Empowering Urban Energy Transitions

Smart cities and smart grids

International Energy Agency

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Abstract

In the context of the recent agreement at COP28 in Dubai and the current state of play of urban power systems – from G7 countries to emerging markets and developing economies – this report analyses the steps needed to achieve net zero emissions from electricity, and considers the wider implications for energy security, sustainability and affordability.

The decarbonisation of cities is a global priority, and local governments are instrumental in achieving national commitments and objectives. Improved access to and use of data for decision making can support faster and more targeted implementation and help align city and power system planning. Digital solutions and systems can be particularly powerful in cities, where high-density environments create economies of scale and can optimise infrastructure and create new opportunities. Exploring a wide range of projects and initiatives implemented in power systems and cities around the world, the report provides insights on emerging best practices, innovative approaches and how barriers and challenges can be tackled. Our focus is on ways national governments can help cities accelerate clean, affordable and inclusive energy transitions, and ensure resilience and an ability to adapt to climate change.

The report also underscores how G7 members can foster innovation through international collaboration, creating enabling environments at the city level to deploy scalable pilot projects, support integrated planning and promote data sharing, all while maintaining electricity security and placing people at the centre of clean energy transitions.

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Executive summary

Global agreement for renewed momentum to implement clean energy transitions

As part of the UAE Consensus at the COP28 climate change conference in Dubai in December 2023, an historic agreement was signed signalling the “beginning of the end” of the fossil fuel era. Governments agreed to double the annual rate of energy efficiency improvement by 2030 and, in the same timeframe, to triple the global deployment of renewable energy capacity, putting the principle of energy efficiency at the centre of policy making. While these ambitions will be translated into national action plans, cities are uniquely positioned to lead the way and serve as transition accelerators because of their high population densities and positioning as centres of commerce, productivity and innovation.

Cities as catalysts for change

Urban areas are the economic powerhouses of their nations. They are undergoing rapid development and contributing to higher energy consumption and rising greenhouse gas emissions. Globally, cities account for around 75% of global energy consumption and 70% of global greenhouse gas emissions – figures that are set to rise.

Almost 10% of the increase in global emissions since 2015 can be attributed to urbanisation. It accounted for the record high urban-related emissions of almost 29 billion tonnes of CO_2. Despite this rapid escalation, many people in urban areas still lack proper access to power grids. For example, of the more than 100 million people living in cities without access to electricity, more than 90% are located in sub-Saharan Africa, the fastest-urbanising region of the world.

Fortunately, cities also present unique opportunities for transformative change. Cities can leverage public procurement to create economies of scale and bring down costs of clean energy technologies. More than 60% of public investment occurs at the subnational level, of which nearly a third is channelled into transport systems, underlying the importance of cities investing in green and resilient urban infrastructure.

This important potential of cities to be front runners in the energy transition is gaining recognition in many regions, including in multilateral forums. Recently, the G7 recognised the transformative power of cities, and the G20 identified the need to finance the infrastructure of the cities of tomorrow. This is critical because, based on existing stated policies, without further urgent action globally in cities and on grids, climate goals will be missed and economic growth could be affected.

Cities fostering innovative and cost-effective people-centred solutions

A people-first approach exemplified by community energy projects not only promotes environmental sustainability, but it also stimulates local economies, reduces energy bills and fosters public trust in clean energy transitions. These advances are crucial to achieving the large-scale change needed to overcome today's status quo. Supporting city-level action has the potential to provide the greatest carbon mitigation return on investment and accelerate inclusive clean energy transitions. The evidence is that investing in infrastructure and technology to decarbonise the energy sector can reduce greenhouse gas emissions by up to 75% by 2050 – as long as the right policies are in place.

Most urban residents around the world are breathing unhealthy levels of pollution, a major portion of which is a by-product of using fossil fuels, which is responsible for around 5 million premature deaths each year. City-led action can improve air quality, reduce energy demand, improve grid stability, and create savings for households and businesses. It can empower people to take on a greater role in managing their energy demand through user-centred initiatives. City-led action can drive inclusive transitions with information campaigns, guidance and advice, policy support for efficient appliances and support for energy communities.

Matching urban growth with increased ambition for inclusive clean energy transitions

Globally, urban populations account for more than half of the 8 billion people on Earth today, a share that is increasing. The total global urban population grew by around 400 million between 2015 and 2020 alone. More than 90% of this growth occurred in cities in emerging markets and developing economies (EMDEs). Between 2024 and 2050 the share of the urban population is expected to increase from 56% today to around 70%, with the number of urban inhabitants increasing by around 1.8 billion. Projections show that urban land areas are expected to expand by around 1 million km^2 up to 2050, equivalent to the total land area of Japan, Germany and Italy combined.

A small number of progressive cities are stepping up and setting sustainability and CO_2 reduction targets that are bolder than those of national governments. Globally, of the cities with more than 500 000 inhabitants, around 20% have proposed or pledged net zero targets, of which only half have stated policies in place. Whereas there may be net zero targets at the national level, at the municipal level, more than 900 cities, many of which continue to grow in size, currently do not have net zero targets.

Power grids feel the heat as climate change begins to take effect

As the world heats up, so the demand for cooling is increasing. The installed capacity of space cooling equipment is expected to nearly double by 2030 from 850 GW today, and then to double again by 2050. Demand for cooling also drives peak demand, which creates challenges for grid operators and poses access and affordability issues for customers. By 2040 cooling is expected to account for 30% of peak electricity demand in ASEAN countries, mostly concentrated in urban areas. This is up from around 10% today, and further studies suggest that globally each degree Celsius increase causes an average increase of almost 4% in peak electricity demand.

Thus, climate change is posing new challenges to grids in increasingly densely populated cities. Around 70% of cities are already experiencing the negative impacts of extreme temperatures and frequent storms of increasing intensity, which push power infrastructure to the edge of its operating limits.

Modernising and expanding power grids for sustainable urban energy futures

The transition away from fossil fuels, including by tripling renewable energy capacity and switching to electrical demand-side energy assets, is vital for countries to achieve their climate goals. This transition leads to an increased demand for electricity in all IEA scenarios.

To achieve the changes consistent with a net zero pathway, the EV fleet is expected to increase tenfold, from nearly 30 million today to around 315 million by as early as 2030, while total heat pump capacity may triple from 1 000 GW today to 3 000 GW by 2030. Substantial electrification of transport and heat, as well as across industry, will see demand for electricity increase. It could increase by up to two and a half times by 2050, depending on the pace of decarbonisation. Based on existing announced national policies, electricity grids will need to expand globally to manage the increased capacity, requiring up to 80 million km of new or upgraded lines by 2040. Crucially, grids will also need to become increasingly smart to manage the increased share of renewable energy capacity.

These ambitious but essential plans to decarbonise the electricity systems, coupled with rapid urbanisation, make it crucial to focus on investment in grid modernisation and digitalisation. As cities become focal points for energy consumption, efficient grid management becomes paramount in addressing urban energy challenges. To be on track for net zero, global annual investment in grids needs to more than double from around USD 330 billion per year to USD 750 billion by 2030, and approximately 75% of this will be needed to expand, strengthen and digitalise distribution grids.

The power of digital-driven integrated planning

Urban areas contribute more than 80% of global GDP. Electricity has facilitated the growth of industry and commerce in many regions, driving GDP and contributing to development. As demand for electricity continues to grow, power grids need to adapt rapidly to manage both today's grid constraints and the challenges of tomorrow, particularly in cities.

Bottlenecks in power grids delay housing developments, prevent the completion of new renewable energy projects and can put the uptake of customer-owned clean energy resources at risk, such as rooftop PV systems and EVs. These bottlenecks could create further problems for up to 1.5 million households by as early as 2030. In the United Kingdom, as an example, grid congestion costs may reach as much as GBP 2.5 billion each year in the same timeframe.

In addition to investment in physical infrastructure, taking advantage of the proliferation of connected technologies, which are creating new data sources, offers the potential to better manage urban power systems and the increasing variability on them. Cities have the right level of density and granularity for demand-side energy assets to be optimised and aggregated at the building, neighbourhood and community levels.

Analysis suggests that digitally enabled technologies could reduce the curtailment of variable renewable energy systems by more than 25% by 2030, increase system efficiency by 30% and reduce costs by up to 30% for customers. However, while regulatory and technological barriers stand in the way of maximising the use of data, many of these barriers could be overcome through closer international collaboration.

International collaboration is essential to address global challenges

Meeting the ambition to double the annual rate of energy efficiency improvement as per the UAE Consensus requires a 4% sustained improvement in primary energy intensity through to 2030. While individual countries have achieved more than 4% in certain years, collectively the world has not reached this target in a single year since the beginning of this century.

Meeting this goal requires global investment in energy efficiency to triple by 2030. However, there are large regional differences, as currently 9 out of every 10 dollars spent on clean energy since 2021 has been spent in advanced economies and China. This regional imbalance means that, whereas in advanced economies spending must more than double by 2030, the increase in emerging economies is closer to a factor of 3.5.

Technologies and solutions exist to fast-track energy efficiency implementation and to support the integration of renewables in power systems; however, they are still not being widely used. Similarly, best practices and innovative approaches exist, but opportunities are being missed due to a lack of co-ordination.

Illustrated by more than 100 case studies, this report showcases the leading role that cities can play in implementing faster decarbonisation and energy efficiency gains. The supportive roles that national governments and other stakeholders need to play are highlighted. We suggest four specific areas where national policy makers can take action to empower cities towards faster and more effective implementation. We have emphasised the potential for cities and national governments: to place people at the centre of policy making in order to build for the future; to support data-driven integrated planning to ensure that grids are fit for purpose; to address specific areas of focus so as to create a supportive environment; and to pursue the benefits of fostering strengthened international co-operation.

Chapter 1: Urban energy revolutions

Key takeaways

- Cities contribute around 80% of global GDP and their associated emissions were responsible for a record 29 billion tonnes of CO_2 in 2023.
- More than half of the 8 billion people alive today live in urban areas, and urbanisation is on an upward trend, with parts of Asia and Africa expected to continue to drive the proportion of the global population that is urbanised to around 70% by 2050, with nearly 2 billion more people living in cities than there are today.
- Cities have an essential role to play in tripling the capacity of renewable energy sources, deploying energy-efficient technologies and the electrification of transport and heating, commitments agreed as part of the UAE Consensus at COP28.

International climate goals

At the COP28 climate change conference in Dubai in December 2023, every participating government signed an historic agreement, agreeing to transition away from fossil fuels in energy systems as part of the UAE Consensus. The landmark pact also includes the call to collectively raise ambitions by doubling the annual rate of energy efficiency improvement by 2030 and accelerating the supply of low-carbon energy by tripling the total capacity of renewable energy sources in the same timeframe.

The shift away from fossil fuels will see many sectors switch to electricity, increasing the demand for power. The biggest consumers of electricity are the buildings and industrial sectors, which together account for over 90% of global electricity consumption. Appliances, lighting, cooking, cooling and heating account for the bulk of energy consumption in buildings, and electricity demand increases for each of these end uses in all IEA scenarios, especially in emerging markets and developing economies (EMDEs). By 2050 electricity demand increases by as much as 150% on a pathway that achieves net zero by mid-century.

Cities are major sources of energy demand for transport, industry and buildings. They are currently responsible for around 75% of global energy consumption and 70% of global greenhouse gas emissions.

