances, machines, urban assets and building structures.

A **geographical information system (GIS)** is a digital framework for identifying spatial information. It standardises locations on the Earth and links them to various physical attributes, making it easy to analyse, manage and integrate geographical datasets.

Artificial intelligence (AI) is a broad catch-all term for machines mimicking traits of human intelligence and performing human tasks. It is used to predict, automate and optimise processes and perform tasks that humans have historically carried out as well as, or better than, humans can.

Machine learning (ML) is a subset of AI, where systems can learn and improve from experience without human intervention – for instance by being fed traffic routing data and finding patterns within it. In ML, computers learn to recognise patterns rather than being fed specific rules about the world.

Digital twins are highly visual 3D representations of physical systems. They range from a visual flow of data in a local grid showing where power is injected and withdrawn, to simulations that can run virtual experiments testing the impacts of different conditions and forecasts outside the real world.

Fifth-generation mobile networks (5G) are expected to provide a radical step change in ICT, enabling higher bandwidths and massive data processing capabilities, leading to the major scale-up of sensing through IoT devices.

Cloud computing comprises sets of data storage and manipulation services made accessible to a large number of users by remote central servers.

Edge computing is a model for data services similar to cloud computing, but based on servers and data processing devices closer to the location where the data is needed. Edge computing provides high computing power and saves bandwidth.

Enhancing urban planning

For urban decision makers, diverse, large and frequently updated sets of energy data are increasingly available, and data volumes are increasing significantly. IoT connection points are expected to reach 83 billion worldwide by 2024, and everything that is network-connected provides data. Datasets can cover air quality, energy consumption patterns in buildings, geospatial data, asset and intervention databases, and traffic control systems. Sources for these datasets range from dedicated sensors to online operations on smartphones, Global Positioning System (GPS) tracking and network-connected equipment, appliances and devices. Despite the constant expansion of data generated in cities, it is estimated that 90% of the data generated from these sources is not currently analysed and put to use.

Advanced analytics can help combine datasets from different domains and transform them into information that can support decision-making, both for urban planning and for ensuring the efficient operation of assets and provision of services.

Urban planning based on real-time data can offer a better understanding of existing inefficiencies and problems to be prioritised. Digital tools can help identify opportunities to reduce energy demand, for example by finding the optimal locations for water features or vegetation to counteract heat islands, or trees to provide shading and reduce cooling demand in buildings. Sensors and feedback systems can also help quantify additional benefits of such measures beyond energy savings.

Advanced spatial energy planning, including GIS and digital twin modelling, enables the mapping of local potential and helps identify the benefits and impacts of measures and policies before implementation. For instance, it can help identify where energy efficiency interventions hold the most value, and where and how to set up mixed-use zones to flatten demand curves. Demand for heating and cooling can be mapped, combining weather data 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. Pilot tests in Geneva, Switzerland, and Bistrita, Romania, demonstrated the ability to achieve heat demand savings of 30-40% by retrofitting 70% of the cities' buildings. In the United Kingdom, the London Building Stock Model provides a snapshot of all London's buildings, including demand and energy performance data, helping identify poorly performing buildings.

Another example, Singapore's one-of-a-kind digital twin, Virtual Singapore, is a virtual 3D copy of the city state. It is a model that integrates GIS data with buildings information, modelling data to replicate the city's infrastructure, transport systems and buildings. In addition to providing static information like any other map, Virtual Singapore is updated with dynamic real-time data, on traffic and climate for example. The digital twin supports city stakeholders in their decision-making on diverse operations. Simulations of emergencies can be carried out to optimise evacuation routes. Given its dense population and built environment, Singapore can make use of the tool to optimise the planning of new infrastructure – the authorities in the district of Yuhua are already exploiting the opportunity to investigate building a new bridge in a busy area of the city.

Digital simulations can also show how different designs, technologies and equipment affect energy demand pathways. The LA100 study, done for Los Angeles by the National Renewable Energy Laboratory, aimed to show opportunities to achieve a 100% renewables-supplied city by 2045. Thousands of buildings were simulated, aerial scans and customer adoption models were used to assess rooftop solar potential, and utility planning tools were used to ensure power system stability. Advanced scenarios also showed where energy efficiency needed to be targeted to complement clean energy deployment. The study calculated that these measures would avoid between USD 472 million and USD 1.55 billion in distribution network investments.

Digitalisation supports integrated urban planning practices

Digitalisation can support cities in:	Examples
Enhancing urban planning	• Access to new, granular data • Real-time data for decision making • Models and simulations to identify impacts of interventions
Implementing integrated solutions	• Identifying sources of waste heat and cooling that could be utilised • More effective utilisation of existing space and assets
Deploying clean energy	• Identifying potential and best locations for rooftop solar • Improve the business case for local renewables
Fostering public participation	• Enabling public and private participation in city innovation • Create new platforms for citizen engagement and consultation • Engage citizens in clean energy transitions
Supporting inclusivity	• Improve access to services • Open up new channels of communication • Create new employment opportunities
Supporting nature-based solutions	• Map existing natural resources • Help quantify impacts of nature-based solutions implementation • Help manage and expand natural resources
Strengthening resilience	• Enhance monitoring capabilities • Enable faster response • Help identify effective preventative measures • Enhance communication with citizens during emergencies
Enabling a circular economy	• Provide opportunities to track products, components and materials to enable reduction, reuse, refurbishment and recycling • Stimulate behaviour change • Identify opportunities to reduce and reuse waste
Enabling new business models	• Reduce risks • Improve investor confidence • Create opportunities for start-ups

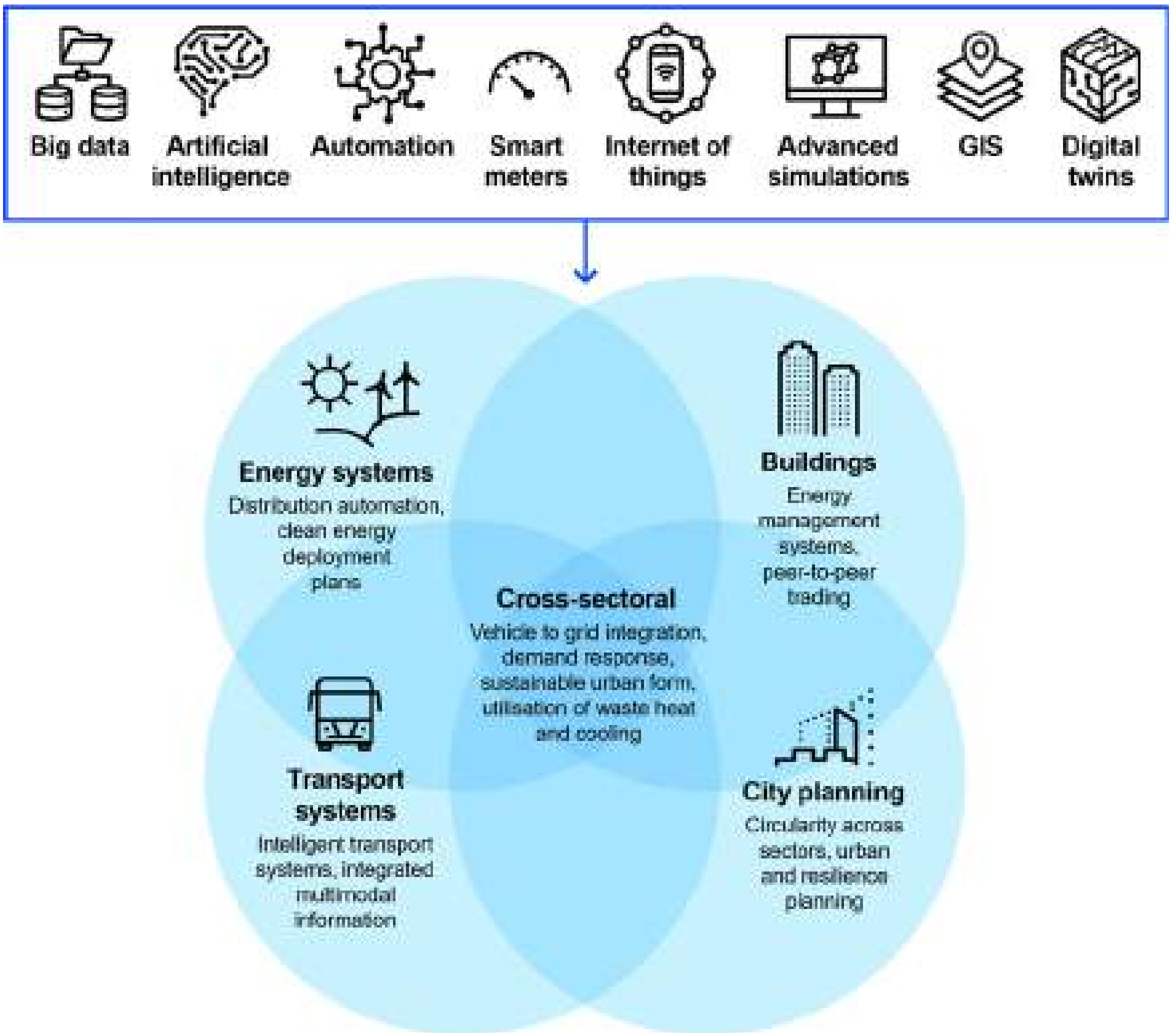
Implementing integrated solutions

Digitalisation can create interlinkages between end uses. For example, interconnecting industrial zones, data centres and district energy networks, in addition to energy-intensive municipal facilities like waste treatment, can empower stakeholders to set up demand response programmes, utilise waste heat or excess cooling, and help achieve higher degrees of efficiency through sector coupling.

Sino-Singapore Tianjin Eco-City in the People's Republic of China ("China"), located 40 km from downtown Tianjin, is a joint project between the governments of China and Singapore, and aims to achieve self-sufficiency in clean energy. It will be used as a blueprint for other smart city projects around China to achieve peak carbon and carbon neutrality. Its energy will be sourced entirely from renewables – with its own centralised energy storage plant, seven wind turbines and solar PV panels on buildings. Heating and cooling for buildings will be supplied from geothermal energy via heat pumps, and the ratio of the green areas to built-on land is over 50%. Solar PV is already supplying almost 13 GWh per year and wind turbines are providing an additional 3 GWh. The city's first zero-carbon building was put into operation in 2021; the large 3 467 m^2 building has 2 600 m^2 of solar PV panels, which generate around 240 MWh, exceeding the building's energy demand. It is equipped with energy storage devices that can feed surplus electricity into the grid. A centralised data network has been set up to monitor the ambient temperature in buildings and manage water use and energy supply. A project is underway to convert food waste into biogas with a capacity to produce more than 3 700 m^2 per day.

Digitalisation enables the identification of integrated solutions that can more effectively utilise available space and existing assets. This factor is particularly relevant for dense urban areas, as well as for resource-constrained cities needing to find ways of utilising assets for greatest cumulative impact. For example, lack of charging infrastructure can limit EV uptake, and at the same time the high cost of chargers, especially fast and smart chargers, can constrain deployment. However, trial solutions are now underway in cities worldwide to integrate EV charging points into lampposts, which can be a cost-effective solution and reduce street clutter, opening access to those without garages. Further opportunities exist to maximise the benefits of smart charging infrastructure whereby apps would direct drivers to V2G chargers at times when the power system needs flexibility.

Digital opportunities for clean energy and system-wide efficiency



Fostering public participation

When supported by good practices, emerging sources of data provide more transparent high-quality information that empowers individual users to make better choices. Citizens, policy makers, private businesses, academia and public entities can utilise the capabilities enabled by data analytics to optimise their everyday decisions and collaborate in the development of smart cities. Opening up data can encourage collective innovation for future development of the city and offer informed feedback to policy makers.

In Colombia, the city of Medellin has inaugurated the innovation centre Ruta N, a hub investigating the role of AI, IoT, machine learning and big data in improving people's quality of life in a sustainable and inclusive way. The Ruta N building brings together 140 start-ups and tech companies, creating 9 000 new jobs. For instance, Ruta N has supported the development of the start-up Uptime Analytics, which collects and analyses data generated by industrial equipment to identify energy-saving opportunities. It has also supported Sistemas Inteligentes en Red, which developed a tool to help companies in Medellin develop sustainable mobility plans to reduce GHG emissions and comply with the regulation requiring all companies with over 200 employees to enact plans to reduce transport-related emissions. A key success factor has been efficient collaboration between local government, business, universities and citizens.

Collective intelligence as a digitalisation tool for sustainable and energy just cities

Collective intelligence (CI) is the enhanced capacity created when people work together with technology to mobilise a broader range of information, ideas and deliberations. CI emerges when a critical sum of people and technology is created for purposes ranging from learning and innovation to decision-making. It covers a range of participatory methods, including crowdsourcing, open innovation, prediction markets, citizen science and deliberative democracy.

CI is not new; it has been around for centuries. However, the rise of new technologies and digitalisation has transformed its ability to connect more and more individuals over greater distances. For example, in the 19th century it took almost 70 years to crowdsource the 400 000-word Oxford English Dictionary. A modern-day digital equivalent, Wikipedia, sees more than 6 million new page additions every month.

CI as a digitalisation process offers tools to help policy makers better understand problems, seek solutions, collaborate in decision-making and conduct monitoring. CI can be broadly divided into three categories: i) connecting people with people; ii) connecting people with data; and iii) connecting data with data. As a governance tool, CI can help government better understand what is going on and what issues people care about. It provides a way to gather cheap, timely data and combines quantitative and qualitative elements. For example, traditional methods of data collection for the 2011 UK census cost taxpayers GBP 480 million.

CI can crowdsource data collection, especially as more than 4.7 billion people globally use a mobile phone. Social media is increasingly critical in energy debates; CI was gathered through a Facebook group in Finland to generate open discussions on the reform of national-level energy policy. There are indications that CI may help attract greater political attention to and financial support for environmentally friendly energy technologies. Recently, a study in Hong Kong showed how social media as a digitalisation tool can induce peer pressure for energy-saving behaviour. Researchers have also derived CI from narratives and storytelling using natural language processing in slums of India, Brazil and Nigeria to explore how injustices in the energy system lead to poverty traps.

Digitalisation makes it easier to harness the CI of citizens, employees and external experts, involving them in everything from policymaking to budgeting. It serves as a critical energy transition tool for co-designing sustainable and low-carbon cities.

Opportunities also exist to increase individual and community engagement across policymaking and planning decisions. Civic technology can foster citizen engagement by making it easier to access information and providing platforms for expression of opinion on local issues, public consultation and online voting. For instance, with the support of C40, South Africa has developed the Smart Buildings digital hub, which provides information and updates on policies and regulation, and facilitates citizen engagement.

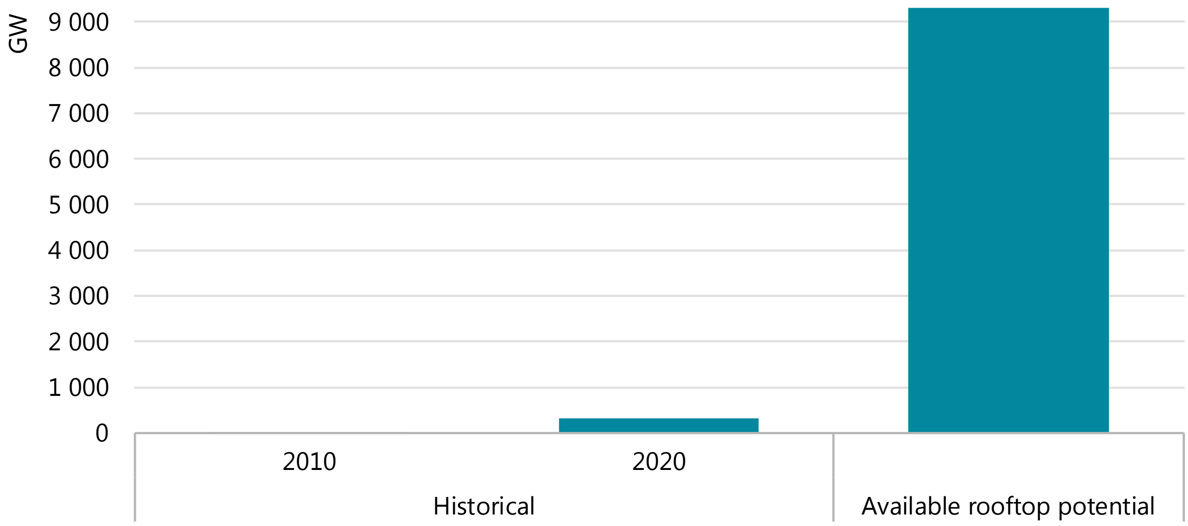
Furthermore, participatory budget platforms can include residents in decision-making processes to allocate city budgets. Decidim, from the Catalan for "Let's decide", is a collaborative project that provides the citizens of Barcelona with a digital open-source participatory platform to contribute to and express support for new proposals and policies developed by the city. The platform was created for the Municipal Action Plan campaign "73 neighbourhoods, one Barcelona. Towards a city of rights and opportunities". Catalonia's first renewable energy co-operative, Som Energia, used the Decidim platform to host its 2018 general assembly and various debates with co-operative members and interested citizens. As of mid-2020, the software underpinning Decidim Barcelona had been adopted by 31 cities, 13 regions and 23 organisations.

The city of Ghent in Belgium set up Buurzame Stroom (neighbourhood power) with the goal of maximising the potential for locally generated clean energy with a collaborative and participatory approach. The partners included Ghent University and two energy co-operatives, EnerGent and Ecopower, which played the role of aggregators. The pilot enabled households to better control their electricity consumption by using smart meters and open data applications to understand electricity prices and electricity usage, and therefore manage their energy use. The project promoted access to clean energy and inclusivity by making solar PV affordable to low-income households, optimising energy production at the local level by better matching supply and demand, and creating a sense of community through deep community participation.

Deploying clean energy

GIS can be used to map renewable energy potential at the city level and identify the best options for siting distribution network infrastructure. This is particularly relevant for rooftop PV, as only a fraction of the technically available potential is tapped.

Global installed capacity of distributed PV



In addition to helping track currently available rooftop, data analytics can also help cities understand how urban development could affect this potential. In India, for instance, providers of finance seeking long-term returns on investment in rooftop solar often cannot predict rapid skyline changes, hampering installation and the pace of reaching India's 175 GW solar target. Access to better estimates of projected generation is seen as a critical way of improving the financing of solar energy generally.

Enabling a circular economy

Digital technologies make it possible to track products, components and materials effectively. This data can be used to analyse both the opportunities and benefits of circular approaches. It can stimulate the development of innovations and tools to promote sustainable production and consumption patterns that focus on reduction, reuse, refurbishment and recycling.

Cities can contribute to upstream, midstream and downstream GHG mitigation by fostering more circular economies. One example is a project in Antwerp, Belgium, that engages residents in the creation of initiatives to stimulate behavioural change. The project uses a range of digitally enabled innovations (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. Similarly, Kolding municipality in Denmark aims to recycle at least 50% of its waste by 2022, driven by the use of mobile apps and IoT sensors.

In Cape Town, South Africa, the Western Cape Industrial Symbiosis Programme (WISP) helps businesses transform waste streams into resources. In the last 6 years, WISP has diverted 104 900 tonnes of waste from landfill, avoiding 309 200 tonnes of GHG emissions and generating over ZAR 120 million (USD 7.2 million) in financial benefits.