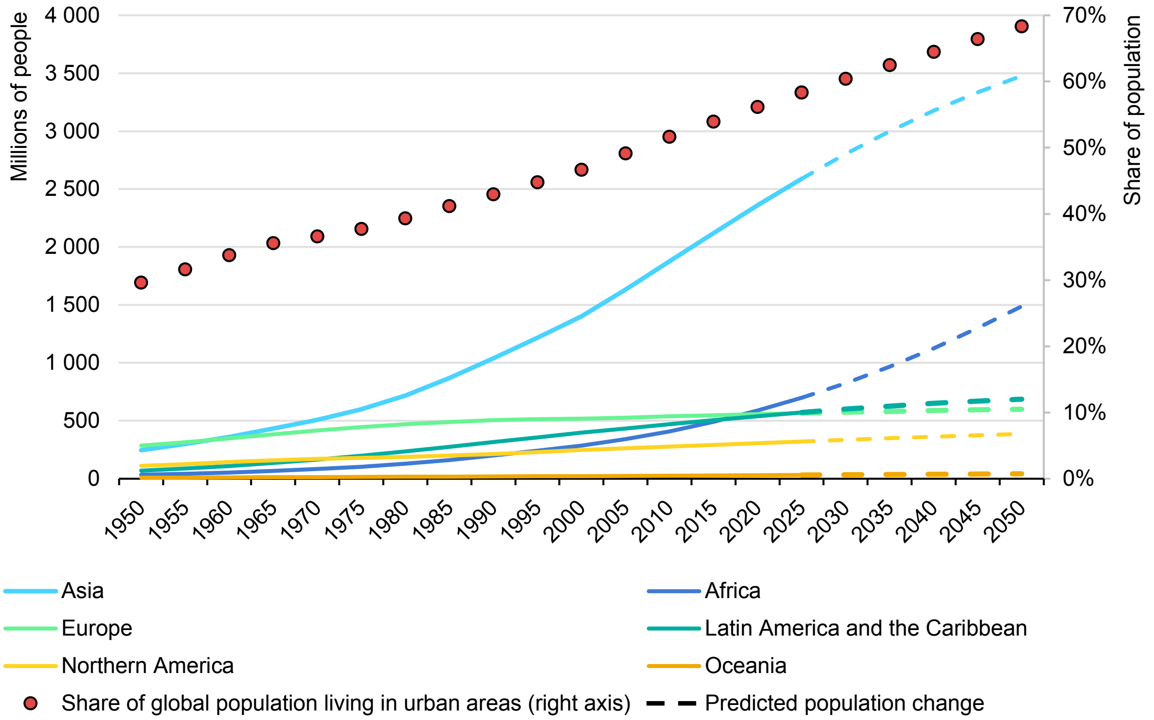
Cities and the climate

Cities drive economic growth, but their emissions are climbing

Cities are the engines of global economies and drivers of economic growth. While they are home to around 56% of the world's 8 billion people, they contribute more than 80% of global GDP. Globally, the urban population grew by around 400 million between 2015 and 2020 alone. Notably that more than 90% of this urban growth occurred in EMDEs, particularly in the regions of Asia and Africa, and above all in India, People's Republic of China (hereafter, "China") and Nigeria.

Urbanisation together with a rising global population is continuing to change the shape of society, and at an extraordinary pace. In 2024 more than half of the world's population already lives in urban areas, and this share is expected to grow to around 70% in 2050, an increase of around 1.8 billion people. In Asia, the total population is set to increase by around a third, while in Africa, the continent's population is projected to double between now and 2050.

Historical and projected urban population by region, 1950-2050



Source: IEA analysis based on UN World Urbanization Prospects 2018.

Combining the overall increase in population and the continuing shift from rural to urban living, the proportion of GHG emissions originating in cities climbed from around 62% in 2015 to around 70% today, taking urban-related emissions to a record high of almost 29 billion tonnes of CO_2 in 2023.

Analysis by the IEA has identified that to double the annual rate of energy efficiency improvement as per the UAE Consensus requires a 4% sustained improvement in primary energy intensity each year through to 2030. While individual countries have achieved more than 4% improvement in certain years, the world's countries have not reached this target on average in a single year since the beginning of this century.

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

Cities can play a central role in achieving international climate goals, but more action is needed

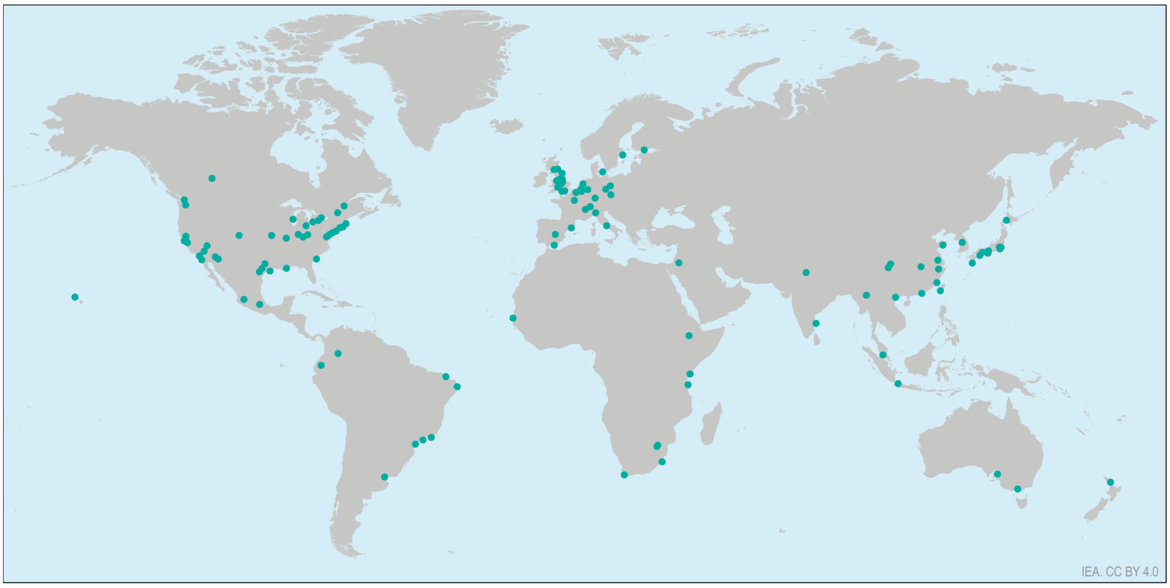
Several cities are frontrunners in national climate ambitions, leading the way to achieving net zero emissions ahead of nationally determined targets. For example, London aims to be carbon neutral by 2030. In 2023 the city extended its ultra-low emission zone to the entire Greater London area, contributing to further reducing air pollution.

Vienna has published a revised smart city strategy, which includes a target of climate neutrality by 2040 and interim goals to reduce per-capita energy consumption, greenhouse gas emissions and the material footprint. The strategy is centred around people, focusing on inclusion and equality, and enabling participation and active engagement. Vienna has created opportunities for the city's inhabitants to collectively invest in clean energy through community-funded solar plants.

Multilateral forums continue to recognise the important role of cities in the pursuit of net zero energy systems. The 2021 G20 Energy-Climate Ministerial Communiqué in Naples (Italy) highlighted the role of urban areas in accelerating the clean energy transition, while the 2023 G7 Ministers' Meeting on Climate, Energy and Environment in Sapporo (Japan) concluded with the announcement of the first ever G7 Roundtable on Subnational Climate Actions in collaboration with Urban7. In their final communiqué, the G7 Ministers address "the vital role of subnational actors in realising the transformation toward net zero".

At COP28 in Dubai, over 40 ministers committed in a joint statement to support and integrate climate action across every level of government. Moreover, 71 countries joined the Coalition for High Ambition Multilevel Partnerships for Climate Action to enhance co-ordination between national and subnational governments in the planning, financing, implementation and monitoring of climate strategies.

Cities with net zero targets in policy documents or laws, 2023



Source: IEA analysis based on data from Net Zero Tracker.

Climate action in urban areas is essential for achieving ambitious net zero emissions goals, and internationally, many cities are emerging as leaders to take a strong stance by supporting initiatives on climate action. The Cities Technological Collaboration Programme is the newest IEA collaborative international cross-cutting initiative that helps cities speed up their decarbonisation efforts by providing scientific and evidence-based information and an international forum on urban energy and mobility system transformation. The Global Covenant of Mayors for Climate and Energy brings together 12 500 cities and local governments to push for climate action, with a view to driving down GHG emissions. Similarly, the C40 cities initiative represents 100 city mayors with the ambition of limiting global warming to 1.5°C, while building equitable and inclusive communities. ICLEI works with more than 2 500 local and regional governments on sustainable urban development. The United for Smart Sustainable Cities (U4SSC) a global UN initiative co-ordinated by multiple agencies, is an international platform for information exchange and partnership building to assist cities and communities in achieving the UN Sustainable Development Goals. The Race to Zero is coalition of non-state actors including companies, cities, regions, financial, educational, and healthcare institutions leading a global campaign to halve global emissions by 2030. The CDP-ICLEI Track provides a platform for more than 1 100 cities to report and track progress on climate action.

However, despite some examples of subnational ambition, globally, only around 20% of all cities with more than 500 000 inhabitants have proposed or pledged to net zero targets. Further still, only 0.6% of these cities have translated net zero targets into law, with a somewhat larger number mentioning targets in policy documents.

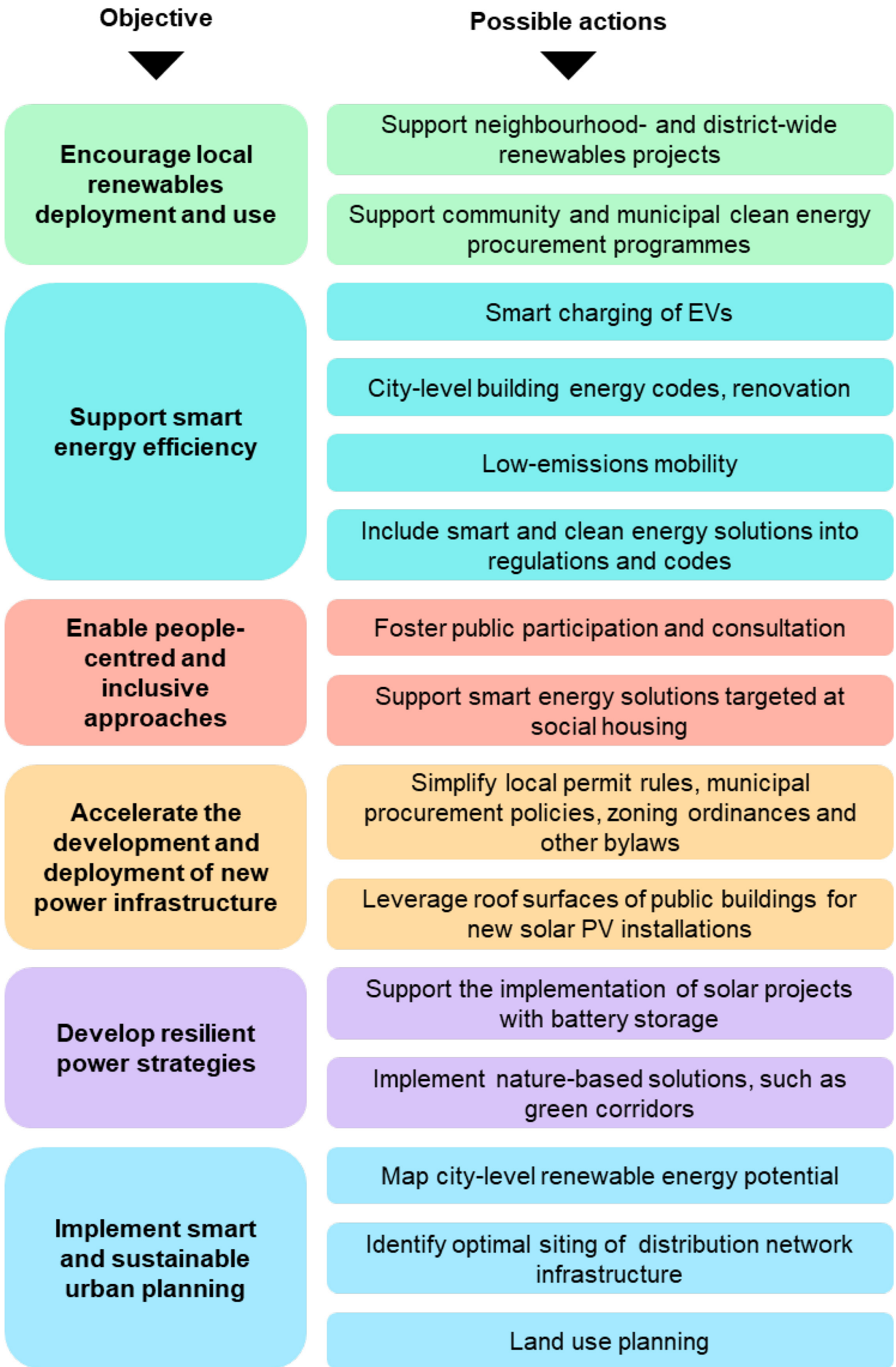
Opportunities for sustainable energy transitions in cities

Examples of city-led action provide a vision for others

Local governments wield significant influence in shaping urban sustainability through urban planning and policymaking. By adopting policies that support smart and inclusive sustainable energy solutions, they engender resilient communities and mitigate climate change. Through initiatives like district-wide renewables deployment and low-emissions transport policies, cities accelerate clean energy adoption. They also play pivotal roles in implementing resilient power strategies and integrating clean energy solutions into regulations, fostering socially inclusive transitions The following examples highlight the active role of cities in supporting a more people-centred approach, while also delivering national climate action.

City governments can **adopt policies that encourage smart and inclusive sustainable energy solutions**. They can support neighbourhood- or district-wide renewables deployment and implement low-emissions transport policies. Community bulk buying programmes can also accelerate the implementation of energy efficiency and the adoption of local renewable energy sources. In 2023 Rio de Janeiro became the first Latin American city to use a renewable power purchase agreement to power public buildings with clean energy, through the Río de Energía Verde Initiative. By agreeing a long-term contract between the city and a renewable energy generator, the arrangement allows the municipality to benefit from stable electricity prices and progress towards its environmental objectives while giving the developer visibility on future revenues and making the operation of the generating facility easier. This first stage of the project is expected to avoid 40 000 tonnes of CO_2 over the next five years and to allow the municipality to save more than USD 6 million in electricity costs, which will be directed towards health and education projects. In Indonesia, the TransJakarta bus system tripled its routes and doubled the number of buses in operation between 2016 and 2020, allowing the bus rapid transit system to reach one million passengers per day in 2020. Achieving the target of complete electrification of the bus fleet by 2030 could add 4 days of life expectancy per resident in the focus area.

Areas for city-led action on inclusive clean energy



- Cities have a powerful role in clean energy transitions by **incorporating smart and clean energy solutions into regulations and codes**. For example, the city of Vancouver 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 multifamily residential buildings, which is usually harder than in single homes. Cities 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.

- Cities can expand on their planning function and make use of geographical information systems to map renewable energy potential at the city level and **identify the 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.
- They can accelerate the development and deployment of new power system infrastructure through **local permit rules, municipal procurement policies, zoning ordinances and other bylaws**. In some cases, municipalities are owners and operators of local utilities. In Germany, more than two-thirds of municipal utility companies use the roof surfaces of public buildings to locate their installations. In the United States, there are more than 2 000 municipal utilities, serving 10% of the country's electrical needs. For example, the city of San Jose in California is creating its own power utility, an early study showing potential cost savings on electricity of between 15% and 25%.
- Cities can **develop 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 with battery storage, protect critical facilities from power outages. In the face of increasing heatwaves during summer, the city of Utrecht in the Netherlands is rapidly expanding its vehicle-to-grid (V2G) infrastructure, thus allowing EVs to store electricity during the day and inject it into the grid during the evening peak hours. The initiative aims to connect up to around 10 000 bidirectional charging EVs to the grid, the estimated amount needed to solve the city's grid congestion according to Utrecht University. In 2022 South Africa experienced over 100 days of rolling blackouts. Cape Town is working with the C40 Cities Finance Facility to install a large-scale solar power plant that will improve the city's resilience.
- Cities can lead the way in **implementing smart solutions** to ensure that local energy transitions are socially inclusive and people-centred. For example, Stirling Council in the United Kingdom plans to equip its entire social housing stock with sensors and tools to enable property owners to effectively address risks including dampness, mould and insufficient ventilation and help tenants better understand energy usage and improve efficiency.
- Cities can **use their powers to implement further solutions** to reduce energy demand and improve well-being. In Australia, Melbourne is planting 3 000 trees every year to lower city temperatures by 4°C, thereby reducing the need for air

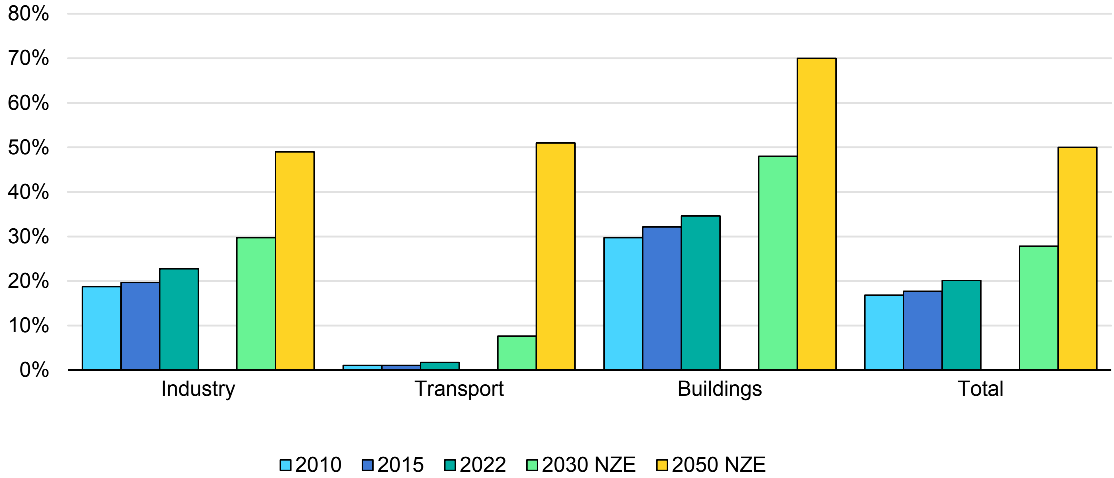
conditioning and providing additional recreation areas. Medellin in Colombia has created 30 green corridors and achieved temperature reductions of 2°C. A growing number of cities, including Paris, Milan and Athens, are providing inhabitants with apps to help monitor heat risks and provide guidance on how to reduce exposure.

The role of grids in urban energy transitions

Ensuring that grids are fit for purpose is necessary to realise decarbonisation ambitions

Electrification is a critical element of reducing fossil fuel demand, alongside efficiency improvements and greater use of low-emissions fuels. The greater role for electricity in the energy mix will have significant consequences for power systems. In 2023 electricity's share of total final energy consumption was 20%, and by 2050 this number increases to over 50% in the IEA Net Zero Emissions by 2050 Scenario (NZE Scenario). Power systems are therefore facing the need for far-reaching change.

Share of electricity in final energy consumption by sector, 2010-2022, and in the NZE Scenario, 2030 and 2050

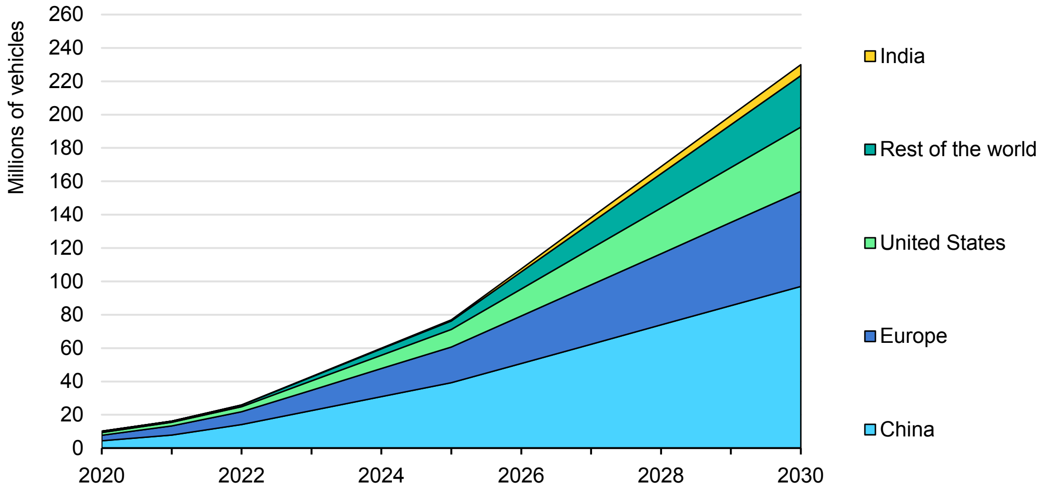


Source: IEA (2023), Net Zero Roadmap: A Global Pathway to Keep the 1.5°C in Reach: 2023 Update.

There are signs that the net zero transition is already well underway, such as the rapid adoption of efficient EVs that is taking place in many cities today, with sales of new EVs estimated to be 35% higher in 2023 than in 2022. EV ownership and the deployment of electrical equipment (e.g. heat pumps and air conditioners) and distributed energy generation (e.g. rooftop solar PV) are expected to continue to rise in coming years.

Global sales of electric cars jumped from around 6.5 million in 2021 to 13.7 million in 2023, while in the previous two years, from 2018 to 2020, EV sales increased by only 950 000 units. In 2022 the global stock of electric cars was around 27 million units and it is likely to increase almost ninefold by 2030 in the IEA Announced Pledges Scenario (APS) reaching 230 million units, driven mainly by China, while it increases to up to 315 million units in the NZE Scenario.

Global stock of electric cars by region in the Announced Pledges Scenario, 2020-2030

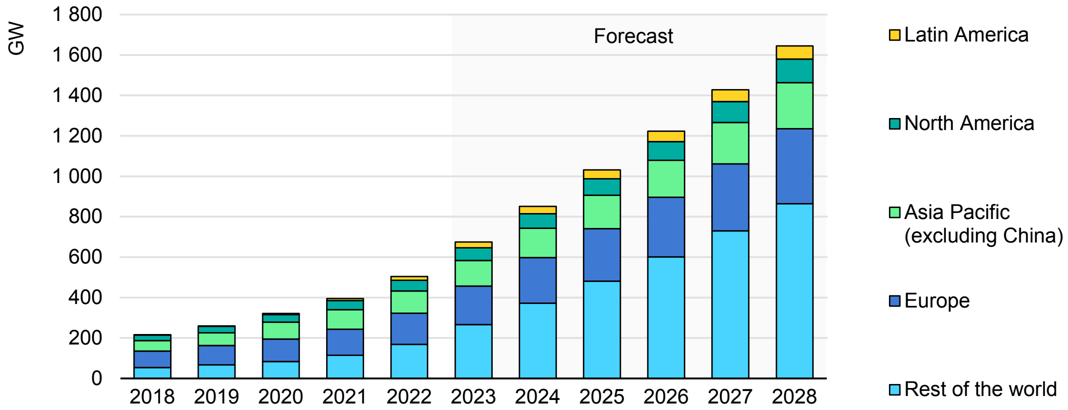


Source: IEA (2023), Global EV Data Explorer.