Supporting nature-based solutions

Digital technologies can facilitate the creation of effective urban green spaces and nature-based solutions to:

- Provide carbon sequestration.
- Reduce heat islands and the need for cooling.
- Improve air quality by regulating particulate matter, NO_x, SO_2, CO and O_3.
- Mitigate floods and runoff.
- Contribute to liveability in cities.

The promotion and creation of nature-based solutions can be greatly enhanced by identifying existing assets to be preserved and prime locations for new assets, and by quantifying the benefits. For example, while the carbon stocks of cities in Ghana's national and regional carbon budgets are assumed to be zero, a study using satellite imagery and GIS mapped and estimated a considerable carbon pool (around 3.8 million tonnes) and identified where the most effective carbon sinks are located. This provides valuable evidence not only to complement national and regional carbon budgets and plans, but also to preserve and expand the value of nature-based solutions for city planners. Moreover, the data and advanced analytics can help incorporate ecosystem benefits into policy and investment decision-making processes. Remote sensing data can also monitor changes in urban green spaces over time, quantifying biomass and carbon mapping and assessing vegetation health.

Carbon capture and storage in the built environment through engineered timbers is an emerging nature-based solution. Digital tools like construction robots, computational design and digital twin models are supporting the large-scale build of tall-timber structures that are renewable, energy efficient and act as carbon sinks.

Strengthening resilience

Extreme weather events and natural hazards are increasing in frequency and scale. Digital solutions enhance the accuracy and granularity of land use plans, incorporating natural hazards such as landslides and earthquakes, and climate-related risks including flooding and heatwaves. Similarly, they can improve maps and data on the geographic location of critical infrastructure systems or facilities, and nodes of community utility needs (e.g. energy, water and fuel use and generation).

While digitalisation can enable improvements within specific sectors, even more significant improvements can be achieved by interconnecting systems, including electricity, water, sanitation and waste management, transport, security, environmental monitoring and weather intelligence. This also enables information sharing and co-ordination to enhance resilience, for example through the management of incidents in one sector that impact other sectors.

Taking the example of flood risk, predictive maintenance and monitoring can be used in watershed management to provide insights into the probable timing and geographical extent of flooding. This can then be shared with sectors that may be affected and need to take pre-emptive measures, such as transport. Predictive intelligence can save time and resources, enable faster interventions and avoid damage to assets and infrastructure across cities. Digital tools can provide earlier warning of extreme weather events and enable more co-ordinated responses. Since it was established in 2010, the Rio Operations Centre has enabled 14 participating departments and organisations to communicate, exchange information and co-ordinate responses in the event of flooding. The initiative was developed in response to earlier deadly flooding incidents.

Digital tools can also improve the efficiency and security of systems by detecting leaks or faults. For instance, 40 cities across China are using Beidou (China's satellite) and methane/ethane lasers to detect gas leakages. The municipalities are using real-time data to examine pipeline networks within their cities and between cities, and upload this data to a local (e-governance) cloud. The system can detect leaks that are 100 km away. Its aim is to increase urban safety and promote sustainable smart cities.

Power interruptions are already a major concern in cities like Cape Town, where regular outages are driving further need for distributed solar, and better forecasting is required to ensure distributed energy generated at a local level can be more effectively matched to demand. Resilient power technologies, such as solar generation plus battery storage, can protect critical urban facilities from power outages. Embedded microgrids, which combine renewable distributed generation with energy storage, load management and smart systems, can disconnect from the main grid through "adaptive islanding" in the event of major disruption. Microgrid solutions are emerging as a critical element of urban energy system resilience.

Supporting inclusivity

Urban energy poverty affects millions of households across the world, primarily in emerging countries, although many citizens in developed countries are also affected. Approximately 1 billion people currently live in informal settlements, primarily in urban areas in low- and middle-income countries. When deployed appropriately, energy-efficient smart energy systems provide multiple benefits across society, especially for the most vulnerable residents and communities.

Mobile communications technology can play a crucial role in expanding decentralised clean energy solutions to vulnerable urban communities, as mobile banking and payments unlock new business models for residents in remote or low-income areas. Mobile-enabled digital solutions are uniquely positioned to address these challenges as they have made basic services, such as energy, water, sanitation, waste management and transport, more accessible and affordable to low-income urban dwellers.

For example, pay-as-you-go business models help low-income households to cover the cost of their clean energy investments over the long term, as per their consumption, instead of paying a high initial lump sum. These models, enabled by smart meters and two-way digital communication, have helped customers in urban, peri-urban and rural areas in disadvantaged regions to leapfrog traditional providers and install renewable energy and efficient technologies in their dwellings.

In Bandung, Indonesia, the city command centre model was modified to make it more open and participatory while adopting local digital solutions to give citizens a voice, in a similar way to Lapor!, one of Indonesia's first online feedback programmes. The tool provides an integrated and accessible portal for citizens to submit complaints and inquiries as a means of enhancing public participation and responsiveness from local authorities.

The Engie subsidiary Fenix has built on the potential of the pay-as-you-go business model and helped more than 600 000 sub-Saharan African households shift from kerosene to solar-powered energy, and thereby access secure energy supply and experience clean air indoors. Through a smart phone app, Fenix customers pre-pay whenever they want to use the energy produced by their personal solar panels until they fully cover their initial investment, after which they become the official owners of the purchased power system.

Similarly, Reeddi, a spin-off from the University of Toronto, provides stand-alone power capsules to African customers living in rural or urban communities where reliable and affordable energy access is still a challenge. The energy-as-a-service model – enabled by digital interfaces – allows customers to rent the capsules from central solar-powered charging stations. Customers use the capsules to power lighting, computers, appliances and any other electrical items used in the home. The start-up currently helps 600 households and businesses per month in Nigeria to avoid fuel-based self-generation, reduce their energy expenses by 30% and access sustained supply. The business model has also created further small and medium-sized energy-based businesses in participating communities.

In this way, innovative digital solutions and distributed renewable resources could be harnessed to improve access to energy services to the approximately 1 billion people living in informal settlements. Informal settlements are defined by poor-quality houses or shacks built outside formal laws and regulations. In emerging and developing countries 30-50% of the population of many cities live in informal settlements. City authorities and utilities have an imperative to find innovative ways to provide services to these communities. Urban dwellers who live in informal settlements and who work in the informal economy are a crucial part of urban economies. For example, iShack in South Africa provides solar home systems to residents of informal settlements while also supporting capacity building, green skills training and local job creation.

Enabling new business models

Digital platforms often make projects more attractive by distributing infrastructure costs and risks across multiple applications. Benefits include:

Reduced transaction costs. The link between the end consumer and the provider of the urban service becomes automated, precluding the need for intermediaries that settle transactions or maintain ledgers of activity in the city, and increasing convenience.

Exponential scale. Digital platforms make use of economies of scale and do not necessarily own the physical energy infrastructure behind them. A number of smart city companies have grown from start-ups to digital unicorns in a very short time span.

Expanding opportunities. When they are open and well-managed, digital platforms can reduce barriers to entry for new service providers.

Digital technologies can help de-risk and encourage private investment in smart city projects that aim for net-zero emissions. They create new business opportunities and revenue streams, enable innovative and participatory financing mechanisms, and improve the risk perception of financiers and investors.

New revenue streams can be generated through the use of digital tools that facilitate collaboration among diverse stakeholders, such as between governments, banks and other companies. For instance, New York City leveraged its visibility to attract private capital into the LinkNYC project of 10 000 smart kiosks. Each station features digital advertising panels, which allowed the city to set up the system for free. A tool is under development in the United Kingdom to pinpoint potential synergies between electric grid investments and local authorities' low-carbon plans.

Cities can encourage new business models by increasing transparency with digital tools. The NRGcoin financing mechanism supports renewable energy production via smart blockchain contracts and a virtual currency. The scheme offers advantages to energy consumers, prosumers, utilities and governments, and reduces the risk of policy change by allowing the selling and buying of electricity at a fixed price. Crowdfunding opportunities also enhance civic participation in cities. In the Netherlands, Rotterdam was able to build a green pedestrian bridge thanks to residents' contributions. The crowdfunding platform ioby raised more than USD 13 million for city projects in the United States and added local and long-lasting value to city neighbourhoods.

City governments can improve investors' risk perceptions by taking full advantage of the large amount of data available to assess the success potential of new business models in advance. The city of Copenhagen, Denmark, launched the City Data Exchange to sell, buy and share datasets among citizens, public entities and private-sector companies. Another example, FIWARE, is a platform that boosts the development of smart solutions by providing access to public and royalty-free application programming interfaces (APIs), big data and real-time media. Finally, the European Commission unveiled the De-risking Energy Efficiency Platform (DEEP), open-source software to collect transparent data on over 10 000 industrial and buildings-related projects. Its main goal is to help developers and investors to assess the financial risks and benefits of energy efficiency business opportunities.

Linking energy and urban planning more closely can build confidence in the siting and financing of clean energy deployments. In India, financiers seeking long-term returns on investment in rooftop solar often cannot predict rapid skyline changes, which is creating barriers to achieving the country's 175 GW solar target. Tools such as aerial imaging and digital twins can enable better estimates of projected generation, which is crucial to increase the financing of solar investments.

Peer-to-peer trading models can allow for increased renewable energy deployment, while also providing flexibility services to the electricity system. SunExchange in South Africa is a "peer-to-peer solar leasing platform". It crowdfunds towards the capital cost of solar rooftop investments on schools and other buildings. An investor can purchase a solar cell for as little as USD 5. Recipients of the solar power pay for the electricity generated at a rate lower than that offered on the grid and investors receive monthly lease payments in return, in local currency or bitcoin. The IEA Technology Collaboration Programme User-Centred Electricity Systems has set up the Global Observatory on Peer-to-Peer, Community Self-Consumption and Transactive Energy Models, which brings together more than 175 experts and creates opportunities for sharing experiences and learning.

Smart city initiatives in China

With over 700 smart city pilots involving five ministries and government agencies, China is a hotbed of smart city activity. Smart city pilots started as a nationally led initiative in 2012 and transitioned to local government control in 2016. This led to new cities launching their own pilots, with the central government taking on the role of developing nationwide standards on pilot design and technology.

City governments in China can have a broader range of functions and responsibilities than in other countries, so smart city projects benefit from the expanded scope and reach. Digital twins based on GIS platforms are the most common implementation. In the coastal province of Jiangsu, drone, camera, satellite and other data feed into a digital twin simulation that is helping optimise future infrastructure planning.

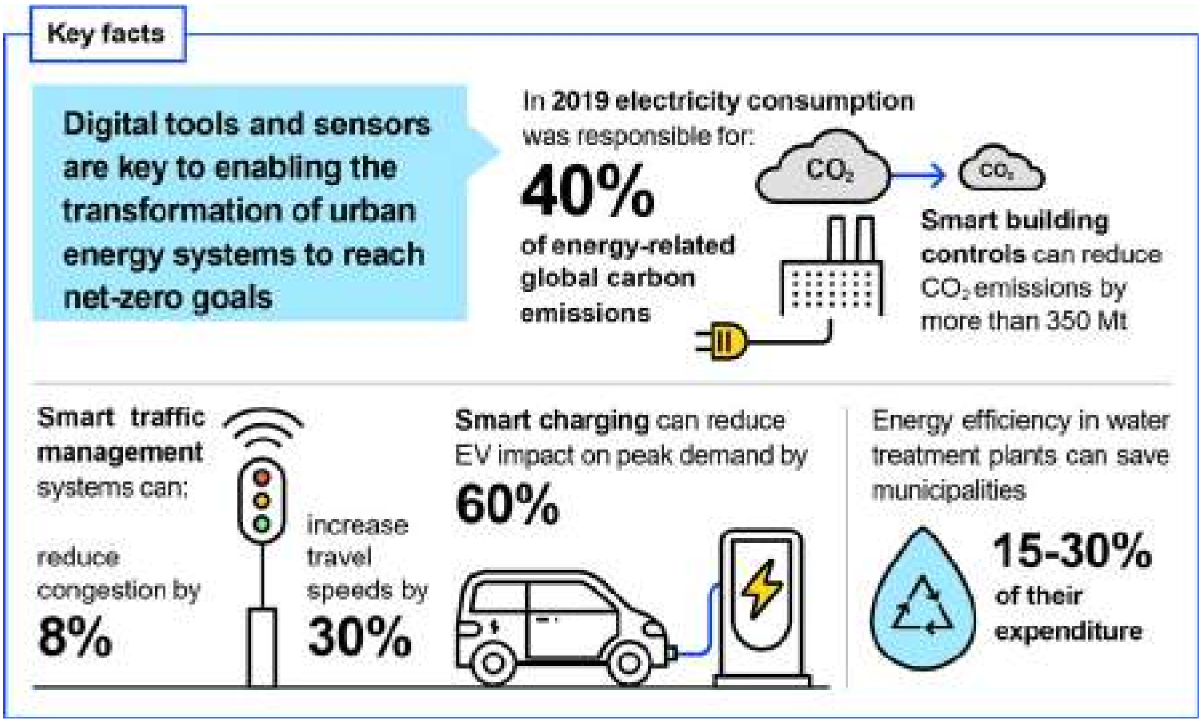
While many pilots focus on public security, sustainable development is at the forefront of smart city initiatives in cities like Xiamen, Wuhan, Hong Kong and Shanghai. Shanghai is in the process of deploying 100,000 smart chargers that collect data on driving habits and vehicle location to enable vehicle-to-grid integration and the development of new standards including for a “plug&charge” application that enables drivers to utilise multiple charging networks. Smart city initiatives in China often exploit synergies across urban services: in Hong Kong, smart water initiatives use robots to inspect piping systems and optimise energy consumption for pumping. Cities are also developing smart platforms that include distributed energy resource management systems (e.g. for rooftop solar, behind-the-meter batteries, demand response) and other forms of grid management.

Beyond city-wide developments, smart city providers in China are targeting building complexes and individual buildings, as local solutions are often faster to roll out. Data ownership and privacy, as well as clear regulation of data exchange, remain key barriers.

Under China’s 14th Five-Year Plan, provinces are announcing smart city pilots, notably to reach environmental and energy objectives.

Source: BNEF (2021), Technology Radar, Smart City Trends in China, 13 April 2021.

Sector-specific opportunities for smarter sustainable cities



In this chapter we provide an overview of a range measures that cities can consider, targeting different sectors. We have highlighted the benefits that digitalisation can bring by accelerating progress, lowering costs and creating new opportunities in the transition to net-zero emissions.

Built environment

The need for new buildings is growing at an unprecedented rate. Floor area in the buildings sector worldwide is expected to increase by 75% between 2020 and 2050, of which 80% is in emerging economies. Buildings are currently responsible for 28% of global energy-related CO_2 emissions (including emissions from upstream power generation, but not taking into account construction CO_2). In the IEA's recent report, Net Zero by 2050: A Roadmap for the Global Energy Sector, buildings sector direct emissions decline by more than 95% from almost 3 Gt in 2020 to around 120 Mt in 2050.

Digitalisation in the built environment can provide benefits for the environment, users and businesses

Digitalisation can reduce the energy demand of buildings, reduce their embedded carbon, improve their operational efficiency and enable them to contribute to power system flexibility and resilience. IEA analysis has shown that digitalisation and smart controls enable efficiency gains that can reduce emissions from the buildings sector by 350 Mt CO_2 by 2050, from a total of 3 Gt in 2020.

Improving building performance

At the construction stage, digitalisation enables the systematic collation of data on the performance of construction materials and practices. When used effectively, this can promote energy-efficient and thermally comfortable low-carbon buildings. The IEA Energy in Buildings and Communities Programme carries out research and development activities aimed at achieving near-zero carbon emissions in the built environment. Its joint research projects are directed at energy-saving technologies and activities that support the practical application of technology.

Digitalising construction processes can also reduce the embodied carbon in buildings. The GlobalABC Roadmap for Buildings and Construction 2020-2050 sees four main uses of digitalisation in building: improving data collection and life-cycle analyses; supporting more efficient design, optimisation and avoidance of over-engineering; extending the useful life of buildings and facilitating sustainable dismantling, repurposing and recycling; and reducing construction times and waste.

In operation, energy efficiency gains at the building level can be derived from so-called “intelligent efficiency”. This involves a system of smart devices having the capability to receive inputs (e.g. from sensors, from other devices or from the cloud), process those inputs and independently take action to optimise their energy consumption. The 4E Electronic Devices and Networks Annex (EDNA) of the IEA 4E Technology Collaboration Programme studies these topics and provides targeted policy guidance to members and other governments.

Smart buildings provide multiple benefits, beyond energy savings, such as improving comfort while reducing energy consumption by adapting energy use in real time. For example, they can regulate the temperature according to occupancy patterns and monitor air quality. This can increase productivity and reduce the number of employee sick days. Analysis conducted in an office building in

Washington, DC, suggests that the productivity benefits resulting from increased ventilation with an economiser system could save employers up to USD 1 500 per person every year.

Making energy consumption flexible

Efficient smart buildings bring flexibility to the power system, in addition to helping reduce overall consumption. They can shift the energy consumption of some appliances (e.g. water heaters, dishwashers) to periods when variable renewables are active, avoiding carbon emissions and ultimately curtailment. They can also co-ordinate different end uses to operate more efficiently, so as to minimise peak load, for instance by ensuring that EV charging and water heating do not happen at the same time. With the right market design and regulatory framework, this flexibility can be made available to balance the power system in the short term, and reduce the need for investment in expensive infrastructure and new capacity in the long term, thanks to reduced peak consumption.

In 2040 buildings could provide more than 4 000 TWh in demand response potential. Assessments indicate that the United States could reduce peak demand by 20% and save USD 15 billion annually by 2030, by transferring consumption out of peak hours through economically feasible buildings-related demand response solutions.

Enabling people-centred systems

Digitalising buildings can also help increase participation in demand response and behaviour change programmes, especially among residential consumers. These programmes are normally assisted by interactive communications platforms and digital apps.

During 2018, behavioural programmes in the United States provided more than 785 MW of flexible capacity, with 2.7 million people participating. Baltimore’s SmartEnergy Rewards programme is the largest of its kind in the United States, with 1.1 million homes enrolled and more than 70% participation in shifting peak load. Any customer that installs a smart meter is automatically enrolled in the programme and can opt out. Participants are notified the day before “Energy Savings Days” (typically hot summer days). If they manage to reduce their consumption on these days, they receive a bill credit of USD 1.25 for every kilowatt hour they save compared to their typical usage.

BSES Rajdhani Power Limited, a leading distribution company in New Delhi, India, will shortly be initiating a Behavioural Energy Efficiency Program and has signed a memorandum of understanding with Oracle Opower, a provider of software-as-a-service customer engagement platforms for utilities. Under the programme, selected residential self-consumers will be provided with home energy reports. Such programmes are usually expected to generate 1-3% energy savings. But in addition, the programme will put a specific focus on energy savings during the peak to identify the greatest potential, especially in overloaded areas.

In May 2021 the city of Pinerolo, in northwestern Italy, unveiled the first self-consumer residential building in Italy. The project stems from a joint venture between Acea Energie Nuove, the local electricity provider, and Tecnozenith, an energy service company, in collaboration with Politecnico di Torino's Energy Center. Apartments are equipped with interactive displays embedding building management systems to control and monitor each room's temperature and to track energy consumption. The rooftop PV system, coupled with solar thermal, meets 90% of the energy needed in the building, which features heat pumps and ventilated facades to boost its performance.

New business models

Digitalisation can enable service and financing models that are beneficial for building occupants and which would not have otherwise been possible. Heating or cooling "as a service" schemes use data about a building and its occupants to optimise comfort and cost outcomes. Energy as a service schemes help homes and businesses bypass the high capital costs of installing energy assets. In the case of cooling, technology providers own the cooling system, pay the up-front investment and running costs, and maintain the equipment. The occupant pays an agreed amount according to the quantity of cooled air it uses. This removes operational uncertainty for clients and provides long-term revenue streams for technology providers. In the city of Pune, India, the CaaS model has helped Elpro Business Park, a community of commercial and educational buildings, install India's most intelligent air-conditioning system, running fully on solar energy and using AI algorithms for performance optimisation.

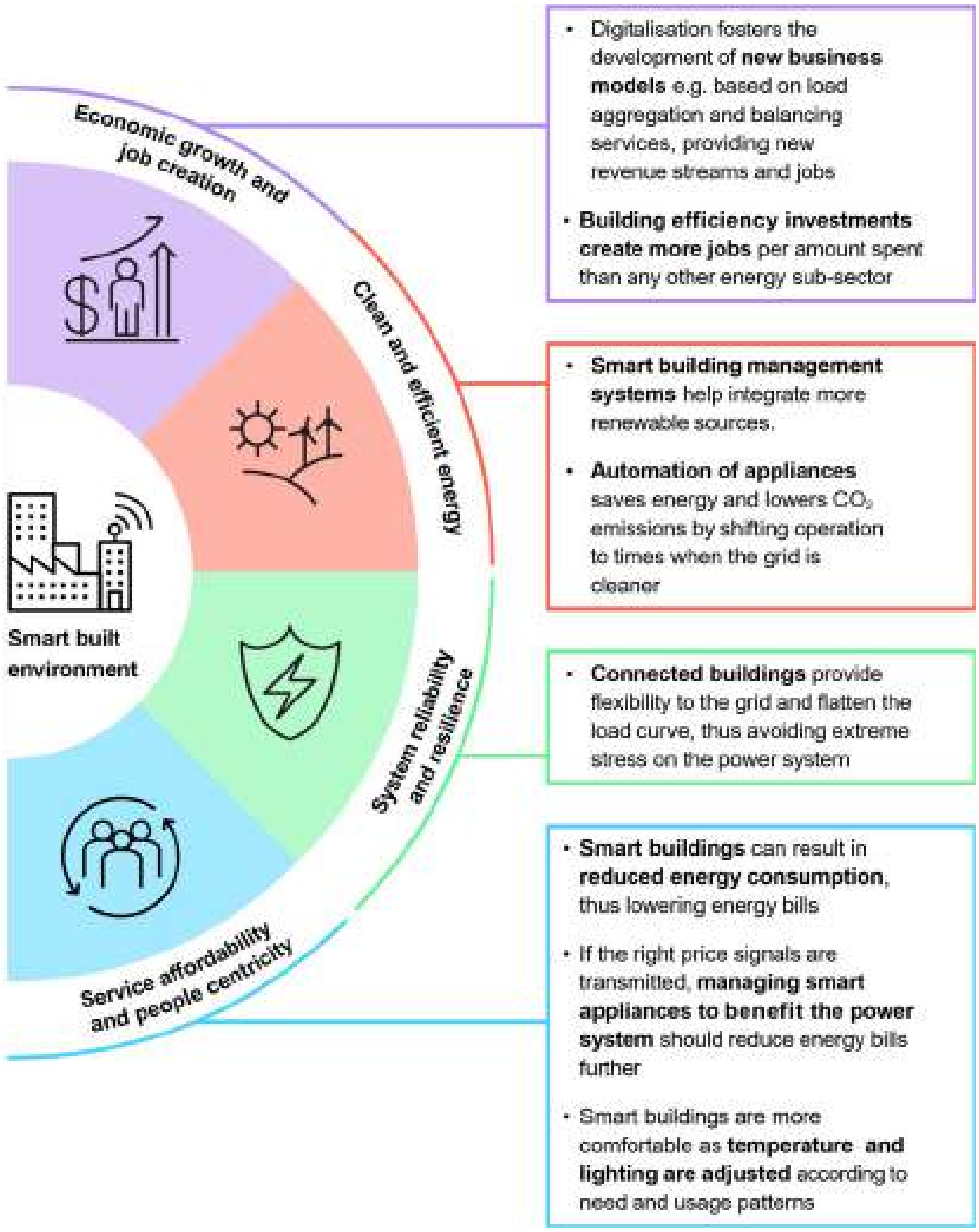
Smart cooling

Globally, space cooling was responsible for emissions of about 1 Gt CO_2 and nearly 8.5% of total final electricity consumption in 2019. Demand for cooling is growing rapidly with rising incomes and a warming climate. By 2050, 60% of the world's households are expected to have an air conditioner, up from 35% in 2020, half of which will be in China, India and Indonesia. In the Net-Zero Emissions by 2050 Scenario, electricity demand for space cooling grows annually by 1% to reach 2 500 TWh in 2050.

In some countries, space cooling accounts for a large share of peak demand, placing stress on the power system, especially during periods of extreme heat. In Saudi Arabia, cooling comprises 50% of buildings' annual electricity consumption and can account for up to 70% of peak demand. Between 2010 and 2015 electricity demand for cooling in Saudi Arabia rose by around 6% every year.

Meeting peak demand could therefore become particularly costly and be reflected in consumer electricity prices. But digitalisation can help lower this cost – smart, responsive air conditioners (possibly coupled with the storage of water chilled during the off-peak period) can help to shift consumption from peak times while maintaining occupant comfort. The ability to shift cooling demand increases with more efficient building envelopes. The efficiency of air-conditioning equipment also has a significant impact, with one analysis suggesting that a 30% improvement in equipment performance globally by 2030 would reduce peak load by the equivalent of as many as 710 mid-sized coal power plants.

Benefits of smart technologies in the built environment



Co-ordinated approaches, standards and incentives are needed to tap buildings sector potential

Although digitalising buildings can bring significant benefits, a number of issues need to be tackled to enable widespread adoption. One of the biggest barriers is the question of data management: a wide range of data and communications protocols are needed to make buildings smart, and these protocols have to be agreed and adopted by all relevant stakeholders. Standards are necessary to ensure that appliances of all kinds are able to communicate with the building management system or with the grid.

Therefore, making buildings smart requires co-ordination between diverse stakeholders across the buildings, technology and energy sectors, civil society, government and others. Municipal governments play an important role in bringing these stakeholders together to ensure that smart building initiatives benefit all residents equally and that risks to residents are minimised. The collection and utilisation of data requires robust data management systems, strong data protection and transparent information for stakeholders on how their information is stored and used.

The issue of co-ordination is also relevant at a smaller scale. In shared buildings, all owners need to be involved in investment decisions, which can slow decision-making processes. Regulations and guidance from city governments can help smooth this process.

Building codes can incorporate measures such as readiness for demand response, which is the ability to provide flexibility services to electricity systems such as by ensuring heating systems and large appliances can be programmed to a certain pattern, or connected to a grid signal. In the IEA pathways to net-zero emissions by 2050, "zero-carbon-ready building codes" include a component that allows integration with the power system and are implemented in all countries by 2030 at the latest. The European Smart Readiness Indicator is a first step in that direction: the index measures the smart readiness of a building, which means its ability to adapt to usage patterns and to external signals. The indicator is for now only informative, but is intended to encourage smarter practices in both existing and new buildings.

Lastly, measures will be needed to ensure that power systems make the best use of building flexibility. This means making sure that demand response is given market access and is adequately remunerated, a topic that is beyond the scope of this report.

District heating and cooling

District heating systems cover about 8.5% of the world's total space and water heating demand in buildings – a share that has been stagnant since 2000. The majority is concentrated in China, the Russian Federation ("Russia") and the European Union, but it is also rapidly growing in Korea. District heating provides

65% of the total heat for buildings in northern China and more than 47% of the total heat supply in Russia. In Europe, district heating supplies around 60 million people, representing 12% of the heat used for buildings in the European Union and over 60% in Denmark and Latvia.

While still a nascent market, district cooling is set to grow quickly. In the IEA Net-Zero Emissions Scenario, electricity demand for space cooling grows annually by 1% to reach 2 500 TWh in 2050.

Digitalisation in district heating and cooling networks supports decarbonisation

Digitalisation unlocks three main opportunities for district heating and cooling networks: integrating demand-side flexibility measures; supporting the incorporation of clean heat sources, including heat pumps, appliances, renewables, and storage and waste heat from industry; and enabling new business models. Digitalisation can also enhance the energy efficiency of networks by improving their performance and continuously monitoring their operation.

Digitally enabled low-temperature district heating networks are highly efficient, losing substantially less heat than conventional networks. Such systems enable optimal utilisation of heat sources including seasonal heat storage, as well as thermal energy exchange between buildings with different needs and incorporation of low-grade renewable and waste energy sources. Smart controls enable the delivery of heating or cooling services in the precise volume and temperature that is needed.

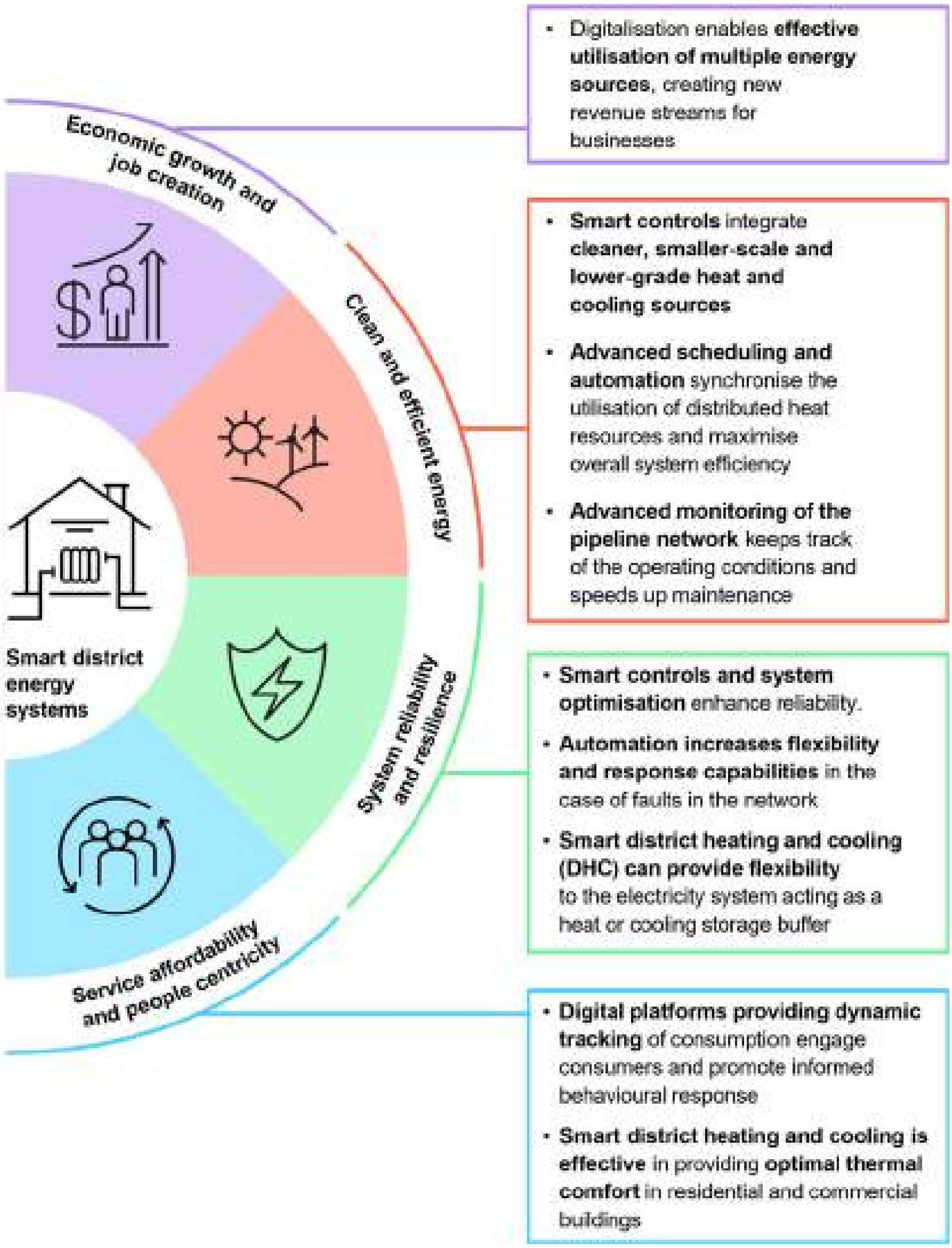
Digitalisation and the renovation of existing networks help lower the distribution temperatures of district heating systems – inefficient systems operate at water temperatures greater than 80°C, leading to losses of 10-30% or more in networks that serve sparse supply points and are controlled manually or remotely. In the town of Assens, Denmark, the district heating service provider, Kamstrup, installed smart heat meters in households and integrated its Heat Intelligence platform into the town's network, decreasing the flow temperature by 6-8°C, annual heat production by 2.5% and pipe-related losses by 12%.

Industrial heat recovery offers opportunities to improve business profitability and decarbonise energy infrastructure. For example, in Helsingborg, Sweden, 96% of the heat for the city-wide district system is provided by renewable sources, with around a quarter of its needs provided by waste heat from a local manufacturer of sulphuric acid and 8% derived from water treatment plants. Digital devices help improve district heating and cooling system performance by monitoring the networks' pipelines, collecting real-time data and detecting leakages. Smart metering and control devices in customers' premises facilitate the development of predictive heat demand profiles. Advanced controls, coupled with new forms of insulation, greatly reduce network losses. Hybrid insulation (combining polyurethane foam with vacuum or aerogel layers) of district heating pipelines can reduce losses by 15-20% compared with polyurethane insulation.

The district cooling system in the Gujarat International Finance Tec-City (GiFT City) in the Indian state of Gujarat provides reliable cooling to residential, commercial and industrial buildings. The system, regulated by advanced metering and supervisory control and data acquisition (SCADA) systems, is expected to consume 60-85% of the energy used in conventional air conditioning.

New business models enabled by digitalisation can effectively drive the capture of waste heat, contributing to improvements in energy efficiency and carbon footprint reduction in sectors such as ICT. For example, in 2014 Stockholm Exergi, Stockholm's district heating operator, launched the Open District Heating service to recover excess heat from data centres and commercial buildings. Through this platform, customers can profit by selling their excess heat that otherwise would be wasted. In 2018, 113 GWh heat was recovered – equivalent to heating 31 000 homes per year.

Benefits of smart technologies in district energy systems



District heating and cooling requires investment and may not be suitable for all areas

District heating and cooling systems require high upfront investment. It is not possible to set up systems in all areas due to space constraints and the cost and disruption associated with pipe network installation in built-up areas. Electric heat pumps are proving to be cleaner, more efficient and more convenient for smaller and more remote homes, and may be better suited to meeting cities' targets of phasing out fossil fuel-based co-generation plants.

Smart technologies can help new business models bring down the cost of district heating and cooling systems and increase engagement with local people. Operators can learn lessons from the electricity sector and introduce service-oriented business models, such as dynamic pricing enabled by smart metering infrastructure.

One major challenge faced by cities in planning or expanding their district heating and cooling networks is the complexity of pre-existing infrastructure that used to leave network operators with limited spatial planning capacities. Digital GIS models and heat maps, powered by large volumes of city data, can help stakeholders expand their networks by choosing optimal pipe routes and covering areas with high heat demand.

Energy communities

In energy communities, citizens have democratic control or ownership over their energy supply. Energy communities vary from one community to the next: some simply host wind and solar generation installations, while others are a fully balanced, self-sufficient system functioning as a microgrid; some have a local footprint, while others cover a larger area geographically. Moreover, they can focus on renewable electricity and heating only, or include a range of other energy activities, for example peer-to-peer energy trading and electromobility.

Energy communities could be paving the way to more inclusive energy systems

Digitalisation can enable connectivity among all energy market players. Through designated technologies, it can monitor, control and optimise dynamic flows of energy and data, enabling communities to be self-sufficient. Digital tools can greatly reduce transaction costs, support local energy trading platforms and create trusted asset ownership structures that bypass centralised utilities and altogether enable community-based energy approaches.

Optimised use of energy

Smart energy communities can optimise the use of renewable energy. The Kauai Island Utility Cooperative in Hawaii is a non-profit generation and distribution community comprising over 30 000 electric accounts and 236 MW of installed capacity, of which half is renewable. Members use a digital tool called SmartHub to manage their electricity flows, monitor bill payments and report outages. Another example is the community-based Virtual Power Plant project in Ghent, Belgium, which has coupled more than 100 PV systems with storage and energy management systems.

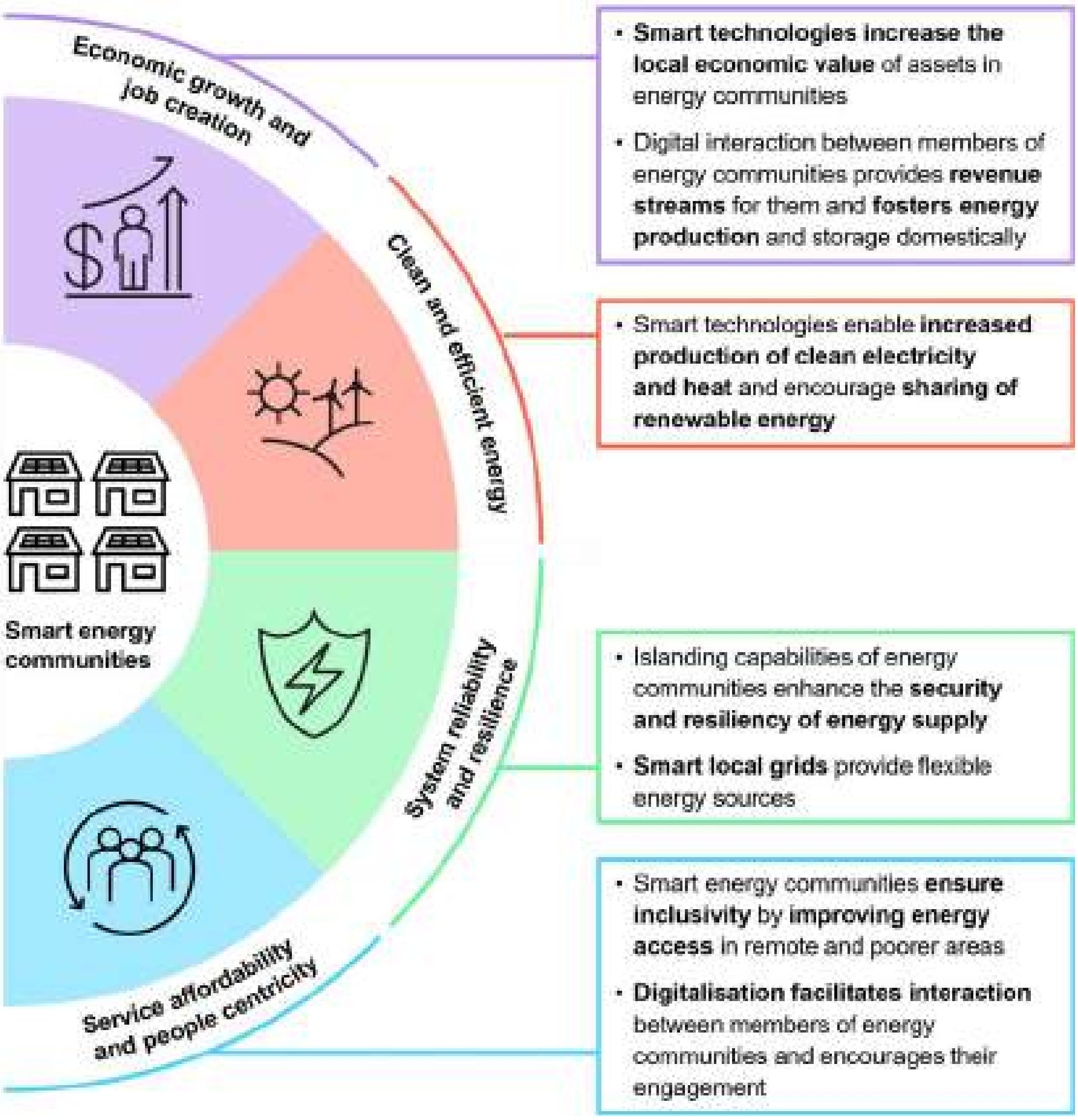
Innovative models around energy community using an "undergrid mini-grid approach" have been piloted in some Nigerian cities, involving tripartite agreements between the community, the private developer and the utility company. Digitalisation can greatly support such initiatives by creating innovative billing mechanisms and generating data that will provide important investment information to the energy market.