In the recent IEA report Renewables 2023, almost 3 700 GW of new renewable capacity is forecast to come online over the period 2023-2028, driven by supportive policies in more than 130 countries. Growth continues in mature markets, but there is also new capacity coming online in emerging markets and developing economies.

Global distributed PV capacity is expected to increase on average more than 7.5 times by 2028 compared to 2018, and by an astonishing 68 times in Latin America. Nigeria is expected to add 5 GW of distributed solar PV capacity between 2023 and 2028, with Angola and Kenya achieving 2 GW each. Brazil is expected to deploy 7 GW each year through to 2028. In some regions the ramp-up of residential solar installations will play a particularly significant role, as in Latin America where the share of residential solar PV in total distributed capacity – which includes commercial and industrial installations as well as off-grid solutions – will almost double, reaching 58% in 2028.

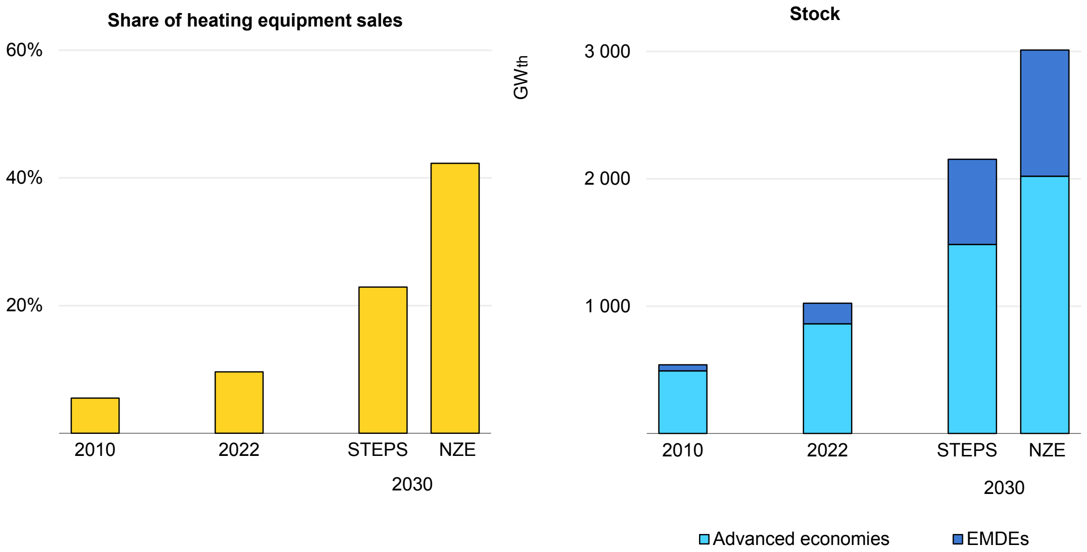
Distributed PV cumulative capacity by region, 2018-2028



Source: IEA (2024), Renewables 2023.

Simultaneously, the electrification of heating is rapidly increasing, with global sales of heat pumps increasing by 11% in 2022, marking a second year of double-digit growth. In 2022 heat pumps met around 10% of heating needs in buildings, corresponding to over 100 million households. According to the latest IEA analysis, in the Stated Policies Scenario (STEPS) the share of heat pumps in total heating equipment sales more than doubles by 2030, and in the NZE Scenario their share increases fourfold, tripling the global heat pump capacity. Also, in both scenarios around one-third of the global stock of heat pumps is in EMDEs by 2030, while in 2022 these countries accounted only for 16% of the global stock.

Global heat pump sales and stock, 2010-2022, and by scenario, 2030



Note: GW_{th} = gigawatt thermal capacity.
Source: IEA (2023), World Energy Outlook 2023.

Investment in grids is needed to deliver resilient grids and avoid bottlenecks

Substantial investment in grid development will be needed to facilitate the integration of increased electricity demand and intermittent generation. There is already evidence that power system operators need to invest substantially more in digitalisation and flexibility to meet the challenges of clean energy transitions. It is vital to ensure that grids are fit for purpose, not just for today's demands, but also for future challenges, enabling countries to follow their decarbonisation pathways in an equitable and cost-effective manner.

Delays in grid investment and reform could substantially increase emissions, slowing energy transitions and potentially putting the 1.5°C goal out of reach. For example, grid congestion due to increased electrification of heating and mobility in the Netherlands is causing more than 3 500 large consumers to be placed on waiting lists for their applications for new or added grid capacity, and risks affecting up to 1.5 million residential customers in the coming decade. This is already happening in several regions in the Netherlands.

Driven by soaring temperatures during May-August 2023, areas of Mumbai experienced power outages due to escalating peak demand for air conditioning. As African countries move towards the target of achieving universal access to affordable, reliable and sustainable electricity by 2030, cities are already facing challenges. Lagos is projecting an increase in peak electricity demand of 400% by 2040.

In urban environments, grid upgrades will be particularly important. Grid congestion due to clustered residential load can be exacerbated by the combination of space heating and cooling demand, EV charging and distributed solar. For instance, researchers found that the local distribution system in California would need to upgrade five times more feeder lines than originally planned in order to accommodate EVs by 2030.

The grids of the future will need to support cities to adapt to new conditions, deal with greater complexity and manage significantly more actors and assets, all with diverse impacts on the system. Modernised and digitalised grids can also deliver significantly more efficient systems, at lower cost, with greater resilience and while achieving decarbonisation goals simultaneously. This requires national and local policy makers and utilities to act to deploy the technologies and establish the capabilities and functionalities necessary to support future power systems. Efficient and resilient power systems require urban planning to be aligned closely with power system planning.

Accelerating clean energy investment in Africa's cities

Africa accounts for around 20% of the world's population, but attracts less than 2% of its spending on clean energy. To achieve the region's 2030 energy development and climate goals requires energy investment to more than double from USD 90 billion currently, with around two-thirds going on clean energy. For example, energy efficiency spending needs to increase sevenfold by 2030, in areas such as green and efficient buildings and consumer appliances.

At the same time, the unprecedented expansion of Africa's cities is calling for massive investment in urban infrastructure. It has been estimated that African countries will need to invest about 5.5% of their annual GDP in their cities, approximately USD 140 billion per year. In particular, around 70 million new homes will need to be built by 2030, almost equivalent to a quarter of the current residential building stock in the entire continent. A substantial change in the transport infrastructure will be essential as well, as the demand for road mobility alone is expected to increase by two-thirds by the end of this decade in the entire continent.

Unlocking green investment in Africa's cities can result in a win-win situation. According to analysis conducted by the Coalition for Urban Transitions, the total benefits from delivering compact, connected and clean urban development across 35 major cities in Ethiopia, Kenya and South Africa are valued at USD 1.1 trillion to 2050 (up to 250% of their annual GDP).

To accelerate this process, the AfDB has recently announced that it will provide projected lending of around USD 2 billion in 2024 to cities and municipalities. In addition, the AfDB will direct its Urban and Municipal Development Fund (UMDF) to support cities with a budget of USD 50 million for the period 2023-2027, to be spent on urban project preparation, urban planning and municipal access to financial support ecosystems. The Africa Investment Forum (AIF) is now starting to prioritise bankable projects that can secure investment for cities. The UMDF is already supporting local governments in developing inclusive decision making processes and improving urban infrastructure, while addressing climate challenges.

Modernising power grids can contribute to doubling efficiency and accelerating decarbonisation

Ensuring that grids have sufficient capacity and flexibility to adapt to fluctuating electricity demand will facilitate decarbonisation on a massive scale, reduce emissions, improve air quality and see individual efficiency gains across the power system contribute to huge overall improvements in energy efficiency.

Urban travel accounts for 40% of the global carbon dioxide emissions from passenger transport and contributes significantly to urban air pollution. Electrified public transport in cities plays an important role in reducing congestion and greenhouse gas emissions. Analysis of 192 cities indicates that subways have contributed to halving city population-related CO_2 emissions from transport in those cities. The transition from internal combustion engine vehicles offers the prospect of achieving large efficiency gains as EVs are between three and five times more efficient. This switch is already contributing to significant emissions reductions. In Norway, for example, where EVs account for around 80% of new car sales, the positive effects are already being felt, with transport emissions falling by over 8% since 2014. This relies on a power grid that can manage significant flows of electricity on a bidirectional basis.

Buildings also offer great potential for efficiency gains, particularly for decarbonising heat. In the United Kingdom, emissions from gas boilers are around twice that of the entire fleet of gas power stations. The deployment of heat pumps to replace oil and gas boilers will drive electricity demand, but this is far outweighed by the savings in fossil fuels due to heat pumps' much greater efficiency, with those currently available on the market three to five times more energy efficient than natural gas boilers. The United States which has a high urban share of the population at around 80%, has adopted a roadmap for the nationwide adoption of efficient grid-interactive buildings (EGIBs), that is energy-efficient buildings with high-quality building envelopes and grid-connected smart technologies that leverage distributed energy resources to optimise energy use and energy flexibility. This could lead to energy savings from homes and buildings in predominantly urban areas in the range of 164-401 TWh per year and peak demand savings ranging between 42 GW and 116 GW, depending on the efficient and grid-interactive solutions implemented.

Grid digitalisation by upgrading with new intelligent and energy-efficient technologies has the potential to bring significant benefits, such as improved visibility of distributed energy resources for power system operators, co-ordinated control and loss reduction. This is particularly valuable in EMDEs that are experiencing high levels of transmission and distribution system losses, but is central to achieving potential energy efficiency gains in all settings. A recent study of the potential for digitalisation of the power sector found that by 2050, based on electrification across all sectors, while electricity consumption would rise by up to 20%, deploying cross-sectoral digitalisation would contribute to a 30% efficiency gain per year. A modern digitally enabled power system will be essential to achieve these efficiency gains and to contribute to the doubling of the annual improvement in global average energy efficiency. It can only be enabled by concerted action by national and subnational governments, regulators, utilities, communities and individuals.

In this context, the Italian government is playing a transformative and far-sighted role in accelerating clean energy transitions through its support of the IEA Digital Demand-Driven Electricity Networks (3DEN) initiative.

3DEN is developing analysis and guidance to help inform policy making in EMDEs and beyond on opportunities to scale up investment in smart power infrastructure, ensuring the benefits associated with digital investment are widely shared. At the same time, the IEA is convening a series of high-level and peer-to-peer exchange opportunities and supporting the creation of a community of practice around these topics. The uniqueness of the 3DEN approach lies in strongly linking policy guidance with implementation and the wide dissemination of findings. The IEA is working with the Italian Ministry of Environment and Energy Transitions (MASE) and the United Nations Environment Programme (UNEP) to support the implementation of pilot projects on how digitalisation can contribute to flexible and resilient energy systems and to disseminate the results.

Chapter 2: Cities and grids on a heating planet

Key takeaways

- Continuous record-breaking heat events together with more frequent storms are placing strain on people, cities and grids, driving the uptake of cooling appliances and challenging system reliability. China recorded a 70% year-on-year increase in air conditioner sales in 2023. Electricity demand for cooling in Africa could increase 400% this decade. Grids in cities are on the frontline of these challenges.
- Global final energy consumption is undergoing a shift towards electrification, with a remarkable rise from a 20% share to more than 40% in 2050 on the basis of announced government pledges, even surpassing 50% on a path consistent with net zero. This shift is driving a significant increase in electricity demand, particularly in urban areas, where studies suggest a potential tripling of peak electricity demand by 2030.
- To meet these challenges and ensure security of supply, it will be necessary to expand and reinforce grids, providing access for those currently underserved, and by 2050 to unlock more than four times the amount of new flexibility sources than exist today to manage peak demand and ensure continued affordability for consumers.