Increased power system resilience

Energy communities can also co-operate with system operators to increase the resilience of the energy grid by taking full advantage of the large number of active households involved, benefiting from the aggregation of demand response and offering flexibility to the system operator. In fact, one of their principal aims is to shift energy consumption to times when local resources are generating, thereby enhancing the system's resilience and deferring grid reinforcements.

Community energy microgrids, when designed with so-called "islanding" capabilities, can remain energised during outages and reconnect when safe. California has created a USD 200 million incentive to support clean energy microgrids as part of an initiative to improve community resilience against wildfires.

Benefits of smart technology deployment by energy communities



Energy community initiatives are constrained by a number of barriers

Low awareness of energy community opportunities and their design among banks and investors increases the cost of capital, decreases their bankability and hinders development. To counteract this, authorities can: channel resources and expertise towards investors and developers; deploy public funding schemes like feed-in tariffs; leverage national and international funds; and provide digital upskilling opportunities to citizens.

As the role of digitalisation in energy communities grows, data privacy and protection become an increasingly important issue. There are few standardised rules or obligations for data handlers and utilities in the context of energy communities. Efforts to address these challenges are underway. For instance, the city of Eindhoven in the Netherlands has introduced a smart society charter and guidance for open data platforms and IoT technologies. These include guaranteeing people's privacy, ensuring they understand how their data will be used and making anonymised data easily accessible to relevant stakeholders. Redundancy and competition between local energy communities and the local distribution system operator should also be avoided to prevent any potential negative effect on regional customers.

Streetlighting

The electricity consumed for streetlighting globally is equivalent to Germany's total annual electricity consumption. Most public lighting is concentrated in cities, where it can constitute up to 65% of municipal electricity budgets. Smart streetlighting can reduce electricity use by up to 80%. Around 320 million streetlighting poles are in use globally, but fewer than 3% of these are smart enabled.[2]

Smart streetlighting reduces costs dramatically and provides numerous benefits

Smart lampposts can radically improve electrical efficiency and enable a number of new services. They use efficient LEDs and poles equipped with sensors and communication technologies. They can be powered by electricity from the grid or can be equipped with PV modules to harvest and store solar energy during the day to power lighting at night.

Smart streetlights can adjust their output according to ambient light levels, dimming or brightening as needed. They can also be used to adapt the luminous flux adaptively on the basis of the vehicular traffic flow. They can be used to monitor traffic, pedestrian crossings, noise and air pollution, seismic activity, or atmospheric changes, as well as enhance public safety and increase coverage of cellular and Wi-Fi networks. Furthermore, LED lights have a longer lifespan than conventional lights, are less prone to failure and require less maintenance, which further reduces costs for the city authorities.

[2] Mordor Intelligence (2021), Connected Streetlighting Market – Growth, Trends, Covid-19 Impact, and Forecasts (2021-2026).

Digitalisation can also help improve streetlighting maintenance, for instance by spotting faults more efficiently. In Italy, an app developed by Enel X allows citizens to report faults on the city's lighting system on their smartphones. In addition to the app, local administrative bodies in around 2 000 Italian cities can also monitor the status of their lighting system and maintenance activity thanks to a dedicated web platform that specifically addresses the needs of public administrations.

Lastly, smart lampposts can also incorporate charging points for EVs. This combination of the electricity network for lighting and charging increases the utilisation rate of the infrastructure by expanding it into the day.

Job creation, budget savings and new revenues

In the United States, the city of Chicago has embarked on the largest city-led smart streetlight programme in the country. The city aims to create jobs and cut energy use by up to 75% by replacing 85% of its streetlights with smart lights. The majority of the 270 000 lights will be made in a facility in Chicago and at least half the people working on the project will be Chicagoans. Furthermore, Chicago aims to achieve 27% minority business enterprise participation and 7% women's business participation. Similarly, the authorities in Milan, Italy, have deployed 136 000 smart streetlights since 2015, saving more than 50% in energy usage and reducing CO_2 emissions by more than 23 000 tonnes per year.

Smart streetlighting can also provide new streams of revenue through dynamic digital signage systems. In addition to providing traffic management, wayfinding, public communication or emergency information services, digital signage can be rented to advertisers. For example, New York's LinkNYC system is expected to generate over USD 1 billion in advertising revenues in their first 12 years of operation.

Among the multiple benefits smart streetlighting can generate are off-grid bundles of lighting and ICT connectivity. In 2020 the not-for-profit organisations GreenCape and ThinkWiFi signed a memorandum of understanding whereby ThinkWiFi as an ICT company will deliver Wi-Fi-enabled solar streetlights to a community of 2 500 households in the Witsand informal settlement of Western Cape, South Africa. The project was developed through a co-design approach to ensure community-led energy provision. With this approach, the Witsand community prioritised area lighting and connectivity as their priority energy needs. Wi-Fi-enabled solar streetlights enhance safety and security in the surrounding area, while also facilitating the development of micro-businesses by allowing them to stay open after sunset.

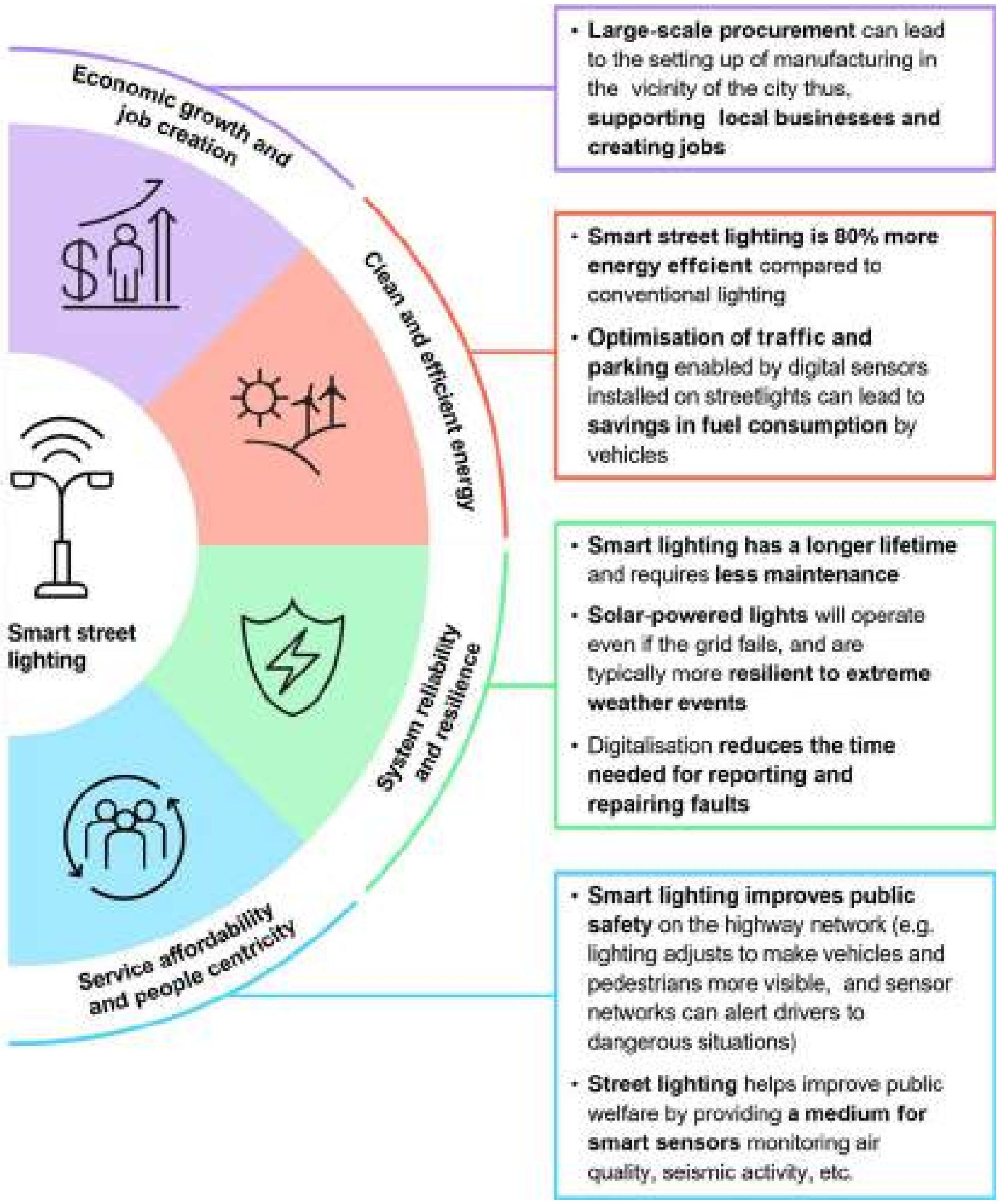
Peak power mitigation and emissions reduction

Smart streetlighting can lower peak power demand. In 2019 India's Ministry of Power announced it had installed 10 million smart LED streetlights under the Streetlighting National Programme, helping India avoid almost 1 161 MW of peak energy demand and reduce annual CO_2 emissions by 4.8 million tonnes.

Similarly, Buenos Aires, Argentina, started a replacement programme in 2013, and in 2019 became the first metropolis in Latin America to use 100% LED lights for streetlighting. A digital platform allows remote monitoring of the streetlights, optimising maintenance, and the efficient management of the intensity of the LEDs. Electricity consumption has been reduced by over 50%, saving 100 000 MW and 50 000 tonnes of CO_2 emissions annually. Over 125 000 streetlamps have been replaced and 35 000 new LED lights installed since the start of the project, which has also helped to improve public safety.[3]

[3] Magdalena Aybar, General Director of Lighting, Ministry of Public Space and Urban Hygiene of the Government of the City of Buenos Aires. Inputs provided.

Benefits of smart streetlighting



Arrangements for the ownership and operation of street lighting can be a barrier to modernisation

While the return on investment from smart streetlighting systems is good, installation has an upfront cost that needs to be covered. In some cities, streetlighting is provided by a local utility or service provider and the city authority pays a fixed rate per light, which leads to a lack of incentives for authorities to drive modernisation projects. However, some have started taking back control of streetlights from utilities and are moving towards a total cost of ownership approach when procuring smart streetlights. This includes the cost over the asset lifetime, as well as the value of other services supported. “Lighting as a service” could be a further option. In such schemes, suppliers receive a specification to meet and are incentivised to reduce costs and consumption in the long term, including though smart approaches.

In some cases, smart streetlighting can give rise to concerns among city residents, resulting in them not being supportive. They may have privacy concerns related to the combination of other applications with smart streetlighting (e.g. security cameras). To counteract this, cities are consulting and engaging with residents; for example, Eindhoven in the Netherlands involved residents in the development of its smart streetlighting project, giving them the ability to suggest functionalities and preferences.

Mobility and transport

Urban transport accounts for 4 billion tonnes of CO_2-eq annually, more than 40% of the sector’s total emissions. Congestion can result in commuters losing as many as eight days per year stuck in traffic, with the economic cost of congestion estimated to be as much as 4% of national GDP. Air pollutant emissions can be reduced by up to 75% by eliminating congestion hotspots.

Smart transport systems save fuel, time and emissions

Smart transport systems use a range of solutions, from intelligent transport systems to shared mobility applications, to make cities more energy efficient and liveable. They are crucial to decarbonising the transport sector, particularly by reducing congestion – increasing traffic and bus service speeds by 30% and improving bus punctuality. For example, smart traffic management systems in London are estimated to have reduced congestion by around 8%. Smart systems in Seoul have increased travel speeds by 30% on average. They can also reduce air pollution and traffic noise.

These systems are underpinned by digitalised data hubs and benefit all types of transport users. Car drivers can reduce time spent in traffic, public transport users benefit from real-time information, shared mobility apps and cashless payment methods, while active travel users can readily access cycle hire and optimised online maps. Making sustainable transport modes more attractive facilitates climate mitigation in the IEA Net-Zero Emissions Scenario; for example, behavioural change measures reduce emissions from cars in cities by more than 320 Mt CO_2 in the mid-2030s.

People-centred transport platforms

Smart technology has been critical to the establishment and success of people-centred transport schemes. Seoul's Night Owl Bus is one example where data informed and optimised bus routes, while real-time information helped enhance the perceived reliability of the system. The cost of a bus journey on the service is less than a quarter of the taxi equivalent, providing economic benefits to vulnerable users. Over a four-year period, USD 12 million worth of economic benefits have been redistributed.

Smart mobility applications can improve access to lower-carbon transport modes by offering services such as integrated mobile ticketing and real-time service updates across modes, including car hire, public transit and shared micromobility schemes. Open data also improves access to active transport modes, for example through urban cycle hire schemes by making locating bicycles and docking stations more convenient. With the right policies, shared mobility companies could handle 10% of public transport journeys in 2025, a tenfold increase from 2014. Shared mobility embraces ride sharing and shared parking, enterprises and individuals lending and borrowing vehicles, plus cycle and scooter hire schemes, and of course public transport.

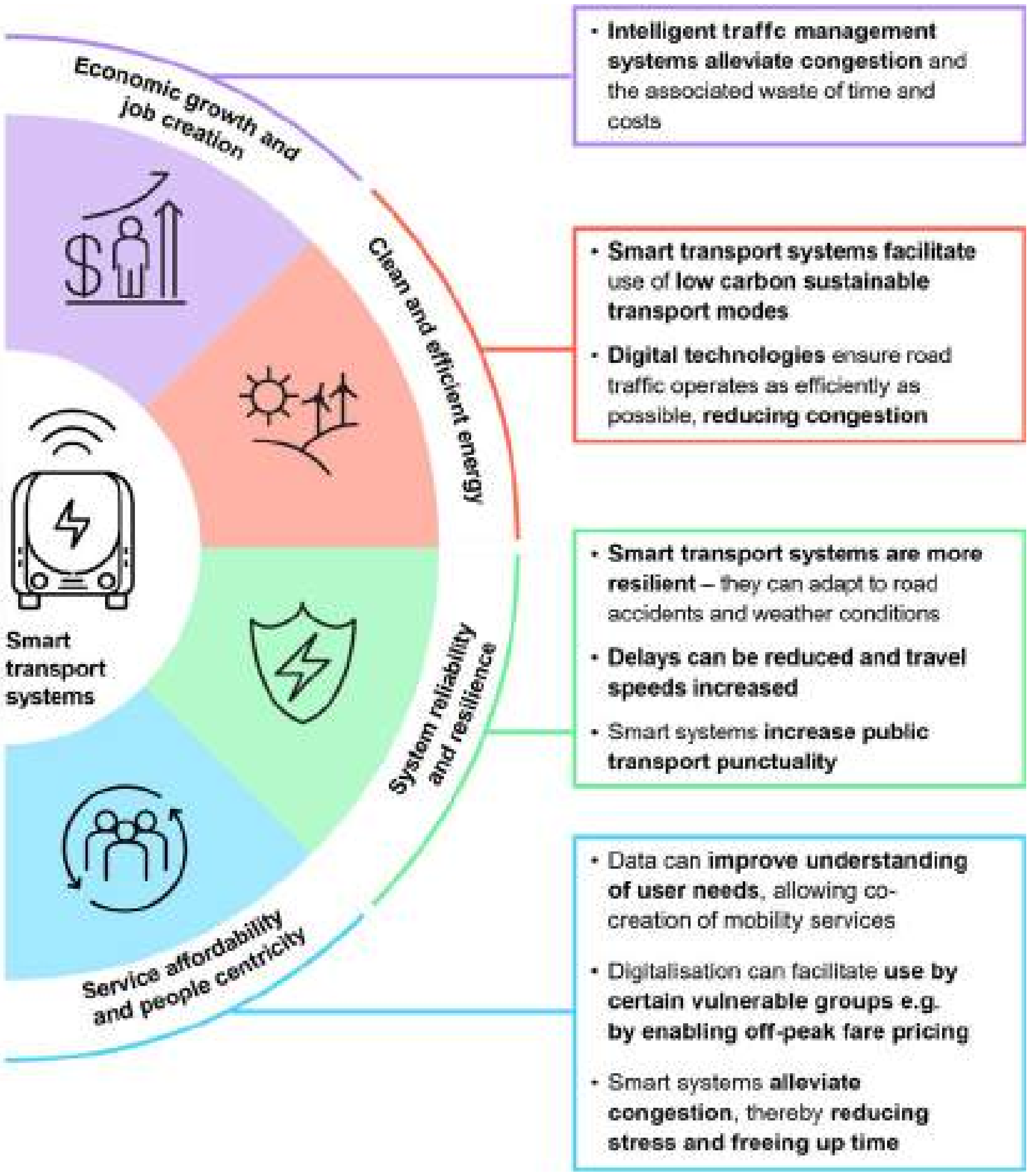
The Finnish city of Lathi has launched a mobile application that visualises the different transport modes available for a certain journey and their respective carbon emissions. The app encourages residents to reduce their carbon footprint by adopting more sustainable transport alternatives and providing virtual credits to those that remain below the personal emissions budget initially calculated. Residents can use these credits to buy a range of consumer and city services and products.

Data sources can be aggregated from private transport, public transport, transport infrastructure and the operational layer of transport systems. The Jakarta Smart City initiative has offered some important solutions to Jakarta's energy and urban challenges. To reduce congestion and GHG emissions, Jakarta has integrated public transport management and payment systems to provide reliable, safe and affordable services. Authorities are thereby transforming the city from car dependency to transit-oriented development. Under PT JakLingko Indonesia, this comprehensive integration process increased the number of Transjakarta users from around 397 000 per day in December 2017 to just over 1 million per day in

February 2020. It also allows the provincial government to collect data on 2.5 million passengers in the Greater Jakarta Area (Jabodetabek) and perform analytics on urban mobility. In Singapore, a centralised Common Fleet Management System employs predictive analytics to manage demand for bus transport, as well as driver behaviour, and has extended its application across its different fleet providers. In Berlin, large numbers of radar sensors detect empty parking spaces over an extended period, while a big data component conducts analytics and extracts intelligence to inform users which areas have available parking spaces and when.

Mobile applications allow EV users to plan routes that identify charging points along the way, thus helping reduce range anxiety – a key barrier to EV adoption. Data on real-time availability of charging points and the cost of charging at various locations will be critical to ensure the popularity of EVs.

Benefits of smart transport systems



Smart transport solutions need to be inclusive

While smart mobility applications can increase access to services, they can also widen existing inequalities by creating barriers to their use for low-income or technophobic users. Barriers can include the cost of the technologies and access to data, as well as the level of digital skills needed to use them. For example, a recent survey shows that one in three people in Italy are experiencing restrictions to their mobility by (for example) not being able to access travel information because they lack digital skills. Moreover, it indicated that fewer than one in five people over the age of 65 feel confident using digital tools.

Smart mobility applications can also bring disruption and regulatory challenges to cities, such as impacts on traditional taxi drivers resulting from the advent of ride-sharing applications. City authorities will need to recognise the positives from innovation while addressing safety and equity risks.

EV charging infrastructure

EVs are rapidly forging ahead in the global vehicle market, with electric cars accounting for 4.6% of global car sales in 2020, and even higher market penetration in other modes, such as two-wheelers and urban transit buses. In 2020 EVs saved more than 50 Mt CO_2-eq globally, emitting half the amount of an equivalent fleet of internal combustion engine vehicles. In addition to improved air quality, EVs also hold potential for noise reduction. Cities are leading on transport system electrification, with over 40% of global passenger EV sales occurring in 25 metropolitan areas. In China, Shenzhen's bus fleet was the first in the world to turn fully electric, with 16 000 EVs saving over 1 Mt CO_2 per year. Similarly, Colombia requires its cities' mass transport systems to be 100% electric or zero emissions by 2035.

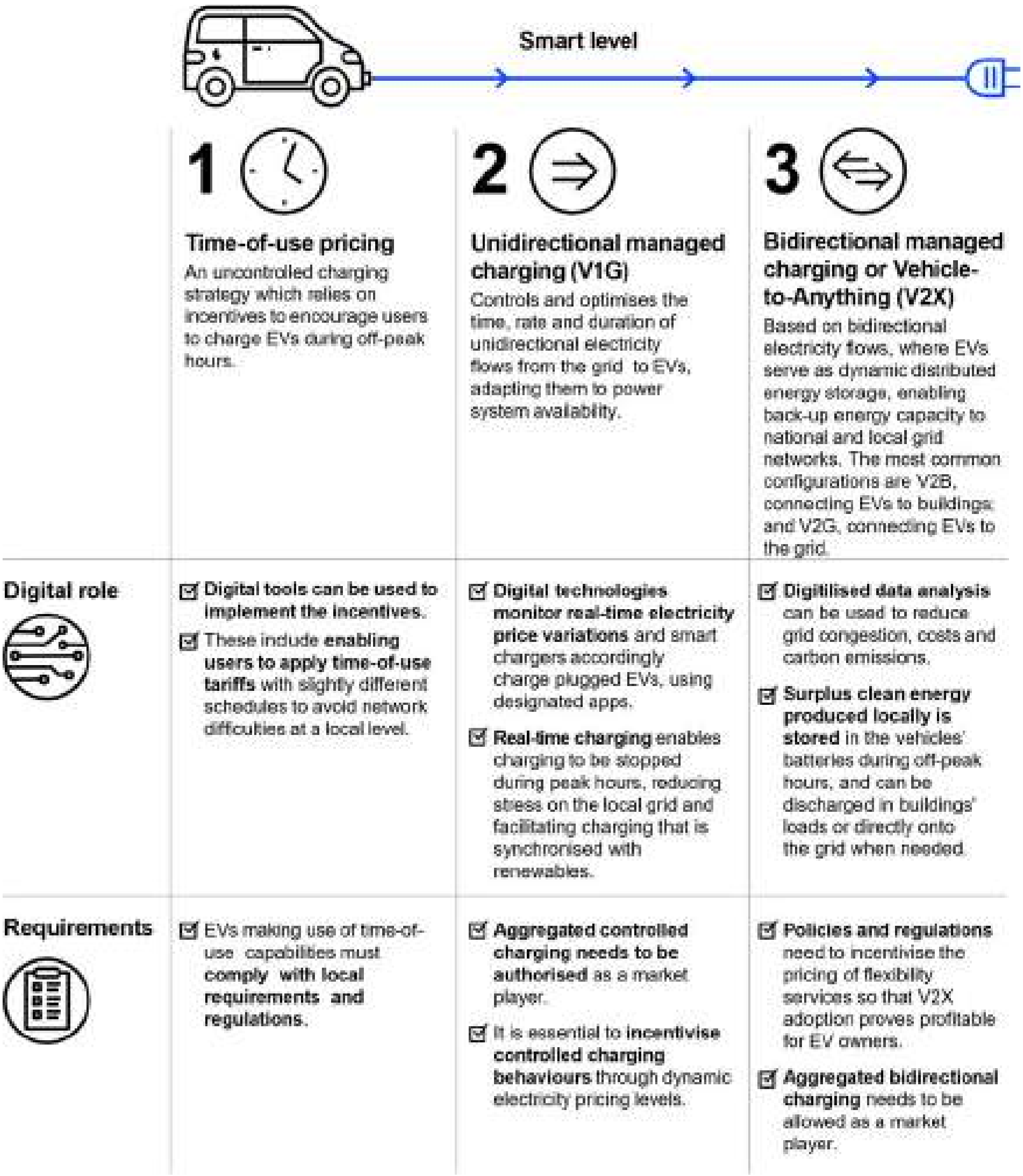
The IEA is involved in the Electric Vehicle Initiative (EVI) to accelerate EV uptake by facilitating dialogue among energy ministers across the larger world economies.

Smart charging reduces strain on electricity systems

If unmanaged, growing fleets of EVs might increase strain on the electricity grid, representing additional power demand at peak hours. The number of publicly accessible EV chargers increased to 1.3 million in 2020, and analysis shows that the share of EVs charging during peak demand hours could rise by up to 10% by 2030 compared to 2020 levels, potentially triggering line failures. Time-of-use strategies can optimise this demand, shifting around 60% of the power generation capacity needed for charging EVs away from peak loading.

Digitalisation enables further flexibility services to access the grid, allowing smart EV chargers to react to price signals and incentives, and work in symbiosis with local building and grid loads. Digital aggregation platforms can combine the reactions of thousands of EVs across cities, creating a virtual flexible load. Energy system modelling for California showed that V1G and V2G solutions can reduce peak power and add much more flexibility to the grid than uncontrolled charging. Further opportunities exist to create a smart charging network infrastructure whereby apps could direct drivers to V2G chargers at times when the power system needs flexibility. However, beyond a small number of projects, most charging infrastructure is currently not yet enabled with smart features.

EV charging strategies and related digital and policy requirements



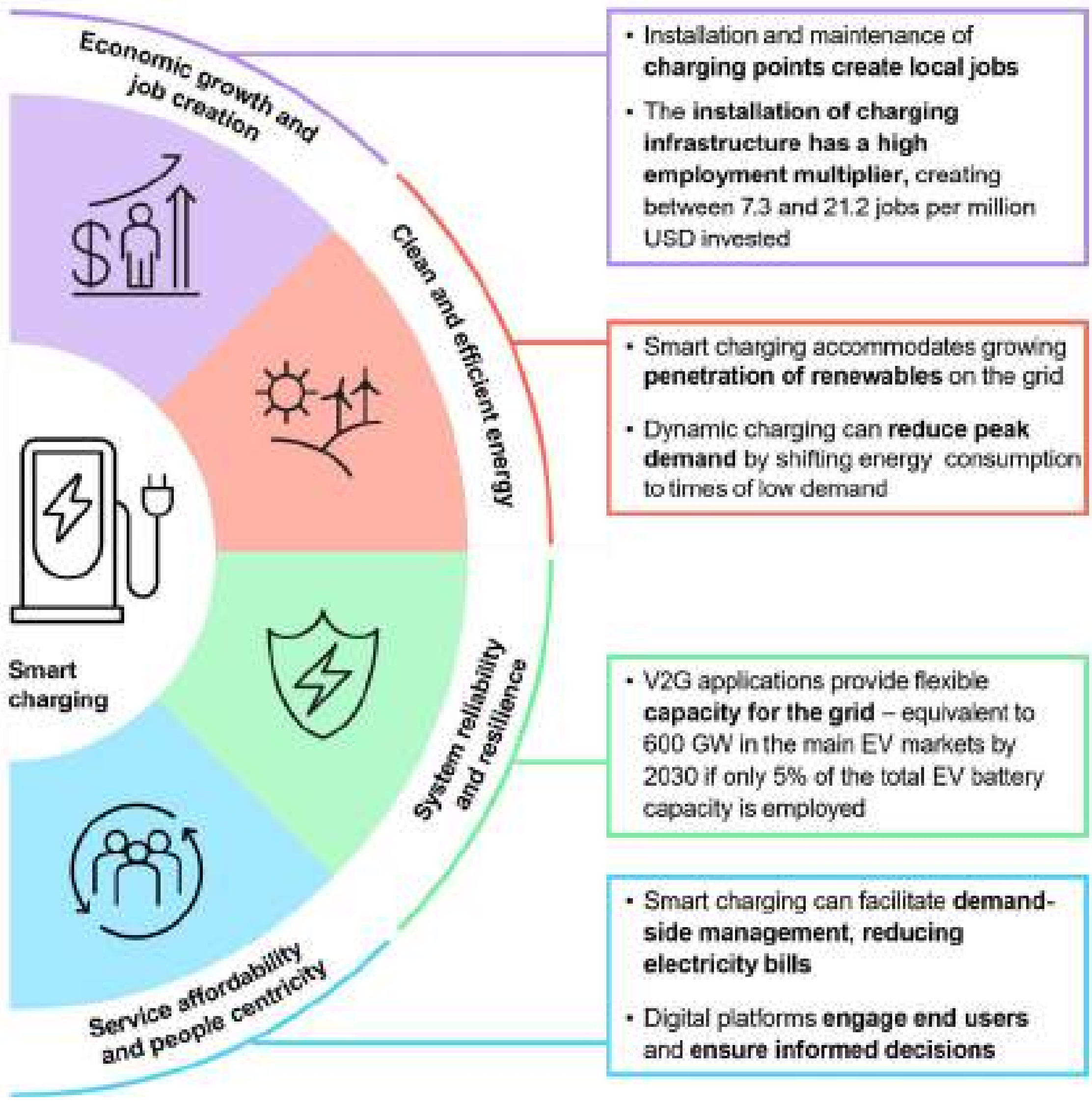
Smart level

	1 Time-of-use pricing	2 Unidirectional managed charging (V1G)	3 Bidirectional managed charging or Vehicle-to-Anything (V2X)
	An uncontrolled charging strategy which relies on incentives to encourage users to charge EVs during off-peak hours.	Controls and optimises the time, rate and duration of unidirectional electricity flows from the grid to EVs, adapting them to power system availability.	Based on bidirectional electricity flows, where EVs serve as dynamic distributed energy storage, enabling back-up energy capacity to national and local grid networks. The most common configurations are V2B, connecting EVs to buildings and V2G, connecting EVs to the grid.
Digital role	**Digital tools can be used to implement the incentives.** These include **enabling users to apply time-of-use tariffs** with slightly different schedules to avoid network difficulties at a local level.	**Digital technologies monitor real-time electricity price variations** and smart chargers accordingly charge plugged EVs, using designated apps. **Real-time charging** enables charging to be stopped during peak hours, reducing stress on the local grid and facilitating charging that is synchronised with renewables.	**Digitilised data analysis** can be used to reduce grid congestion, costs and carbon emissions. **Surplus clean energy produced locally is stored** in the vehicles' batteries during off-peak hours, and can be discharged in buildings' loads or directly onto the grid when needed.
Requirements	EVs making use of time-of-use capabilities must **comply with local requirements and regulations.**	**Aggregated controlled charging needs to be authorised** as a market player. It is essential to **incentivise controlled charging behaviours** through dynamic electricity pricing levels.	**Policies and regulations** need to incentivise the pricing of flexibility services so that V2X adoption proves profitable for EV owners. **Aggregated bidirectional charging** needs to be allowed as a market player.

Source: IEA (2019), *Global EV Outlook 2019*, https://www.iea.org/reports/global-ev-outlook-2019.

A range of solutions can bring these benefits to cities, including the aggregation of large fleets in residential, commercial and industrial centres; integrating EV charging into urban planning; and amending building codes to encourage smart charging. San Diego's Power Your Drive Program incentivised the rollout of intelligent chargers at workplaces and dwellings to foster V2G integration, with 3 040 charging points installed at 254 sites. The project avoided 3 400 tonnes of CO_2 emissions and managed over 4 GWh of energy.

Benefits of EV smart charging



Smart charging requires standards and transparency

City authorities and national governments are gradually rolling out EV infrastructure, but they are not always requiring it to be V1G/V2G compatible. The implementation of smart charging on a large scale will require standardised EV cables and infrastructure for easier integration and interoperability. For example, the United Kingdom's 2018 Automated and Electric Vehicles Act mandates smart features to be enabled in all electric chargers sold and installed in the country.

However, stakeholders might not be willing to share data. City authorities could encourage transparency and the availability of data recordings from the owners of charging facilities, EV owners and utilities. Enhanced communication among stakeholders at national and city levels would allow for replicable smart charging and energy management models.

Second-life EV batteries

Cities can reduce emissions through circularity. After serving in EVs, batteries retain 70-80% of their initial capacity and can serve in stationary storage systems. Innovative business models are exploring this opportunity, and digitalisation can improve their performance through algorithms that monitor and manage battery systems in real time. At the end of their second life cycle, batteries can be returned to designated companies for recycling. There is a certain urgency for the battery market to adopt these circular economy approaches: in the last decade, the amount of raw minerals needed for new power generation capacity has grown by 50% and the number of retired EV batteries is expected to surge after 2030.

Management of municipal services

The provision of public services and infrastructure is one of the core functions of local government. Smart solutions can enable local governments to improve the quality and economic efficiency of their municipal services, including water supply, wastewater treatment and solid waste management, thereby improving local quality of life and economic growth.

Smart management of municipal services reduces costs and resource requirements

Smart water management

According to the United Nations, around 700 million people in 43 countries suffer from water scarcity. Water-related stresses are expected to continue rising; by 2025, two-thirds of the world's population could be living under water-stressed conditions.

In many cities, drinking water and wastewater plants are municipally owned and are among the largest municipal energy consumers, often accounting for 30% to 40% of total municipal energy consumption. The energy costs of municipal water plants can range between 5% and 30% of their total operating costs, and can reach up to 40% in emerging and developing economies. The World Bank estimates that on average up to 25-30% of a utility's water is lost either through leaks or because of metering inaccuracies. These water losses imply wastage of energy used for water transport and treatment.

By incorporating energy efficiency measures into their water and wastewater plants, municipalities can save 15% to 30% of their municipal budgets. Smart energy management solutions can optimise the use of the water infrastructure and ensure safe, reliable and efficient operation in fast-growing systems.

In South African municipalities, water supply and wastewater treatment utilities have high electricity savings potential, accounting for approximately 39% of end-use savings potential among all municipal services. In a pilot project in Milan, Italy, a digital management system at a water treatment plant led to a 30% reduction in energy consumption.

Smart solutions can also detect and control water leakage, for example through the monitoring of pipe conditions in remote locations using sensors and through control of pump pressure. In Merida, Mexico, municipal water quality is monitored on a real-time basis using IoT sensing devices assisted by the 4G network. In the case of detecting a fault or imperfect performance indicators, municipal authorities receive notifications and take immediate action.

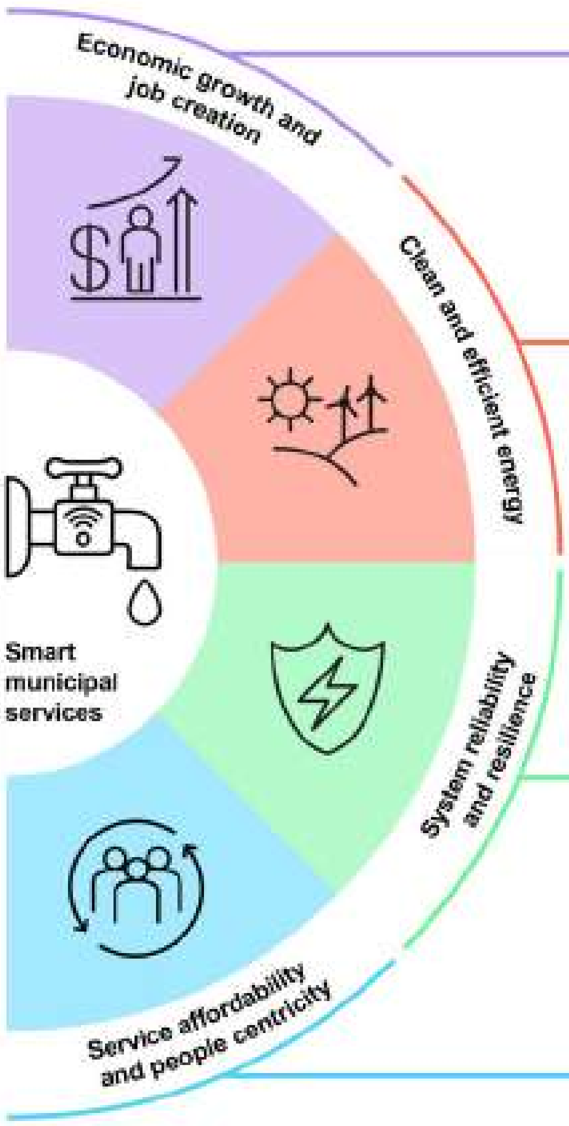
Smart solid waste management

Globally, more than 2 billion tonnes of municipal solid waste are produced annually. Without urgent action, global waste is expected to increase by 60% from current levels through to 2050.

Financing solid waste management systems is a strain for municipalities. Local governments in high-income countries typically incur more than USD 100 in operating costs per tonne of waste. Meanwhile, lower-income countries spend in excess of USD 35. Transport costs are in the range of USD 20-50 per tonne. In many cities in emerging and developing countries, solid waste management can be the single largest budget item for local government.

Digital technologies can help optimise the overall efficiency of solid waste management systems and reduce operational costs for city authorities. For instance, sensors inside waste bins can monitor volume and optimise the routes of collection vehicles, which typically consume high levels of fuels. Using smart controls, waste treatment plants equipped with incineration facilities can be integrated as distributed energy sources into the electricity grid and as heat sources into the district energy network.