Impacts of a changing climate and energy system

Urban areas are seeing changes in peak demand

The ongoing electrification of end-use sectors is poised to substantially increase the share of electricity in global final energy consumption. Projections from the latest IEA World Energy Outlook indicate a remarkable shift, with the share of electricity expected to rise from its current level of 20% to 41% in the APS and surpassing 50% by 2050 in the NZE Scenario.

Power grids in many countries have been pushed to their operating limits in recent years due to climate change-related challenges, and increasingly beyond their limits, leading to a loss of supply due to events such as storms, as experienced in the United States, Europe and Japan. Furthermore, the power sector faces disruptions due to extreme temperatures, intensifying concerns, particularly in regions where electricity demand becomes more sensitive to rapid increases in the call for heating and cooling, primarily met by electricity. Urban areas are at the nexus of these grid-related challenges, with around 70% of cities already experiencing negative impacts. Some studies have estimated a tripling of peak electricity demand in cities by 2030, especially if the decarbonisation of heat and transport occurs rapidly before grids adapt to the increased demands. While cities emerge as critical nodes where the adaptation needs of grids become significant (particularly at the lower-voltage distribution levels), they are also increasingly focal points in providing flexibility.

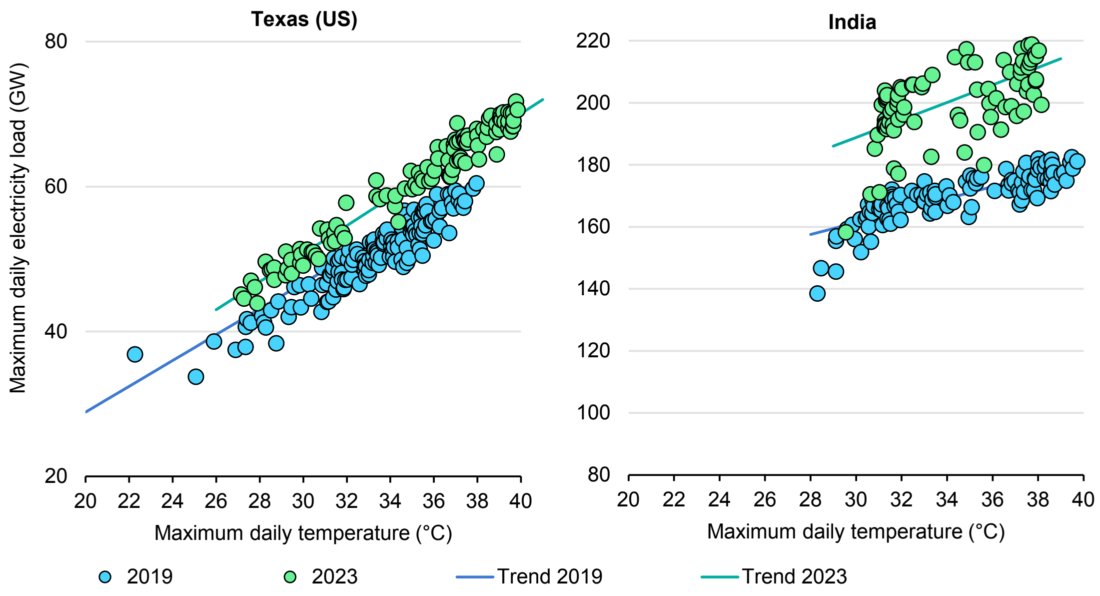
Some cities that previously experienced a single period of peak electricity demand are now seeing a second peak period emerging. In cooler climates, the decarbonisation of heating is driving electricity demand in winter periods and causing higher peaks during cold spells. In the United States, peak demand was historically experienced during the summer, but many states are projected to become winter peaking systems. In February 2021, Texas was hit by a record-setting winter storm, which resulted in power outages for more than 4.5 million homes and disruption of the public water and heating systems. It impacted almost 15 million people across the state and is considered the costliest winter storm on record at over USD 20 billion. At the same time, as global average temperatures continue to rise, there is additional growth in demand for cooling during persistent heatwaves.

More extreme and frequent heatwaves accelerate the need for cooling

Climate change is exacerbating extreme weather across the planet. Record-breaking heatwaves, storms, floods, droughts and wildfires are all becoming more frequent and more intense, as are their impacts on power supply reliability. 2023 was the hottest year on record, with summer temperatures exceeding 50°C in the United States, the Middle East and China. Europe is now the fastest warming continent on Earth.

Online sales data from China in June 2023 revealed an almost 70% year-on-year increase in air conditioner sales. There are continuing signs that temperatures are on an upward trend. 2024 has already experienced the warmest January and February on record, marking nine consecutive months of record highs. The global increase in more frequent extreme temperatures is thus leading to rising global cooling needs.

Daily electricity load versus temperature, May to September 2019 versus 2023

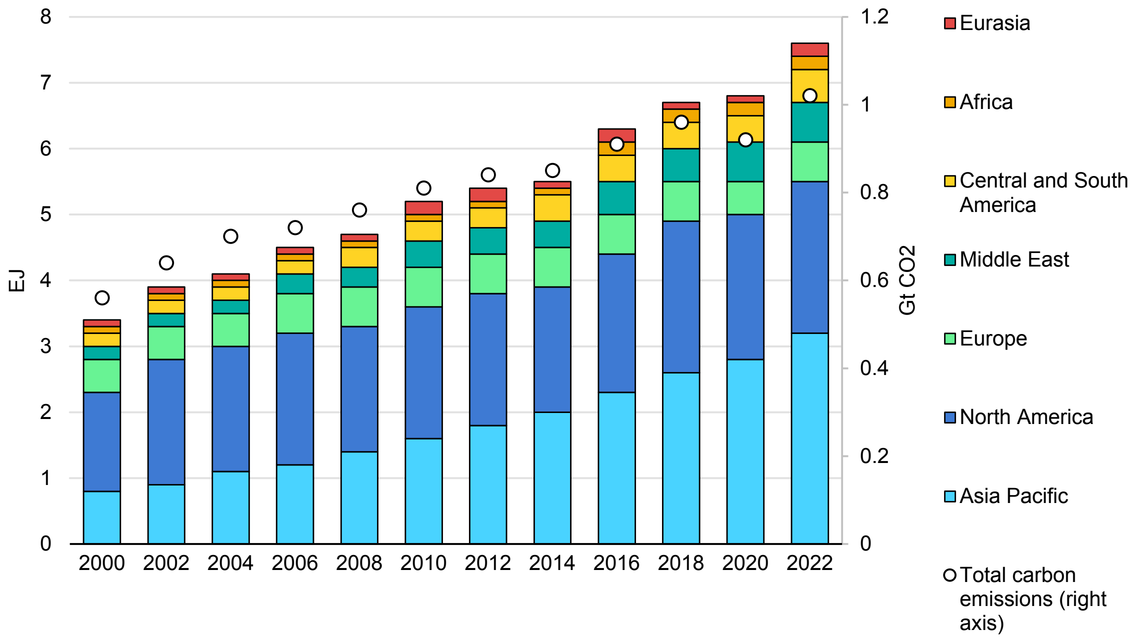


Sources: IEA (2023), Weather for Energy Tracker; IEA (2023), Real-Time Electricity Tracker.

In the period 2000-2022, global final energy demand for space cooling rose at an average of about 4% per year, twice as quickly as for water heating. Furthermore, the number of residential air-conditioning units has tripled since 2000, reaching more than 1.5 billion in 2022.

Extreme heat significantly boosts the purchase of air conditioners, leading to higher electricity demand. In the hottest regions, the capacity of the grid needs to cover a doubling of electricity demand compared with milder months and cooling can account for over 70% of peak electricity demand. In India, where air conditioner ownership is currently low, every 1°C increase in the average daily temperature above 24°C drives an increase in electricity demand of about 2%, whereas in Texas where ownership is much higher, it drives a 4% increase. Indeed, an assessment of 13 cities across different countries suggests that each degree of temperature increase causes an average increase in peak electricity demand of almost 4%.

Final energy consumption and carbon emissions from space cooling by region, 2000-2022



Source: IEA (2023), Tracking Clean Energy Progress on Space Cooling.

Lack of access to appropriate cooling technologies can have severe health impacts. In Bangkok, for instance, heat stroke and food poisoning resulting from bacteria growth in unrefrigerated food have been seen to increase during heat waves. Vulnerable communities are often among the most affected by the heat. For example, in the United States heat-related deaths are higher in disadvantaged communities, revealing stark inequalities associated with rising temperatures in urban areas. Similarly in Buenos Aires, both the income and health impacts of extreme heat are expected to primarily affect its low-income residents.

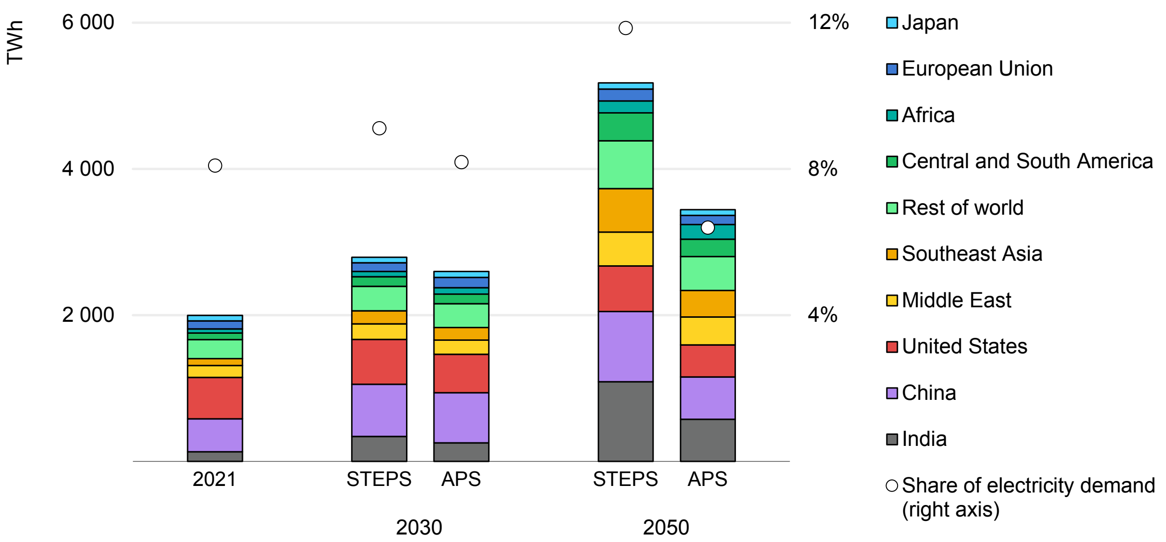
Between May and September 2023 power grids saw record levels of peak electricity demand in more than 10 countries around the world, including China, the United States, Canada, India, Brazil, Thailand, Malaysia and Colombia – together accounting for more than 60% of total global electricity demand. In some regions, such as in the Middle East and parts of the United States, space cooling can represent more than 70% of peak residential demand on hot days.

In the United States it is estimated that for each degree Celsius of warming at the city scale, the energy used per square foot to cool urban buildings will increase on average by nearly 14%. Researchers found that more extreme heat and larger populations will have dramatic effects on energy use in US cities by 2050, pushing up the amount of electricity used to cool urban buildings per unit of floor area by at least 20% in some parts of the country.

Looking ahead, energy demand for fans and air conditioning in Africa is expected to quadruple this decade as urbanisation and climate change rapidly increase the need for cooling. In Morocco, the penetration of cooling devices in the residential sector is expected to grow from just over 9% in 2015 to nearly 50% by 2030.

According to the latest IEA World Energy Outlook 2023, based on stated policies, peak electricity demand in India rises fourfold by 2050 from the 2022 level, more than half of this driven by cooling demand. This surge in demand has the potential to strain power grids, increasing the risk of energy shortages. In April 2022, India faced its worst electricity shortage since 2016 in the middle of an extreme heatwave. Electricity supply fell short of demand by around 1.9 billion units, or 1.6%. Some regions had to schedule power cuts in order to manage the surging power demand.

Space cooling demand by region in the Stated Policies Scenario and Announced Pledges Scenario, 2021-2050



Source: IEA (2022), World Energy Outlook 2022.

While more frequent extreme temperatures are affecting both rural and urban areas, cities heat up disproportionally when compared to greener countryside locations. With dense concentrations of buildings and paved surfaces absorbing and amplifying heat – especially in areas with little tree cover or green space – cities are increasingly becoming heat islands.

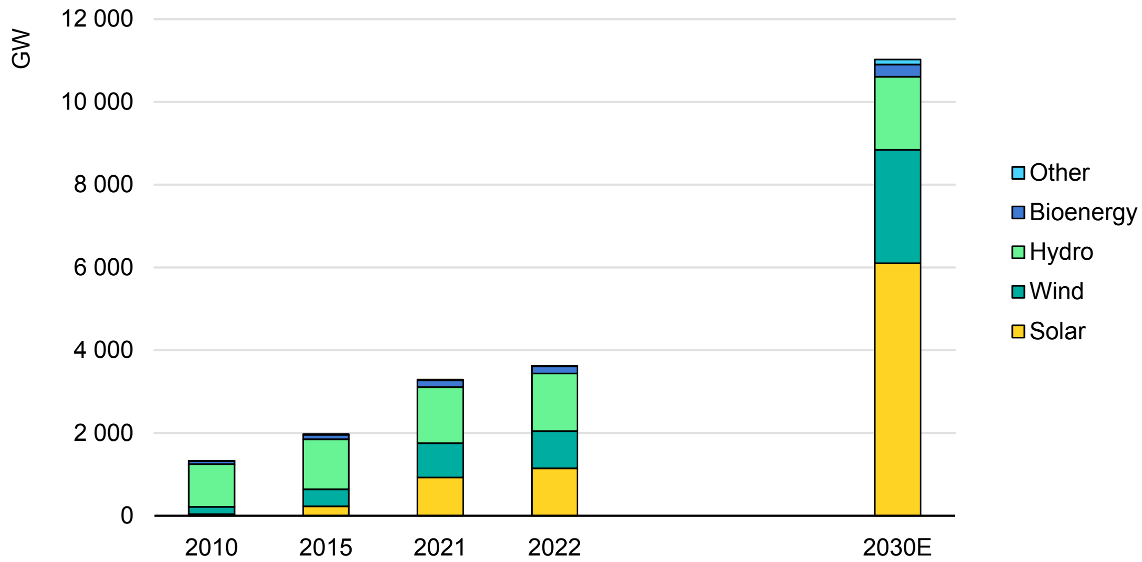
By 2050, three times as many cities as today are expected to experience average summertime highs of 35°C and many of them could experience substantial warming of up to 4°C before the end of the century. The number of extreme heat days by 2050 is expected to increase 15-fold in Freetown, Sierra Leone, compared to 2020, and fivefold in Miami, United States, where a loss of labour productivity of an additional USD 10 billion could be incurred.

At the international level, many countries are already paying attention to heat-related risks. At COP28 over 60 nations signed a Global Pledge for Cooling, committing to take action across cooling sectors and applications in the context of achieving net zero emissions by 2050 by means of deploying passive cooling, increased efficiency and low global warming potential refrigerants.

Grids need to expand to enable decarbonisation

At the same time that grids are under pressure from rapidly growing demand for cooling in cities, they are also required to handle the surge in renewable generation resulting from the energy transition. As international agreements such as the historic UAE Consensus at COP28 signal the beginning of the end of the fossil fuel era, they also signal a need for global ambition for concrete measures to accelerate the energy transition. This means a dramatic increase in renewable energy development, with significant implications for electricity grids.

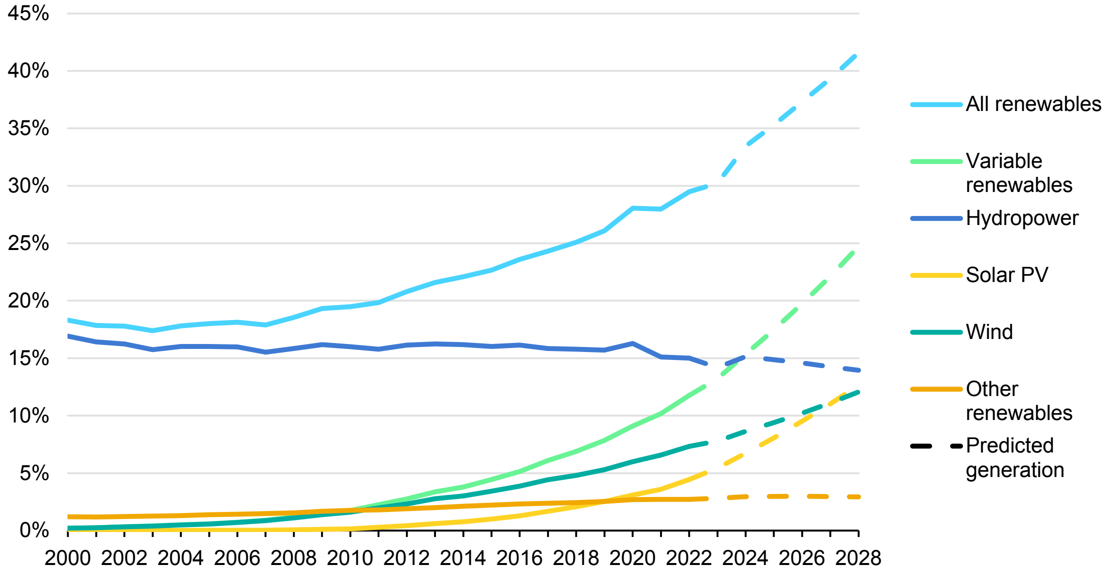
Global installed renewable capacity by technology in the NZE Scenario, 2010-2030



Source: IEA (2023), World Energy Outlook 2023.

In recent analysis by the IEA, the potential growth in renewable electricity generation projected out to 2028 demonstrates that new renewable capacity exceeds the expected global growth in demand. This outpacing indicates a slow decline in fossil fuel-based generation. In 2028 renewables would account for 42% of global electricity generation, with wind and solar PV making up 25%.

Electricity generation by technology, 2000-2028



Source: IEA (2023), Renewables 2023.

In parallel with increasing shares of renewables, cross-sectoral decarbonisation continues through electrification. This evolving landscape of increasing electricity demand and renewables requires substantial grid upgrades to manage peak demand, not least in cities where the growing need for services, such as cooling and EV charging, coupled with distributed generation are having a particular impact. Achieving national goals could require adding or refurbishing over 80 million kilometres of grids by 2040 globally, the equivalent of the entire existing global grid.

Grids need to expand for universal electricity access

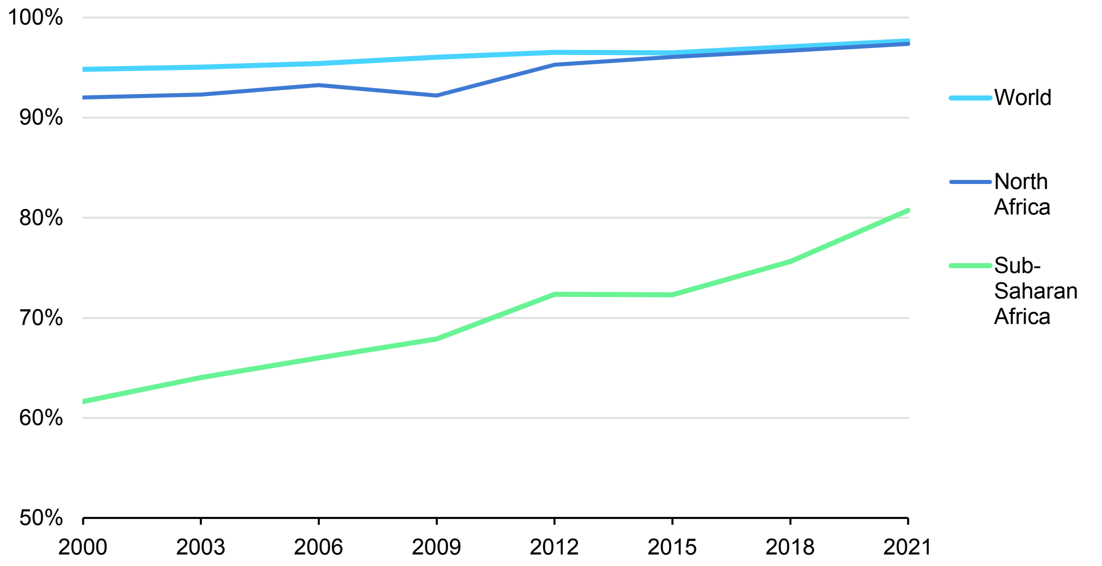
Currently, sub-Saharan Africa accounts for 80% of the global population lacking access to electricity. This issue not only affects rural areas. To achieve universal access to reliable electricity in Africa by 2030, 20 million people living in urban areas need to gain access each year starting from 2022. Bringing access to modern electricity could require an annual investment of USD 25 billion, of which USD 22 billion would be needed for power grids (mainly distribution networks).

While mini-grids are an important vehicle for providing electricity access and improving resilience among rural communities, grid-based electricity service plays a major role in urban areas. For example, in Kampala, Uganda, the grid is the main source of lighting for two-thirds of the city population.

Reinforcing and expanding the grid at the same pace of urbanisation will be a unique challenge for utilities, national governments and municipalities due to obstacles such as insufficient access to finance, regulatory barriers, and political instabilities in some areas. For instance, in sub-Saharan Africa, the cost of capital can be several times higher than in advanced economies.

In some countries, steps are being taken to expand and reinforce the power grid to improve access in cities. In Mauritania, grid expansion plans between the major cities of Nouakchott and Nouadhibou were announced in early 2023. Upgrading the circuit capacity is likely to provide access to 12 000 additional customers. Mali is about to receive more than USD 200 million to upgrade the electricity grid in certain areas, including Bamako and its surroundings. The investment is expected to reduce the city's reliance on small and polluting rental power plants and decrease transmission grid losses (from 8.5% to 4.5% by 2028). Also, expansion in secondary cities will provide electricity to about 400 000 people and more than 1 000 public facilities.

Share of urban population with access to electricity in selected regions, 2000-2021



Source: The World Bank (2021), Access to electricity (percentage of urban population).