Benefits of smart management of municipal services



- Smart solutions **reduce municipal bills** for water and waste management
- Digitalisation **unlocks investment opportunities** and **creates jobs** for technology and service providers

- **Smart water management systems decrease energy consumption** at water treatment plants
- **Smart waste treatment reduces fuel consumption** for waste collection and transport

- **IoT devices** detect leaks and faults in the water network, **speeding up maintenance response**
- Digital technologies help **reduce water scarcity** in critical seasons and regions
- **Smart waste management avoids waste accumulation** in streets and ensures timely collection

- Smart controls **monitor water quality and reduce wastage** of potable water
- Smart water management potentially **reduces the cost of water** and bills of end users
- Smart systems **improve sanitary conditions** through more effective waste collection
- Interactive technologies **open opportunities for residents to take a more active role** in reducing both water consumption and waste generation

Multiple barriers need to be addressed to enable smart management in local government

The deployment of smart technologies in municipal services faces governance, technical and financial barriers, among others. Smart water and waste treatment solutions can face regulatory barriers that prevent the sale of excess energy to the grid and the challenge of variable loads can make it difficult to produce a constant stream of biogas. While smart energy-efficient equipment for water supply and wastewater utilities remains a critical aspect of successful energy management, it is more effective if integrated in the design and planning of new plants than it is to retrofit in existing systems.

Waste as a resource

Biomethane produced from wastewater and solid waste can play an important role in paving the way towards net-zero emissions. Biomethane enables sector integration – it can be used as a fuel for industrial production, to provide energy services in buildings or as a transport fuel. A benefit of biomethane is that existing gas infrastructure can be utilised for transport and distribution. As a local, sustainable source of power and heat, biomethane offers communities and municipalities a flexible option that can contribute to lowering emissions. The use of digital technologies in the production, distribution and use of biomethane is still at its early stages. However, once developed and deployed, these could boost production and further reduce waste and emissions.

Challenges and risks

Barriers and challenges to using digital technologies for decarbonisation

	Challenges	Solutions
Data challenges	• Limited use of existing data • Lack of access to data • Barriers to data sharing • Insufficient data interoperability • Privacy and security concerns	☑ Data-sharing platforms ☑ Harmonisation standards ☑ Data protection frameworks, transparent communication
Insufficient co-ordination	• Lack of dialogue and mechanisms for joint planning between national, regional and local governments • Interdepartmental silos • Lack of dedicated resources	☑ Develop communities of practice ☑ Create knowledge-sharing platforms ☑ Create cross-cutting networks ☑ Create special-purpose vehicles
Lack of capacity	• Limited access to digitalisation skills and capacity • Limited bandwidth to tackle new opportunities	☑ Create initiatives to attract capacity and skills ☑ Develop opportunities for knowledge exchange ☑ Develop training and upskilling programmes
Access to finance	• Limited revenues • Inability to take on debt • Lack of capacity to develop investment-grade projects or access existing clean energy or climate finance	☑ Stimulate public–private partnerships ☑ Support the creation of new instruments e.g. green bonds ☑ Redirect funding and develop dedicated financing vehicles ☑ Introduce training to develop bankable projects ☑ Support the creation of revenue-generating business models
Digitalisation risks	• Cybersecurity • Environmental impact of digital technologies • Lack of equitable access and inclusivity	☑ Develop cyber security frameworks and guidelines ☑ Create options for circularity ☑ Build capacity and create inclusive policies and projects

Cities as diverse as Kampala in Uganda, Cape Town in South Africa, Shenzhen in China and Kitakyushu in Japan are already harnessing digital and demand-side technologies in buildings to integrate renewables, reduce the cost of energy and combat carbon emissions. But much more can be done to realise the full potential of integrated solutions, and this requires co-ordinated national policy alongside city-led action.

National governments have an important role to play in incentivising and accelerating clean energy transitions at the urban level, especially: facilitating access to and use of data; supporting target setting and the development of roadmaps; enhancing co-ordination across levels of government and between departments; supporting capacity building and reskilling; and helping cities mobilise funding.

Using data for decision-making

Demographic shifts, technological transformation, budgetary constraints and the unprecedented impacts of the Covid-19 pandemic are increasing uncertainty for city practitioners and placing pressure on them to make better, faster and more integrated and inclusive decisions.

Cities generate highly complex data in widely differing formats, latency and availability. This data provides value if it is properly processed, handled and contextualised, and available for decision-making. Up to 90% of the data generated in cities is currently unused. City authorities still lack access to relevant data sets that could enhance planning and decision-making, for instance geo-referenced data on energy use.

City authorities often lack the governance frameworks, knowledge and skills necessary to use data assets, and by extension lack innovative tools, methodologies and clear processes for collecting, storing and using data. They may also struggle to access national data due to data protection and sharing frameworks. To incorporate spatial energy planning into the urban context, it is necessary to bring together data from a range of administrative departments that have different roles in energy planning and use different instruments.

Likewise, urban planners often lack the skills and institutional mandate to use data effectively. Planning agencies and urban governments often consider big data unreliable, daunting or irrelevant. Sometimes participatory processes use digital tools to fulfil a legal requirement, improve public acceptance or showcase innovation without actually harnessing the totality of collected data for broader planning purposes.

Effective use of large quantities of data from different sources requires data interoperability; for example, data collected from EVs needs to be compatible with data collected from buildings or from the power system. This requires standards. Furthermore, frameworks need to be in place to safeguard data protection and ensure transparency around data collection and use. National governments can help address all these issues.

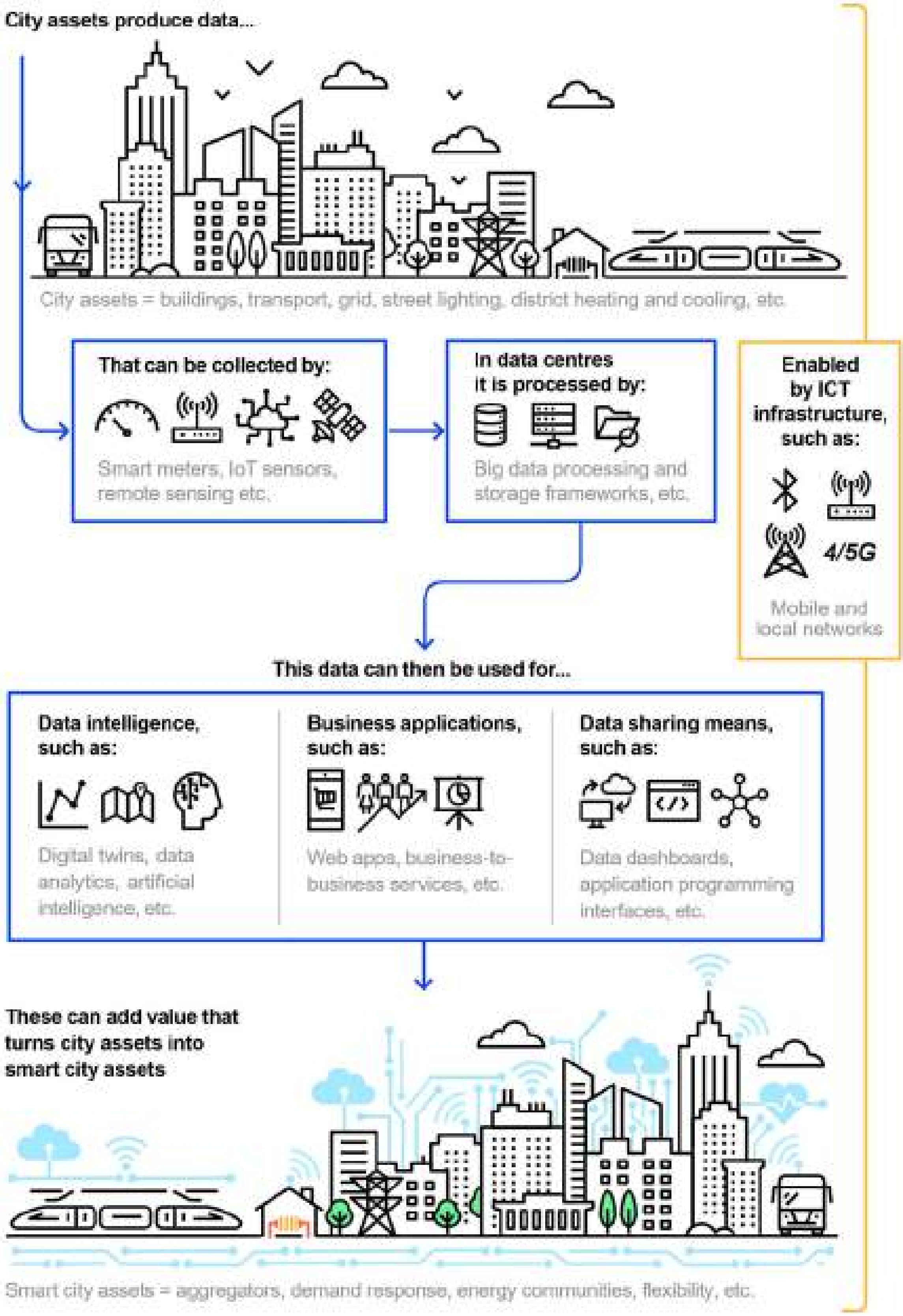
Steps are needed to ensure data access while safeguarding data privacy

National and regional regulation can support open access to data. For instance, the new climate act passed recently by the German federal state of Baden-Wuerttemberg requires municipalities above a certain size to develop heat decarbonisation plans. Because access to data is a known bottleneck for municipalities conducting this activity, the act also requires utilities and industry to share data on demand, the location and capacity of grid infrastructure, potential excess heat sources and other variables, specifying that cities have the right to use all available data, including personal data.

Regulatory intervention can also require utilities to develop digitalisation strategies to make their data more visible and accessible to potential users. In Ontario, Canada, the independent electricity system operator collects hourly data from around 5 million smart meters from 65 local distribution companies. Specific identifiers are chosen to ensure customers' data is anonymised – for example, they should report postal codes rather than street addresses. Before this data is shared with third-party stakeholders, they must be evaluated on their credibility and trustworthiness, and the data must be assessed to guarantee that no re-identification is possible by the third party.

A large share of the data collected in cities is personal. Citizens might be reluctant to share their information for privacy reasons. Since data protection rules oblige data collectors to receive consent, this can represent a barrier to comprehensive data collection. There are several ways in which residents can be encouraged to consent to sharing their data, including via transparent and customisable agreements, anonymised data collection, crowdsourcing and information campaigns on the positive public benefits that data can provide. National governments can assist cities in creating standardised procedures and frameworks.

The journey of data flow creating smart cities



In the Netherlands, privacy concerns significantly delayed the rollout of in-home smart meters, highlighting the importance of data protection for customers. The country has since implemented the EU General Data Protection Regulation, which allows citizens to view their personal data and to object to its use and processing. There are also concerns about the mining of personal data for public surveillance purposes. Worldwide, public hostility towards facial recognition technology is compelling states to act. The European Commission recently unveiled the Artificial Intelligence Regulation, assessing facial recognition technology as a high-risk system only allowed in publicly accessible areas for exceptional security reasons. National governments can support cities in developing policies, guidelines, models and tools to ensure data protection.

Lack of data management frameworks constrain city-led action

Many smart city solutions face barriers to scaling up and interoperability challenges; while trials and pilots can show success, achieving scale requires a larger number of data layers and platforms to become interoperable. In 2020, 92% of smart city investments relied on proprietary platforms, creating a risk of privatisation of public services.[4] However, there is strong evidence that open data ecosystems enable further innovation and accelerate deployment and experimentation.

Most applications of digitalisation in cities require data sharing. But departments within city government are not often set up to share data with each other or externally. In a number of countries, municipal departments report vertically to corresponding provincial or regional government departments, rather than horizontally, and those different departments can operate on different systems and databases.

As data sources and variables become more diverse, harmonisation standards become a necessity to ensure that datasets can be processed and reused by different models, interfaces and devices. Interoperability standards should specify the data variables – or metadata – required for each dataset and the acceptable formats for publishing. A central data pool that respects common standards helps public institutions, companies and academic researchers process datasets and minimise technical and administrative burdens. It is also important to set clear data governance frameworks. These ensure, on the one hand, efficient processing and management of data and, on the other hand, data protection and transparency.

[4] BNEF (2021), *Smart Grid: From Buzz to Business*. Published on 11 February 2021.

Data visibility – including discoverable and well-described metadata – is important to enable the effective use of data. For instance, the Open Energy project in the United Kingdom is creating a user-friendly search function for large, complex data sets.

Examples of good data management and sharing practices in cities are emerging. After equipping a third of Cape Town's municipal facilities with smart meters, city officials were struggling to manage the amount data and identify meaningful patterns for decision-making. In 2017 SmartFacility was deployed to solve this problem as a web-based platform that integrates data from all municipal facilities and presents them in meaningful visualisations through interactive dashboards accessible to all municipal staff through the city's intranet. SmartFacility has not only complemented the smart meter rollout, but has also stimulated the launching of new projects.

Co-operation across the wider international community can help increase access to data – the Data4Cities Initiative of the Global Covenant of Mayors for Climate and Energy compiles climate-relevant data from cities worldwide through partnerships with key data providers, including Google. The data is shared in common repositories according to consistent and transparent standards, helping cities use recognised indicators and measures to track their sustainability targets.

In China, for instance, the Mayor of Shenzhen is championing a smart city working group and has appointed a chief data officer to tackle this issue, As a part of its DataSmart Cities strategy, India considers the data collected as open by default and to be shared publicly in an anonymised way unless classified otherwise, and uses a number of innovative platforms for data analysis and cross-sectoral sharing, where data is given a value and traders can buy and sell datasets. The strategy also addresses data security and privacy concerns via a data policy based on a "privacy first" approach, which allows municipalities to regulate data ownership, collection, sharing and use in a clear way.

Data-driven targets and strategies can support progress

Long-term shared visions, targets and roadmaps are essential for accelerating clean energy transitions. National governments can provide city authorities with frameworks and guidance, and design ways to work in tandem with city officials to set ambitious data-driven targets and support them in developing action-oriented roadmaps and implementation plans.

National governments can also create an enabling environment for ambitious target-setting and to drive a more effective and co-ordinated approach to multi-level governance. Further efforts could be made to develop urban sustainability, advancing environmental quality and equity considerations at the city level. For example, national urban policies can support collaborative relationships between local and national government, enabling city authorities to pursue and track ambitious goals. National urban policies can also guide the energy transition by setting a common vision for cities. More than 50 such policies around the world are already addressing both climate resilience and the low-carbon transition. They capitalise on synergies between low-carbon mobility, mixed-use and compact development, sustainable buildings, risk assessment and risk-sensitive land-use policies.[5]

Key performance indicators can help city authorities identify and understand gaps in their deployment of clean energy solutions and track progress towards their targets. One example is the International Organization for Standardization (ISO) 37120 designation for the sustainable development of communities. ISO 37120 provides a framework for city authorities to better measure the performance of urban services and quality of life. The standard helps city officials systematise the collection of data for the management and evaluation of city policies and progress towards greater liveability. The International Telecommunication Union has developed Key Performance Indicators for Smart Sustainable Cities to allow city administrations to evaluate their achievement of sustainable development goals. They can help cities as well as their stakeholders understand to what extent they may be perceived as smart and sustainable, helping to create common understanding and transparency in urban governance.

National governments can provide similar assessment frameworks to track city progress towards sustainability goals. For instance, in India, the Ministry of Housing and Urban Affairs launched the Climate Smart Cities Assessment Framework to support and incentivise cities to apply a climate lens to their urban plans and infrastructure projects to be implemented under the national Smart Cities Mission. This city assessment framework serves as a preparedness assessment and monitoring tool, as well as a roadmap for cities to integrate climate action targets and improve performance standards. It consists of 28 diverse indicators across five categories. The framework is progressive and allows cities to improve their score in the future and build climate resilience. While local governments are responsible for the formulation and implementation of actions, the national government provides the overarching policy guidelines, standards and funding to enable co-ordinated action. The second phase of the

[5] OECD et al. (forthcoming), Global State of National Urban Policy 2021: Achieving the Sustainable Development Goals and Delivering Climate Action.

framework is supported by an extensive capacity-building programme and network support, where cities can learn from each other's experiences and be inspired to work towards combating climate change impacts collectively.

The role of standards

Standards bodies work closely with government and industry to use standards as an enabler and accelerator of policy outcomes in the energy transition. Standardisation programmes look at the energy system as a whole and provide alignment between policy formulation, technology development and standards. Standards are needed to ensure interoperability, data privacy, grid stability and cybersecurity.

Key international standards-developing organisations working within the realm of smart and sustainable cities include the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC) and the International Telecommunication Union (ITU).

The ITU, IEC and ISO also co-ordinate smart city-related activities under the umbrella of the Joint IEC-ITU-ISO Smart City Taskforce (J-SCTF) to facilitate interoperability and minimise the duplication of work within this field.

In the United Kingdom, the national standards body, BSI, is working with the UK government, industry, academia and public interest groups as part of the Energy Smart Appliance programme to develop standards for energy smart appliances, which includes EV charging points.

The purpose of the programme is to facilitate the uptake of safe, secure and interoperable smart appliances to support the effective management of demand on the electricity network and transition towards a smarter, flexible, zero-carbon grid. The programme has been instrumental in fast-tracking standards in an emerging area.

The Bureau of Indian Standards (BIS), in association with the Smart Cities Mission, Ministry of Housing and Urban Affairs, has developed IS 18000 Unified Digital Infrastructure – ICT Reference Architecture (UDI-ICTRA), a set of ICT smart city standards, which provides a reference architecture for achieving a harmonised, secure and sustainable digital infrastructure in cities. UDI-ICTRA can serve as a template for both the city administrators, who are the consumers of ICT-based solutions, as well as the ICT solution providers.

Sources: ITU (2021), inputs provided; BSI (2021), Sebastian Van Dort, inputs provided.

Improving co-ordination

One of the greatest challenges cities face in undertaking any transformative project is the distribution of authority and responsibilities between national, regional and local authorities. While city authorities are responsible for the majority of day-to-day service provision and the implementation of clean energy transition projects, they are often underfunded and may have limited control over their revenues. National and regional governments often control the majority of municipal funding, while cities have limited influence on national-level decision-making and central government funding to municipalities has been decreasing in the last few years, even before the Covid-19 pandemic. This imbalance can prevent cities from pursuing ambitious digitalisation projects.

National government can work in tandem with local government, for instance through special-purpose vehicles or direct funding for planning activity, target setting or capacity building, including assistance in developing data-driven energy accounting tools.

National government can also leverage international programmes aimed at supporting different levels of government on smart and sustainable city transitions. For example, the OECD's programme A Territorial Approach to Climate Action and Resilience supports countries, regions and cities by strengthening the evidence base at subnational level and by improving policy co-ordination across levels of government in their climate policy and governance frameworks.

In Indonesia, the direction of climate policies is based on President Joko Widodo's vision following the 2015 Paris Agreement. In parallel, Bali's regional government plan, Nangun Sat Kerthi Loka Bali, aims to improve residents' quality of life and access to services while promoting low-carbon green development on the island. To ensure policy alignment, the Bali regional government recently signed a memorandum of understanding with the head of the National Development Planning Agency (Bappenas) to implement low-carbon developments. The memorandum covers five principal areas, namely the transition towards renewable energy and energy efficiency, forest protection, waste management, improvement of agricultural productivity and strengthening of institutions.