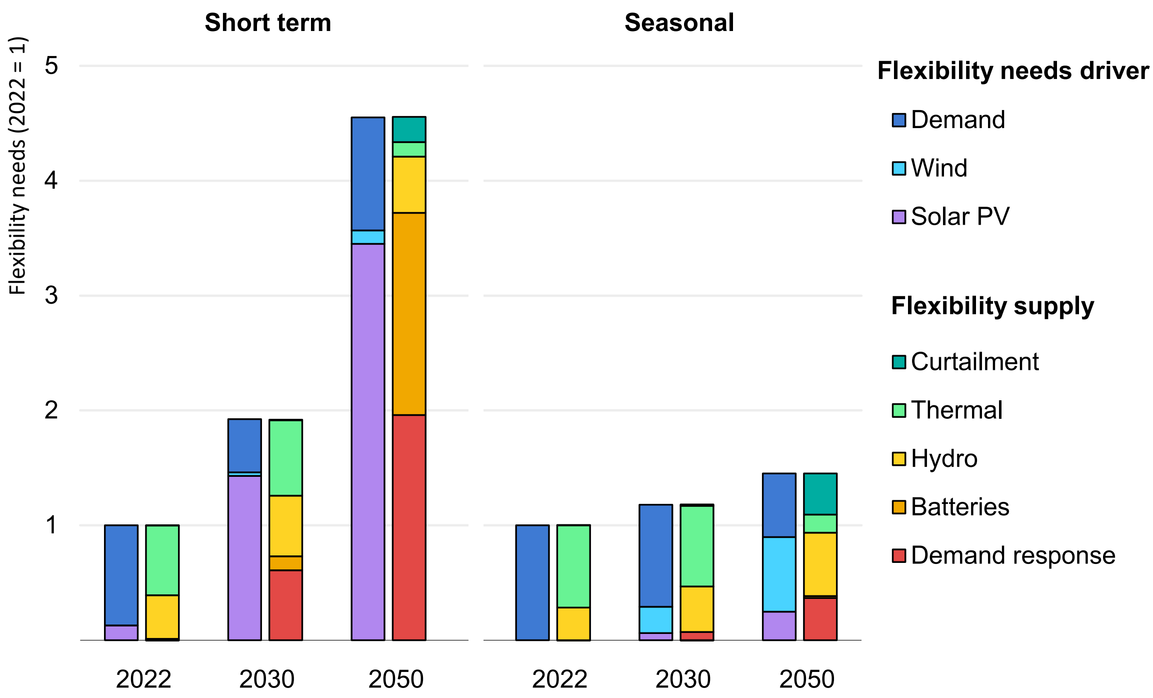
Activating flexibility in cities

Future grids need new sources of flexibility

At present, dispatchable thermal power plants and pumped hydropower, currently the largest source of renewable energy, provide most of the flexibility required across all timescales. Flexibility, in the most basic terms, is the ability to respond in a timely manner to variations in electricity supply and demand. New sources of flexibility need to come online to maintain grid reliability as thermal power plant production declines as they are phased out in the coming decades.

The main sources will particularly be batteries and other storage, and demand response. Demand response refers to balancing demand and supply on power grids by encouraging customers to shift electricity demand to times when electricity is more plentiful or other demand is lower. Electricity storage and demand response are identified as critical services to power systems. Batteries, both distributed (behind-the-meter) and larger grid-scale installations, can provide valuable system flexibility, especially in systems with high shares of PV and peak demand in evening hours, by absorbing excess generation during the day and releasing it during the evening. Curtailment, the switching off of renewables to prevent grid exports, is a further source of flexibility, albeit an unwelcome one.

Global power system flexibility needs and supply in the Announced Pledges Scenario



Notes: Short-term and seasonal flexibility needs are computed for 2030 and 2050 taking into account changes in electricity supply and demand and weather variability over 30 historical years. Demand response includes the flexible operation of electrolysers.
Source: IEA (2023), World Energy Outlook 2023.

While curtailment is rising overall in an increasing number of countries, the percentage of wind and solar PV generation going unused remains relatively low. Typically, curtailment rates range from 1.5% to 4% in most major renewable energy markets, although they tend to be higher in regions that need substantial grid infrastructure expansion to connect renewable energy installations to consumption centres. Failure to invest in infrastructure can contribute to increased curtailment, with further financial consequences.

In the United Kingdom, the cost of wind curtailment hit a record high of more than GBP 500 million in 2021, while in 2022 consumers paid GBP 215 million to turn wind farms off. If this electricity could have been stored and dispatched when needed, then the cost of almost GBP 720 million to buy gas-fired power to make up the difference in supply and demand could have been avoided, with the additional GHG emissions also avoided. National Grid estimated that curtailment due to grid constraints could increase fourfold, with costs forecast to reach GBP 2.5 billion a year by the end of this decade. IEA analysis suggests that digitally enabled demand response could reduce the curtailment of variable renewable energy systems by more than 25% by 2030, increasing system efficiency and reducing costs for customers.

The progressive electrification of end uses offers new opportunities for load shifting in cities, with EVs and electric heating/cooling playing a major part. To make progress towards achieving a net zero energy system, the contribution needed from demand response would need to rise to as much as 500 GW in 2030, around a tenfold increase from 2020 levels.

EVs are expected to make up nearly 40% of global new car sales by as early as 2030 on the basis of announced policies. Integrating EVs into the grid requires careful balancing with other distributed energy resources such as heat pumps, air conditioning, battery storage and rooftop solar. It is important to note that while urban demand response can offer significant system- and cost-related benefits, it typically requires upfront investment to become available in the first place. Consequently, local grid upgrades become imperative, especially in urban environments where residential charging clusters or space conditioning can contribute to grid congestion during peak periods. A cost-benefit analysis on EV deployment in New York indicates potential challenges, with around USD 2.3 billion more required in grid upgrades unless peak demand is managed efficiently.

In the US city of Palo Alto, 80% of all vehicles need to be EVs by 2030 to meet its Sustainability and Climate Action Plan goals, equivalent to around 100 000 vehicles. A recent impact study found that without improvements to its grid infrastructure, more than 95% of the city's low-voltage transformers would be overloaded. Similar challenges are faced in New York, where summer peak load leaves large urban areas with insufficient capacity to manage high EV demand. While not exclusive, many of the locations with low grid capacity are also associated with disadvantaged communities.

However, despite these challenges, smart technologies enabling demand response are capable of providing part of the solution to managing peak demand periods, with their potential to reduce grid stress often being demonstrated in cities first. There are plans to expand the use of virtual power plants (VPPs) in which digitally enabled technologies act as management systems to operate many aggregated distributed systems as a single unit, to maximise their assets.

In Australia, the University of Queensland installed the state's largest behind-the-meter battery, with 1.1 MW of capacity and 2.15 MWh of storage. By joining Enel X's Virtual Power Plant, the university earned more than USD 47 000 in the first quarter of operations, while supporting renewable integration and grid balancing.

In the city of Huzhou, China, an air conditioner demand-side management pilot was the first of its kind aimed at the residential sector. Wi-Fi-connected air conditioners were enabled, allowing users to adjust their settings via a smartphone app in response to prompts from the system operator. The Chinese government has developed demand-side management plans to cover at least 5% of the country's electricity consumption by 2025, mostly from industry and cooling in public sector buildings. The city of Pinghu is developing an air-conditioning flexible regulation and control system, with a controllable load of 15 MW to allow flexible control of air conditioning. By modifying the local central air-conditioning temperature regulation settings, the city can benefit from an additional 15 MW of flexible load.

There is also the potential to boost efficacy by blending digital innovation with more traditional measures. A renovation project in San Diego, California, combined energy efficiency measures to reduce demand in the long-term and help to alleviate peaks, together with a VPP consisting of batteries and solar PV. The project achieved a 30% reduction in the total energy demand and a notable reduction in peak demand.

The benefits of flexibility are multiple

New infrastructure is clearly necessary to respond to the growing peak load and ensure that grids can manage greater amounts of electricity. In the European Union cross-border interconnections between member states' grids need to double due to electricity demand rising by as much as 60% by 2030. In the United States it is estimated that 10% of all infrastructure investment costs are incurred to manage 1% of the annual demand. However, deploying demand flexibility and energy efficiency, if properly leveraged, could reduce some of the need for costly grid upgrades, with the potential to save USD 2-3 for each USD 1 spent on peak demand reduction.

Flexibility-related benefits extend beyond immediate cost savings, and offer the potential for continued economic benefit into the coming decades. In the United Kingdom recent studies have demonstrated that maximising energy system flexibility has significant benefits. By 2030 system flexibility from heating and transport could reduce renewable curtailment annually by around 30 TWh, avoid the need to increase distribution system grid capacity by 25%, and save about GBP 5 billion each year. Examples from the Centre for Net Zero underscore the potential for cities to play a pivotal role in managing peak demand, aligning with broader user-centred approaches. In Paris, in an ambitious scenario where 80% of vehicles are EVs by 2030 and 10% of buildings are equipped with solar PVs and battery storage, 20% of heating and cooling peak demand as well as 40% of EV charging demand could be shifted to off-peak hours of the day, with significant benefits to the system.

Status of demand-side flexibility options

	Sub-hourly	Daily	Weekly
Smart EV charging	🟡	🟢	🟡
Electric water heaters	🟡	🟢	🔴
Heat pumps	🟡	🟢	🔴
Data centres	🟡	🔴	🔴

Note: Ability to provide flexibility: 🟢 = yes; 🟡 = yes, under conditions/not mature; 🔴 = no.
Source: Artelys (2023), Power System Flexibility in the Penta region, as modified by the IEA.

There is significant potential to deploy flexibility services in the form of demand response to offset some of the costs of increasing power generation capacity. Flexible assets can react to signals in the market to reduce or shift demand for a period of time until the load on the grid reduces. Alternatively, grid conditions may be such that there is an excess of renewable energy available, and grid operators may encourage customers to increase their demand to absorb abundant clean electricity to reduce curtailing supply. By accessing a large, aggregated volume of customers to reduce demand and ensure grid conditions are met, more efficient grid expansion could become possible. One estimate is that leveraging residential demand flexibility in the United States could avoid annual grid investment of USD 9 billion, representing more than 10% of the forecast total national expenditure on grids.

There is also an energy security consideration during periods of anticipated high demand. In New York, the system operator offers several demand response programmes designed to reduce load on the system during grid emergencies or when shortages are anticipated. The Emergency Demand Response Program offers the opportunity to earn up to USD 500/MWh for curtailing energy consumption, thus benefiting programme participants. As of July 2022, a total of 4 630 end-use locations were enrolled in one of the demand-response programmes, representing a total capacity of 1 234 MW of demand response.

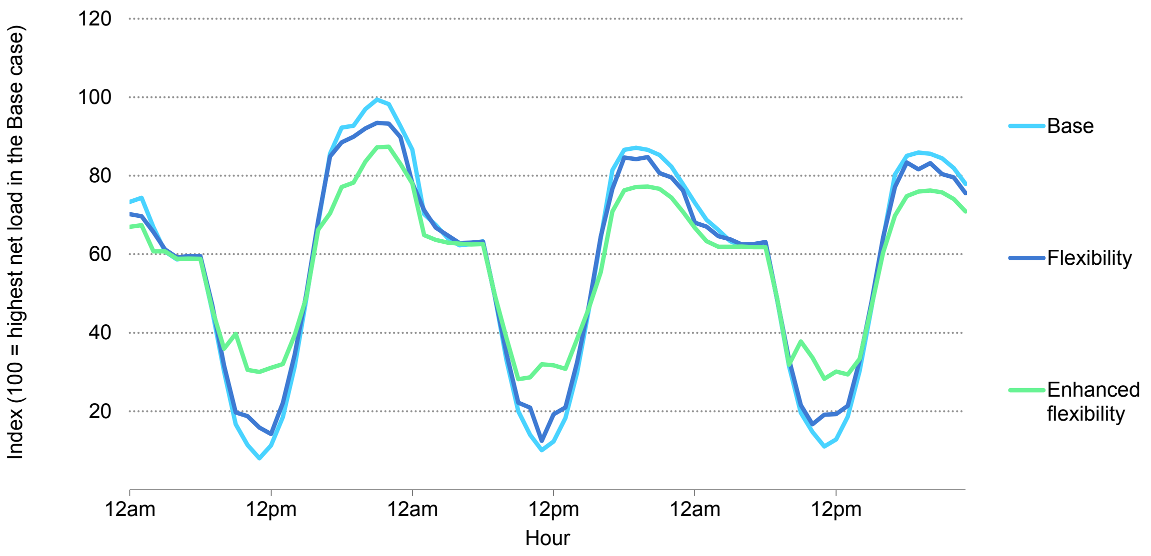
Digital technologies and analytics enable flexible urban solutions

Tapping into the latent demand-side flexibility and energy efficiency potential requires a high level of digital integration to process large data flows in real time, which is not possible using traditional computational methods. The emergence of machine learning and artificial intelligent models may help unlock more rapid progress on efficiency by providing more granular information and timely processing of data. This could increase the visibility of information and maximise energy savings for individuals, enable businesses to manage operations more efficiently, provide system flexibility and improve predictions and forecasting for system operators. Cities are often the first to implement new digitally enabled systems and are poised to enable the development of smarter power systems.