Effort is also needed to guide fragmented stakeholders in identifying and developing synergies between technical areas, sectors and neighbourhoods. Cross-cutting networks have proven successful. For example, the ICLEI-GIZ Urban Nexus initiative provides a framework to break down silos across urban functions and increase institutional performance and urban service quality.

In South Africa, a programme of support for municipalities on integrating small-scale embedded generation into distribution systems has built on networks across levels of government and between different departments to strengthen distribution utilities. This activity had unlocked approximately 282 MW of rooftop solar generation by 2020.

Building capacity

Local governments will need to increase their capacity across the board to deploy both low-carbon infrastructure and the supporting digital infrastructure. Of a sample of 27 countries surveyed by the International Labour Organization in 2018, about two-thirds had well-established platforms to anticipate skills needs in general, but many were disconnected from the specific skills implications of clean energy transitions and, in particular, digital skills.

Capacity building is often overlooked, yet technical capacity is often a major barrier to implementing low-carbon and digital solutions. Many city and regional governments execute their core functions without much scope to identify, develop and operate low-carbon and digital initiatives, or the ability to raise revenues for them. Capacity building can enable city administrators to use digital tools and the resultant data, and to promote working across typical institutional boundaries.

National governments can help to develop a more interconnected "community of practice" around smart and sustainable city development. They can launch mission-oriented initiatives to attract talent to urban positions. National innovation programmes can also launch flagship demonstrations in cities and create innovation zones that attract the necessary capacities and skills. Action can be taken to ensure that education systems prepare new professionals for the workplace and that reskilling and upskilling opportunities are created.

International knowledge-sharing platforms can complement national efforts and expand the best-practice knowledge base for applying urban initiatives in a wide range of cities. As part of its Net Zero Carbon Cities Programme, the World Economic Forum (WEF) is set to launch a digital platform in August 2021 aimed at businesses and city and national governments. Its aim is to share solutions for progressing urban decarbonisation. A related initiative is the G20 Global Smart City Alliance, also hosted by WEF, which brings together municipal, regional and national governments, private-sector partners and city residents around a shared set of principles for the responsible and ethical use of smart city technologies. WEF is also developing common metrics to assess the efficiency, electrification and digital maturity of cities, which can then be used to develop roadmaps and attract finance.

Italy: Concerted action to promote co-ordination and build skills

In 2016 Italy created the Digital Transformation Team (DTT), which is tasked with co-ordinating government and public administration in the integrated management of all digital programmes, promoting technology access, building skills and fostering the accessibility of data. To further develop the digital agenda, DTT has transitioned into the Department for Digital Transformation under the Presidency of the Council of Ministers. In 2020 the Ministry for Technological Innovation and Digitalisation launched the Italian National Coalition for Digital Skills and Jobs. The coalition builds on Repubblica Digitale, a multi-stakeholder initiative that promotes digital skills at all levels of the Italian economy and society. To date, the coalition has launched more than 100 initiatives, most of which are aimed at improving the skills of residents and counteracting the digital divide. Italy is also leveraging the National Recovery and Resilience Plan, with 27% of the total funding targeted at digital transition measures. The digital strategy, "Digital Italy 2026", aims to improve skills and enable access to digital solutions.

In parallel, Italy has launched the Smarter Italy Programme, funded by the national government, which aims to launch innovation tenders for projects on mobility, the environment, well-being and cultural heritage that will benefit residents while accelerating economic growth. Currently, the focus is on mobility and transport; the budget for this phase is EUR 20 million and 11 smart cities and 12 small towns below 60 000 inhabitants (known as "villages of the future") are participating.

To further support cities, the Italian National Research Council is creating digital twins, allowing local governments to make informed day-to-day and planning decisions on energy in cities, urban regeneration and resilience, as well as facilitating awareness raising and active participation among residents.

Mobilising funding

Smart city projects require substantial upfront investment, typically beyond city budgets. Private capital is crucial, but challenges inherent to smart city projects can impede private investment, including the risk associated with new technologies, difficulty in monetising socioeconomic benefits, and lack of a clear path to steady revenues.

Often, city governments have limited capabilities to prepare bankable projects and manage debt, and have limited connections with the financial sector and knowledge about generating financing opportunities.

City authorities' finances can be strongly dependent on economic cycles, and they typically have limited economic and financial hedging capability. The ongoing Covid-19 pandemic has placed further strain on city budgets. City governments also can be subject to fiscal restrictions, such as low credit ratings and legally stipulated debt ceilings. They can have limited revenue-raising capability and often have difficulty in generating sufficient income from projects.

What city governments can do

It is crucial for city administrations to define the business model for projects, identify revenue sources and match them to the most appropriate financing options, including vendor or supplier finance, project financing and infrastructure funds. For example, if a low-carbon project can generate and share steady energy savings with financiers, the project can typically obtain funding in exchange for the shared revenues.

Many city governments develop public-private partnerships (PPP) to provide services using the resources and expertise of the private sector. Under a PPP, city governments can focus more on their areas of expertise – policy, planning and regulation – delegating day-to-day operations to the private sector. The European Commission's analysis shows that 41% of its smart city projects were financed both from public and private funds.

Green bonds are becoming an attractive instrument for financing low-carbon projects. The appetite for green bonds is growing as numbers of public and private funds, including pension funds, are encouraged to invest in climate-friendly projects. In 2013 the city of Gothenburg, Sweden, was the first city in the world to issue green bonds. It raised a total of USD 500 million (SEK 4.36 billion) in four years and funded projects including district heating systems, EVs and a biogas project. Mexico City has issued three bonds, one in each of 2016, 2017 and 2018, each for USD 100 million (MXN 2 billion), which were used for sustainable and climate actions in clean transport, green buildings, energy efficiency and renewable energy.

How national governments can help

National governments can help city governments address their financing challenges by sharing their knowledge and skills relating to financial mechanisms, basic principles and tools for financial modelling and best practices in resource management. They can also provide financial aid directly to support capacity development. For example, the C40 Cities Finance Facility (CFF), funded by the German, UK and US governments, facilitates access to finance for climate change mitigation and resilience projects in urban areas. It provides technical assistance to transform cities' sustainability priorities into bankable investment proposals. The CFF aims to deliver project preparation and capacity development, to share knowledge widely and to establish partnerships between city authorities and financiers.

By providing additional seed or complementary funding and creating links between different types of funding – such as those for innovation and those for project implementation – national governments can offer crucial support. In particular, the heft and credibility of national public funds can be used effectively to mobilise private financing. For example, as part of the Smart Finance for Smart Buildings initiative, the European Commission is developing a flexible guarantee facility to encourage private financial institutions to provide attractive financial products for the energy renovation of buildings.

National governments can also direct Covid-19 recovery and stimulus packages towards creating more opportunities to ramp up investment in cities, such as retrofitting buildings, supporting behavioural changes and planning for a decade of investment in net-zero emissions infrastructure and services. Yet progress has been limited: as of February 2021, only 14% of the total stimulus spending in major economies had gone to support sectors under the purview of city governments (energy, transport and waste) and only 27% of that stimulus spending was specifically allocated to green infrastructure.

The role of international and multilateral financial institutions

International and multilateral financial institutions can also support urban-led action and help build capacity. For example, the European Bank for Reconstruction and Development (EBRD) launched its Green Cities Framework in 2016 to systematically promote sustainable urban development. Now established as a flagship programme, the EBRD Green Cities programme covers 49 cities in 22 countries, with more than EUR 3 billion committed by the EBRD, donors and investors for financial and technical support. In addition to providing investment for sustainable infrastructure, the EBRD also supports cities with action plans that link policy interventions with investment and capacity building to support the development and implementation of projects and policies.

Since 2019, the EBRD has integrated an assessment of cities' digital capacities and needs as part of their Green City Action Plans (GCAPs). To develop their GCAP, cities conduct a Smart Maturity Assessment, to evaluate where they stand on their digitalisation journey and what are the next steps to foster an open-source data environment that enables both the private and public sectors to implement digital solutions for smarter, greener and more inclusive urban services. Cities then reflect the findings of this assessment into their GCAP investment and policy actions to ensure smart solutions enhance actions' positive outcomes.

Addressing risks

A number of risks and challenges are associated with the use of digital technologies in the urban environment. These include cyberattacks, data privacy violations, public resistance, reinforcing socioeconomic inequalities, the growing energy use of digital technologies and further environmental and resource implications over the life cycle of technologies. National governments can support cities by providing policies, guidelines and frameworks that ensure that these risks are adequately addressed.

Cybersecurity

Digitalising energy assets in cities increases their vulnerability to cybersecurity threats. The fragmented nature of smart city solutions contributes to vulnerabilities from the use of different protocols, standards and safeguards. Legacy and new urban infrastructure need to be interoperable. To help address these challenges, numerous civil society and international organisations, such as the IoT Security Foundation and the International Electrotechnical Commission, are developing smart city standards, sharing best practices and developing certification schemes. National governments can support international initiatives and help cities with capacity building and tools.

New York's "Stop Hacks and Improve Electronic Data Security" Act requires organisations that deal with private city data to meet set security standards. These include designating administrative staff to set a security program, assess risks continuously and organise capacity-building workshops. Businesses are responsible for building their own technical and physical safeguards to detect and halt any threats, prevent unauthorised access to data and dispose of used information. A compliance mechanism has been set up and, in the case of violations of standards, legal penalties apply.

Reducing the environmental impact of digital technologies

The concept of the circular economy has significant potential to accelerate progress towards net-zero emissions from ICT and digital technologies. The ITU defines the circular economy as "an economy closing the loop between different life cycles through design and corporate actions/practices that enable recycling and reuse in order to use raw materials, goods and waste in a more efficient way".

Circularity encourages designing products and systems for improved energy efficiency and greater reparability, upgradability, durability and reusability. These qualities enable reductions in material and energy consumption for ICT and digital technologies and in the waste they generate. Digital product passports are being developed to support the implementation of the circular economy. A digital product passport contains digital markings that enable the tracking and tracing of information that is crucial for facilitating circularity, including information on a product's origin and composition, and options for repairing, reusing, refurbishing and dismantling it, as well as handling options once it reaches the end of its life. National governments can promote such initiatives, as well as develop policies to encourage the reparability and upgradability of digital technologies.

The ICT sector and data centres: Climate and energy considerations

Concerns have been raised about the growing energy demand of digital technologies. The IEA Technology Collaboration Programme on Energy Efficient End-use Equipment (4E) has created the Electronic Devices & Networks Annex (EDNA). EDNA has collected data and developed the Total Energy Model 2.0, which provides insights on the current and projected energy use of connected devices.

Data centres – the focal point of information flows in future cities – accounted for around 0.8% of the world's final electricity demand in 2019. The need for data centres is expected to grow as data volumes expand and stronger processing capacity becomes necessary. Nevertheless, this growing energy demand is being offset by energy efficiency practices and technological advances; these advances will prevent increased energy demand in 2022, despite an expected service demand increase of 60%. In 2019 data transmission networks represented around 1% of total electricity consumption. 4G and 5G networks are the leading mobile data medium and are projected to carry 83% of mobile traffic by 2022. 4G networks are between 5 and 50 times more energy efficient than 3G and 2G, respectively. The energy efficiency of 5G is still under evaluation. A 5G antenna consumes three times as much electricity as a 4G antenna; however, it is expected that by 2025-2030 further technological advances can make 5G 10 to 20 times more efficient than 4G.

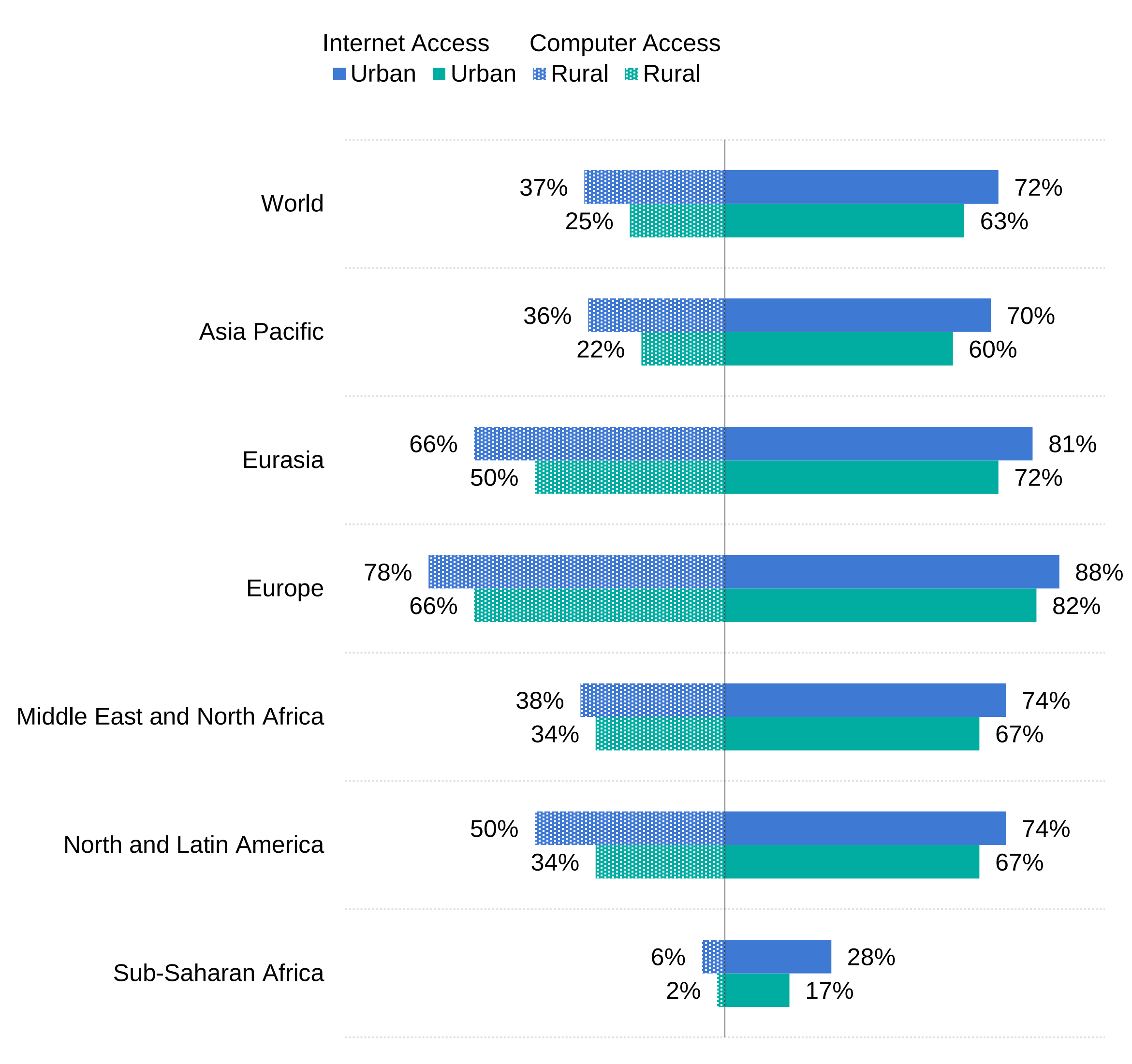
More broadly, the ICT sector, which includes both communication networks and information technology, accounts for about 4% of global electricity consumption and 1.4% of global carbon emissions. Although the carbon footprint of the ICT sector as a whole has remained relatively unchanged, in line with the trends of data centres, there is potential for further improvement and to align emissions reduction trajectories with the Paris Agreement. For example, the ITU has developed a sector-specified standard, Recommendation ITU-T Y.1470 on "Greenhouse gas emissions trajectories for the information and communication technology sector compatible with the UNFCCC Paris Agreement", which enables members of the ICT sector, including operators of mobile networks, fixed networks and datacentres, to set science-based targets to reduce GHG emissions at a rate that is in line with the climate targets in the Paris Agreement.

Equitable access and inclusivity

The IEA Net-Zero Emissions Scenario highlights the importance of citizen participation in achieving net-zero emissions goals. According to the scenario, direct behavioural changes could account for 4% of cumulative emission reductions, with 55% of emission reductions resulting from the adoption of technologies linked to consumer choices. To date, much of the progress towards decarbonisation has not required active involvement from individual consumers. To accelerate energy transitions, policy makers will need broad social acceptance from citizens, and users and providers of smart city solutions will have to navigate broad data protection issues as these are deployed.

While digital technologies present an opportunity to increase citizen engagement, two barriers stand out: digital access and social acceptability. Many cities still only have partial ICT coverage, which limits the effective use of digital tools. Many marginalised groups do not have the educational or technological capabilities to use digital tools, while higher-income households may have better connectivity, exacerbating socio-economic disparities. The Covid-19 crisis has revealed the vital reliance of many economic, educational, health and social activities on digital and connected services. The massive shift to distance learning has prompted many local governments to take stronger action on digital access.

Percentage of households with internet/computer access in rural/urban areas, 2019

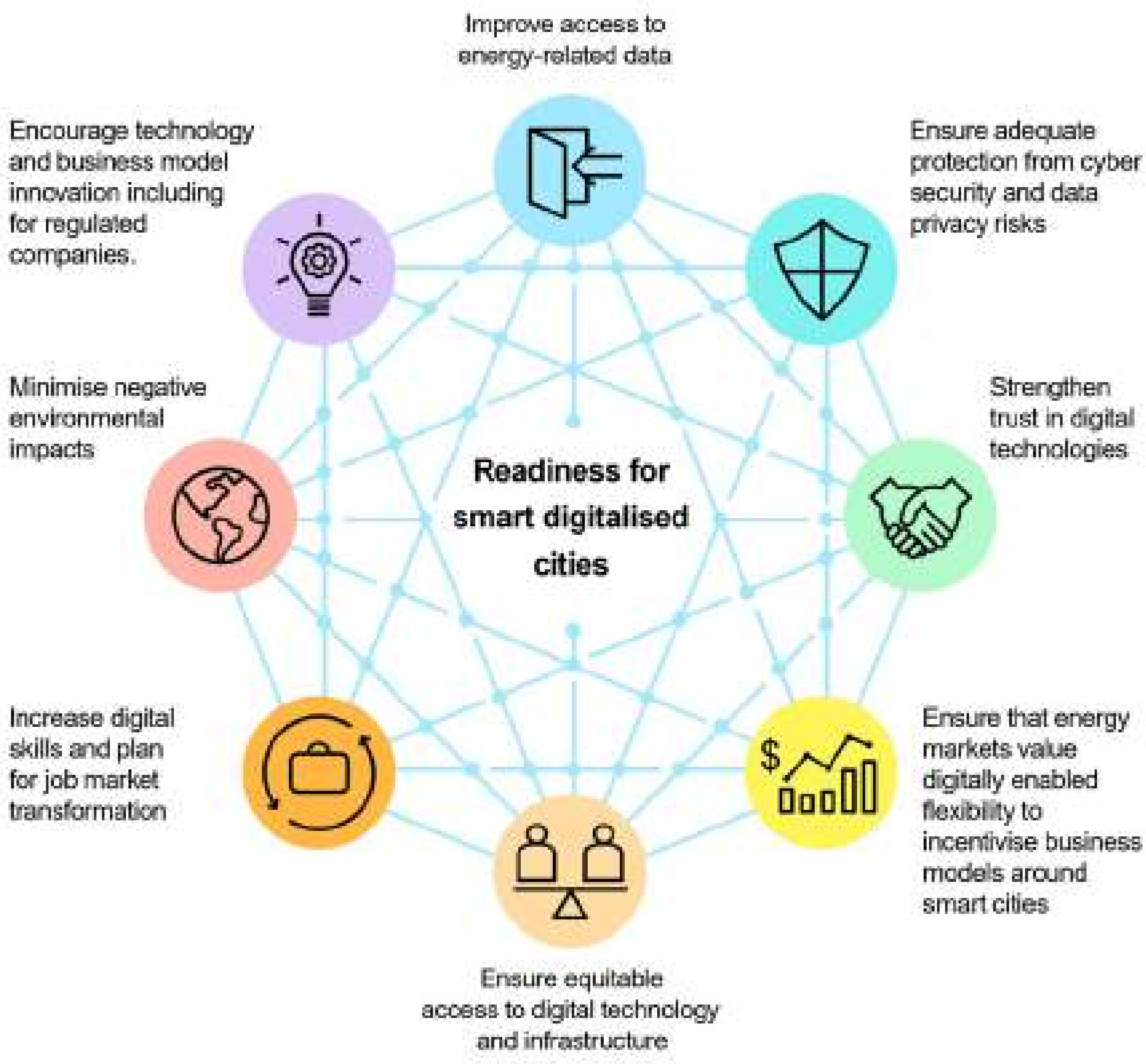


Source: Adapted from ITU World Telecommunication/ICT Indicators Database.
Note: Economic classifications of world regions might differ between the ITU (https://www.itu.int/en/ITU-D/Statistics/Pages/definitions/regions.aspx) and the IEA (https://www.iea.org/countries).

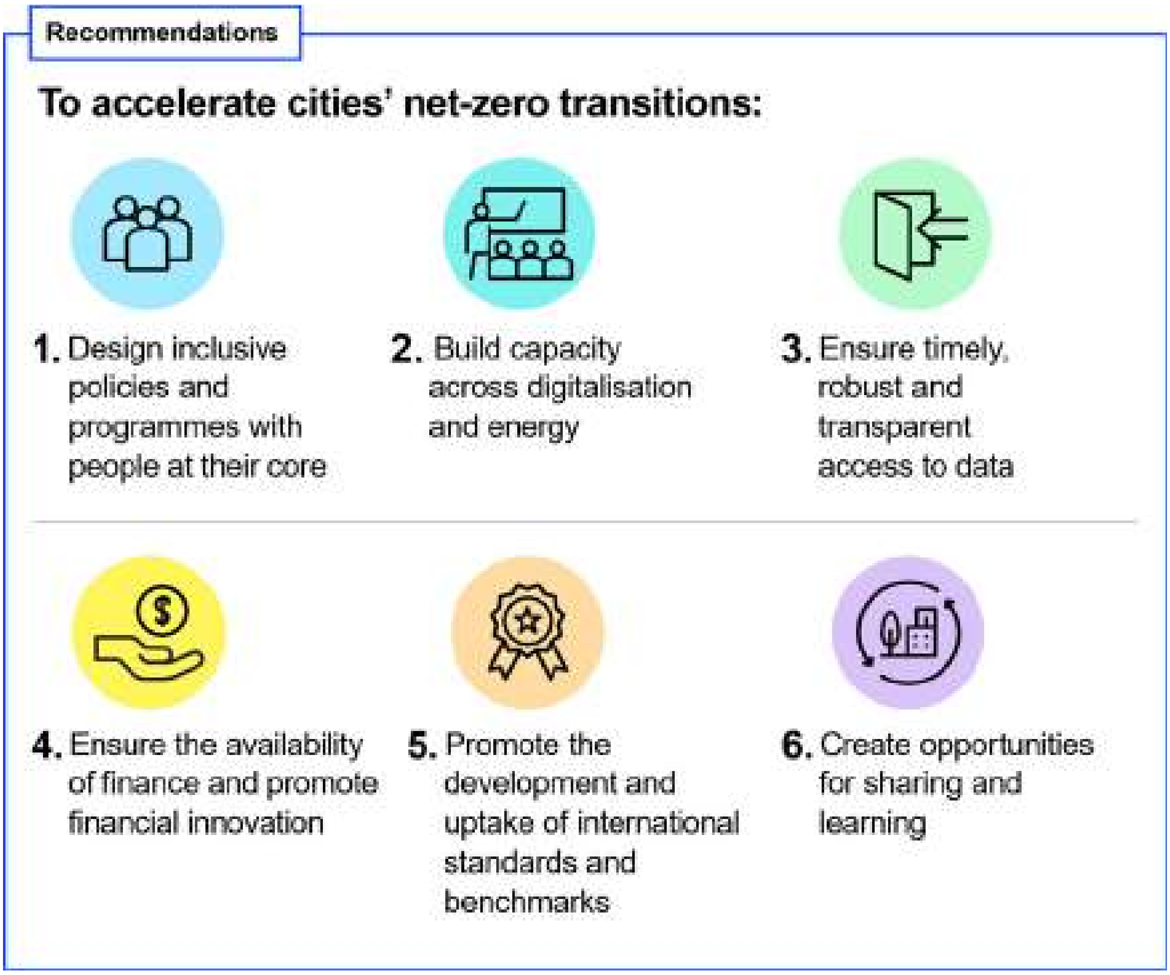
The nature of the digital divide is complex and dependent on national transition pathways. While there is a strong correlation between the digital divide and poverty, there are emerging success stories of poverty alleviation through ICT and digitalisation. E-governance has a critical role to play in narrowing the digital divide by making government portals usable for all, regardless of the level of education. Transparency in the implementation of ICT applications and e-governance strategies could bridge the digital divide by establishing trust in the digital infrastructure. Similarly, powerful instruments in bridging the gap are ensuring affordable broadband access and easy-to-use mobile devices. For example, Simputer is one such innovation that is extremely easy to use, and can be used even by the illiterate.

A comprehensive approach to appropriately assessing the digital divide is essential. It calls for international, national and regional co-operation in designing equitable policy, regulatory and legal frameworks for digitalisation. Ensuring that a basic package of networked e-services is accessible to citizens, and promoting ICT skills and digital literacy in a non-discriminative manner, are both critical for socially inclusive digitalisation.

Digital readiness framework



Recommendations



Collectively, the policies stated by governments around the world do not adequately support clean energy transitions in line with the Paris Agreement goals. In the IEA Net-Zero Emissions Scenario, global annual investment in the energy sector more than doubles, reaching USD 5 trillion by 2030. This would accelerate the deployment of renewable energy, which should generate 70% of the world's electricity supply in 2050.

Digitally driven clean technologies have proven to be effective and are readily available. The question is no longer what technologies to deploy to reach net-zero emissions targets in countries and cities, but how to create an enabling policy environment, particularly at the national level.

In this section, based on extensive consultations with leading experts and a wide range of stakeholders, including two roundtables and a peer review process, we make six high-level recommendations that national policy makers can consider to accelerate net-zero transitions and leverage cities' full potential to reduce emissions. The list is not intended to be exhaustive or definitive, and recognises that circumstances and contexts vary between countries and cities.

1. Design inclusive policies and programmes with people at their core. Policy makers have the opportunity to exchange best practices on policy design and implementation that integrate fairness and inclusivity in urban digital and energy transitions. This enables them to take measures to ensure that digital technologies are deployed in ways that promote a just and equitable net-zero transition. The digital divide means more than unequal access to high-quality Internet connection. To create resilient, smart and sustainable communities, cities need programmes that ensure vulnerable and underserved groups have the knowledge, technology and skills to benefit from advanced technologies. Initiatives could include measures aimed at improving access to communication and energy services, improving access to efficient appliances and retrofit opportunities, re-skilling and up-skilling programmes and programmes to support the development of inclusive business models for clean energy projects. They can draw on initiatives such as the Global Commission on People-Centred Clean Energy Transitions, which brings together ministers and thought leaders to identify global best practice and help governments enact people-centred policies.

2. Build capacity across digitalisation and energy. Digitalising energy systems on the road to net-zero emissions requires ongoing access to staff with digital expertise. Education policies and technical training will be critical to ensure an adequate pool of relevant digital expertise. National governments can also promote more direct ways of developing capacity across typical sectoral boundaries. They can:

- Support appropriate investment in human resources.
- Set up training programmes and partnerships to support cities in acquiring the necessary skills to develop and implement digital projects towards net-zero emissions.
- Help set up broad national and international communities of practice.
- Support research and development.
- Create innovation areas in cities that attract digital and clean energy technology talent.

3. Ensure timely, robust and transparent access to data. Digitalisation-based solutions and business models to achieve net-zero emissions can only be realised with open, transparent access to data. They need, among others, data on energy use and transport patterns, information on the condition and use of energy infrastructure, and spatial information on energy assets including distributed energy. Beyond access to data, data management frameworks and analytical tools are a further requirement, enabling the effective use of data for urban policy making. Policy makers should continually review existing regulations to ensure data access balances privacy protection with innovation. National governments can help by developing useful guidelines and mechanisms to enable data use and sharing at all levels of government.

4. Ensure the availability of finance and promote financial innovation. Several challenges inherent to net-zero digital projects can impede private investment, including new technology risks, difficulty monetising socioeconomic benefits and lack of a clear path to steady revenues. National governments can:

- Remove barriers to accessing finance.
- Create new finance opportunities.
- Set the conditions for the development of innovative funding schemes.

These actions may then attract private capital and build capacity for cities to access finance. Policy makers can make green, climate and other finance more accessible to cities by leveraging resources such as the G20 Sustainable Finance Study Group and its forthcoming roadmap. Further measures could include taking steps to remove barriers to new business models that support a net-zero emissions trajectory.

5. Promote the development and uptake of international standards and benchmarks. Successfully developing urban energy systems that produce net-zero emissions requires technologies and solutions to work seamlessly across applications, cities and countries while taking into consideration any environmental, social and sustainability implications. Many technologies and applications use proprietary protocols that can lead to vendor or supplier lock-in and limit development and innovation. Harmonised international standards enable the interoperability of technologies and solutions, while best practice benchmarks and tracking frameworks permit the monitoring of deployment and policy progress towards net-zero emissions. Further measures could include standardised tools to establish baselines, set targets, create roadmaps and select indicators to track progress.

6. Create opportunities for sharing and learning. Each country is different, and urban ecosystems are equally diverse. However, there are lessons to be learned from the experiences of other governments and jurisdictions. Emerging knowledge-sharing networks that span cities and countries, such as the IEA Technology Collaboration Programmes, can be useful for this purpose. The importance of cities and urban environments can also be integrated into large energy transition programmes, as being done by Mission Innovation, where integrated solutions on the optimal energy and technology mix are being further explored.

Annexes

Annex A: Drivers, risks and opportunities for the net-zero transition in cities

Drivers	Positive implications (+) and risks (-)	Mitigating risks, maximising opportunities
Rise of variable energy power generation	+ Faster decarbonisation + Progress in low-carbon generation technologies - Lower availability of dispatchable generation - Limited resource availability in cities given competing land use and limited surface area - Increased complexity in system balancing, calling for additional sources of flexibility to ensure grid stability	• Improve forecasting • Leverage digital monitoring of consumption through smart metering • Improve co-ordination between system actors • Ramp up demand flexibility, distributed storage and fast frequency regulation
Rise of distributed energy resources	+ Increased reliability, resiliency and security of supply at distribution level + Reduced costs of energy mix + Local jobs created to build, operate and maintain distributed energy resources - Operational challenges for local network operators	• Sector coupling: connect thermal and electricity domains with local infrastructure networks (district heating/cooling) to enhance local storage, flexibility and local production • Empower local network owners and operators to take measures as more power is injected at the distribution level • Promote energy communities and user-driven capacity installation • Regulate the market and allow for decentralised balancing
Electrification (transport, heating) and new demand (cooling, appliances)	+ Faster decarbonisation + Reduced urban air pollution + Uptake of more-efficient technologies + Increased potential for flexible demand provision + New options for distributed storage and flexibility services - Higher peak demand - Local networks too slow to upgrade	• Promote innovation around efficiency and demand shifting • Smart charging and V2G solutions, also by means of grid interactive buildings • Enhance energy forecasting and planning • Cross-sectoral co-ordinated planning

	- Spatial planning challenges to deploy new infrastructure - Increased seasonal mismatch between variable energy generation and demand profiles	• Local low-temperature district heating/cooling based on heat pumps for new developments
Changing climate	+ Increased focus on mitigation + Increased resilience and better adaptive capacity - Extreme weather events bringing down the distribution grid and leading to energy supply disruptions	• Increase consumer awareness and use price signals • Promote resilience by investing in infrastructure and smart technologies • Adapt standards and introduce ad hoc regulatory framework • Create new market signals and business models around resiliency
Transforming infrastructure for net-zero emissions	+ Increased investment in new sustainable infrastructure and large-scale retrofits - Pressure and costs of upgrading existing infrastructure - Risk of sunk costs from existing infrastructure	• Deploy digital tools such as smart meters to monitor infrastructure transformation and enable demand-side flexibility • Use digital urban planning technologies such as digital twinning • Maximise the use of existing assets towards the transition, such as telco infrastructure hosting • Innovative financing mechanisms for long-term green and digital urban infrastructure
Working from home impacts on commuting to and across cities	+ Potential to address congestion and transport demand and helps meet reduction/efficiency targets - Increased uncertainty of demand projections affects investment in supporting infrastructure - Higher residential energy consumption and change in load profile	• Cities expanding safe and accessible walking and cycling infrastructure • Increasing deployment of micromobility and last-mile options for more flexible passenger transport options
Increased last-mile freight logistics/home delivery/ mobility as a service	+ Increases accessibility of active transport and shared mobility options - Increased congestion in city centres especially if night delivery restrictions - Too early to tell if this increases emissions in the long term	• Ensure training and a range of service formats are provided to broaden access • Focus on decarbonisation and efficiency of last-mile freight logistics • Increase multi-modality of mobility options

Investment for recovery	+ Increased opportunity for investment into infrastructure and planning that align with net-zero emissions + Potential for creation of millions of decent and sustainable jobs	• Apply conditions to recovery spending that avoid locking in carbon-intensive infrastructure and industries
	- Emissions returning to pre-pandemic levels very quickly - Hundreds of billions in unconditional support to carbon-intensive industries	

Annex B: Abbreviations, units of measure, glossary

Abbreviations

AI	artificial intelligence
API	application programming interface
ASEAN	Association of Southeast Asian Nations
BIS	Bureau of Indian Standards
CaaS	cooling as a service
CFF	C40 Cities Finance Facility
CI	collective intelligence
CO	carbon monoxide
COP26	26th UN Climate Change Conference of the Parties
CO_2	carbon dioxide
CO_2-eq	carbon dioxide equivalent
DTT	Digital Transformation Team
EBRD	European Bank for Reconstruction and Development
EV	electric vehicle
GDP	gross domestic product
GHG	greenhouse gas
GIS	geographic information system
GPS	Global Positioning System
ICT	information and communications technology
IEC	International Electrotechnical Commission
IEA	International Energy Agency
IoT	Internet of things
ISO	International Organization for Standardization
ITU	International Telecommunication Union
J-SCTF	Joint IEC-ITU-ISO Smart City Taskforce
ML	machine learning
NO_x	nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
O_3	ozone
PPP	public-private partnership
PV	photovoltaic
SDG	UN Sustainable Development Goal

SO_2	sulphur dioxide
UDI-ICTRA	Unified Digital Infrastructure – ICT Reference Architecture
V1G	unidirectional managed EV charging
V2G	vehicle to grid
WEF	World Economic Forum
3D	three dimensions or three-dimensional
4G	fourth generation of mobile telephone technology
5G	fifth generation of mobile telephone technology

Units of measure

Gt	gigatonne
Gt CO_2	gigatonne of carbon dioxide equivalent
GWh	gigawatt hour
Mt	million tonnes
Mt CO_2	million tonnes of carbon dioxide
Mt CO_2-eq	million tonnes of carbon dioxide equivalent
TWh	terawatt hour

Glossary

Aerial scans: 3D and laser scanning usually based on drones.

Ancillary services: services that help the electricity grid maintain balance between generation and demand.

Application programming interfaces: computer interfaces that play an intermediary and matching role between different software or hardware applications.

Artificial intelligence: programming models and algorithms imitating human intelligence.

Big data: large datasets with high reporting velocity, too complex to be processed by traditional data management tools.

Blockchain: distributed digital ledger storing data in blocks chained to each other and permanently recording transactions.

Building information management: digital model of a real-world facility or infrastructure project.

Cooling as a service: business model that helps buildings and businesses owners avoid capital costs of air-conditioning units by paying subscription fees according to their consumption.

Cyberattack: offensive assault targeting computer devices, networks or databases.

Cybersecurity: protection of computer systems, networks or computer programs from cyberattack.

Default risk: lenders' risk that borrowers might be unable to repay their debt.

Demand response: mechanism by which electricity demand is shifted over given time periods in response to price changes or other incentives, but not necessarily reducing overall electrical energy consumption. This can be used to reduce peak demand and provide electricity system flexibility.

Demand-side response: actions that can influence the load profile, such as shifting the load curve in time without affecting total electricity demand, or interrupting demand for a short duration or adjusting the intensity of demand for a certain amount of time.

Digital twin: virtual replica of a physical object, building or city, used to simulate and manage city operations.

Distribution system operator: organisation managing the electricity distribution grid at low voltage level.

District heating: network of pipelines distributing water heated by a central source to residential and commercial buildings.

Energy as a service: business model in which customers pay for the energy units they consume without the need to pay for upfront equipment investment and installation costs.

Fintech: innovative financial scheme supported by advanced technology.

Flexibility: ability of the power system to alleviate disruption between supply and demand.

Geographic information system: conceptualised framework to capture, collect and analyse spatial and geographical data.

Internet of things: network of physical devices and sensors connected to a common network and reporting data dynamically to central receivers.

Interoperability: capability of computer systems or software to match data according to predefined standards.

Machine learning: application of computer systems that use algorithms to learn and exploit patterns from data and automatically improve themselves by reiteration.

Microgrid: decentralised energy system that can be islanded from the main grid with its own sources and loads.

Net-Zero Emissions by 2050 Scenario: IEA scenario showing government actions required for the global energy sector to achieve net-zero CO_2 emissions by 2050 through the implementation of climate policies.

Peer-to-peer: sharing network model in which entities can act both as seller and customer.

Public-private partnership: arrangement between a governmental entity and a private-sector company.

Smart charging: system by which the system operator optimises the charging profile of an electric vehicle according to how much energy the vehicle needs over a specified length of time, how much energy is available, the price of wholesale electricity and grid congestion, among others. Relies on the sharing of real-time data.

Transmission system operator: organisation managing the electricity transmission grid at high voltage level.

Virtual power plant: a network of digitally aggregated distributed energy resources, flexibility providers and storage technologies, centrally controlled to provide efficient dispatching and integration into the power market.

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