Digital technologies play a pivotal role in the evolving energy landscape, and smarter power systems in particular. Smart charging (also known as responsive charging), electric heating, battery storage and demand response are crucial elements in meeting flexibility needs. For instance, smart charging of EVs and demand response in buildings and by urban and peri-urban industrial users could provide up to 35% of the short-duration flexibility needed to manage the variability of renewables.

Recent IEA analysis illustrates the impacts of flexible resources in India's future power system. By using digitalisation and flexible-load strategies for buildings appliances by 2030, the peak load (total load minus solar and wind generation) would be reduced approximately by around 13% compared to the base case in which appliances operate under a fixed pattern. Additionally, the flexible operation enabled by digital tools in this model decreases variable renewable energy (VRE) curtailment by around 78%. Reducing curtailment of renewables will be important to maximise the potential of assets as India strives to achieve 100 GW of installed capacity in the same timeframe.

India net load curve of sample days in summer in the Announced Pledges Scenario, 2030



Notes: Net load refers to total load minus wind and solar PV generation. In the Base case electrical appliances operate under a fixed operation pattern. In the Flexibility case digital technologies determine the operational patterns of electrical appliances, considering market conditions (one-hour flexibility for heating and cooling assumed). In the Enhanced flexibility case digital technologies enable electrical appliances to have more extended and larger-scale demand shifting than in the flexibility case (five-hour flexibility for heating and cooling assumed).

Source: IEA (2023), Using Digitalisation in Emerging Markets and Developing Economies to Enable Demand Response in Buildings.

Half of the global potential for demand response is anticipated to come from buildings, particularly those adopting zero-carbon practices that rely on digitalisation and automation. Therefore, accelerating the deployment of grid-responsive appliances is paramount to untapping demand response. As a part of the IEA Technology Collaboration Programme Energy Efficient End-use Equipment (4E), the Efficient, Demand Flexible Networked Appliances Annex (EDNA) is providing analysis and policy guidance to members and other governments aimed at improving the energy efficiency and the flexibility readiness of connected devices. For example, heat pumps equipped with smart technology play an important role in more than doubling EU demand-side flexibility by 2030, their share of total flexibility resources jumping from 8% in 2021 to around 12% in 2030.

Leveraging distributed energy resources and microgrids in cities

There are many potential benefits to leveraging distributed energy resources such as rooftop solar PV, battery storage and other grid-connected assets. In the case of outages, one way to provide backup power is through distributed energy resources. City governments can consider adding distributed energy resources such as batteries to municipal buildings as a way of ensuring continuity of government function during power outage. Incentives to encourage distributed energy resources in other locations can also promote wider community resilience, especially for buildings providing critical services, such as hospitals. Santa Barbara has installed a battery energy storage system at its water treatment plant that is projected to alleviate pressure on the power grid and save the city USD 700 000 in energy costs over the next 20 years. In the US, AVA Community Energy serves more than 14 cities, providing access to distributed solar PV systems and batteries at no upfront costs and reinvesting earnings to create local clean energy jobs and projects.

Microgrids can help improve resilience and provide power during outages. Los Angeles Department of Water and Power established a community-oriented microgrid facility at one of its fire stations. The project consists of a rooftop solar system combined with a 40 kWh battery energy storage system. In the event of a grid outage, the facility can operate independently using the microgrid system. Beyond applications in urban areas, microgrids are an important vehicle towards increasing access and improving resilience of communities as was demonstrated in August 2023 in Kenya, where despite a 24-hour power outage across the whole country, the village of Kitonyoni managed to keep the lights on thanks to a solar mini-grid.

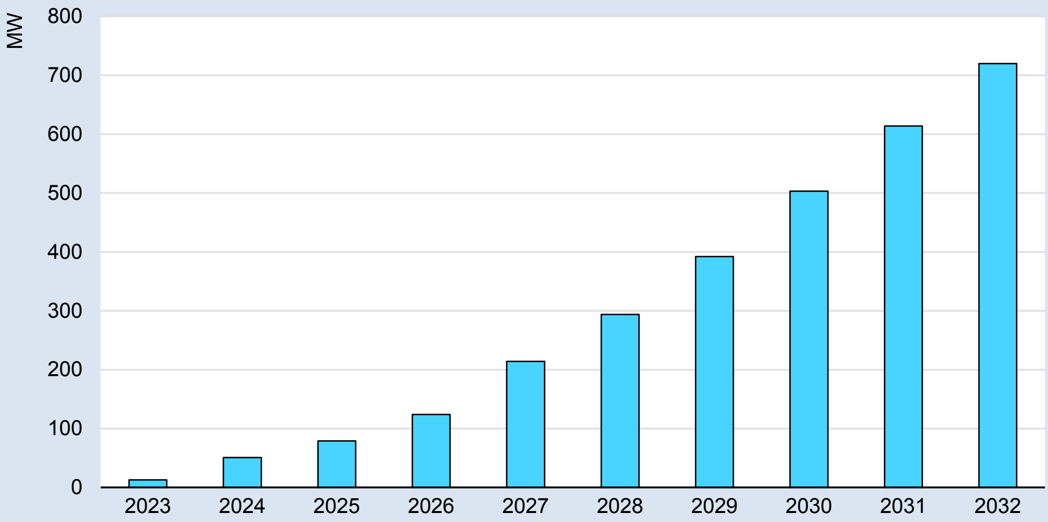
Rome demonstrates urban flexibility for higher renewables integration

Effective system planning is thus crucial for well-integrated wind and solar PV growth and should encompass considerations such as the regional distribution of generation and the development of policies to encourage system flexibility. Additionally, power markets can evolve beyond the traditional design and regulation models to create a more accommodating environment for higher renewable energy integration, as demonstrated by the Romeflex project. In 2021 ARERA, the Italian Regulatory Authority for Energy, Networks and Environment, set rules to allow distribution system operators (DSOs) to experiment with projects for local flexibility markets, aimed at providing local ancillary services (e.g. congestion resolution, voltage regulation) to the distribution network. Among the DSO projects approved by ARERA, Rome's DSO Areti started to implement the Romeflex pilot project, while Italy's largest DSO, e-distribuzione, awarded its first round of tendering under its EDGE project at the end of 2023, with additional rounds planned for 2024. For this pilot project, e-distribuzione identified specific areas in Benevento, Cuneo, Foggia and Venezia provinces, characterised by the presence of users eligible for providing local flexibility services and thousands of prosumers connected to the medium- and low-voltage networks

Flexibility needs and solutions in Rome

A study carried out by the DSO Areti in the city of Rome estimated that peak load could reach 3 300 MW by 2032, with periods of peak electricity demand above 2 500 MW occurring for about 1 000 hours per year. Deploying demand-side flexibility measures during peak hours could help reduce peak demand and contribute to slowing the need for grid expansion by leveraging up to 720 MW of distributed resources by 2032, consisting of battery storage, EVs, and heating and cooling systems.

Estimated flexibility potential in Rome, Italy, 2023-2032



Source: IEA analysis based on data by Areti.

To explore the potential flexibility available, in partnership with the electricity market operator GME, Areti is implementing the Romeflex pilot project to test a local flexibility market that would allow 1.7 million customers to modulate their energy consumption and production in return for remuneration based on the capacity they make available and on the actual service provided, thus offering flexibility services to the electricity grid.

Under Romeflex, customers ranging from 3 kW residential houses to industrial sites can individually or in aggregated form participate in auctions targeted at specific urban zones and for an identified period. The first auction closed in November 2023 and saw wide participation among aggregators and prosumers, resulting in 3 MW of flexibility mobilised for the period February-April 2024.

The open digital platforms used to procure flexibility in Romeflex were initially tested in a European pilot project (PLATONE). They have been scaled up and integrated into the grid control systems and the market platform of Italy's national energy market operator, indicating their potential for replication in other energy markets.

Chapter 3: Community at the heart of the city

Key takeaways

- Community-focused initiatives can improve access to clean energy technologies, reduce costs and relieve strain on power systems. In the United Kingdom more than 200 000 people are engaged in projects and have contributed to reduced bills for participants worth over GBP 3 million.
- Interest in community and local energy projects is growing, with some countries providing significant financial and technical support. In the European Union at least 2 million people are engaged in more than 7 700 community projects.
- Implementation of community projects is on the rise, creating opportunities to learn and build on emerging best practices. Local solar development in the United States can create five more jobs on a per-megawatt basis than utility-scale solar generation.

Community energy projects

Community-focused initiatives can offer multiple benefits

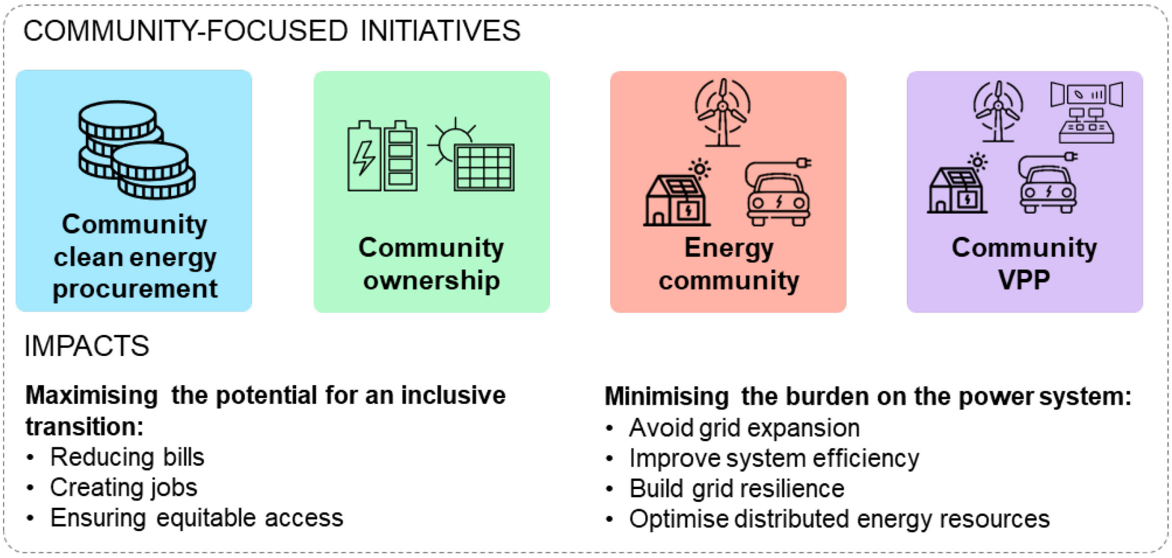
Increasingly, community-centred approaches are being developed and implemented to accelerate the transition to clean and efficient energy systems, for example, community procurement, people-led renovation, community microgrids, energy communities, community virtual power plants, and positive energy districts. Community energy projects can be framed as part of a broader effort to promote environmental sustainability and social inclusion, by reducing reliance on fossil fuels and promoting clean energy technologies. At the same time, these initiatives enable individuals and communities to take an active part in clean energy transitions and can also build trust, enhance public acceptance, and support affordability, equity and fairness.

Moreover, from a city and power system planning perspective, community or neighbourhood-focused approaches can offer economies of scale via aggregation and enable more systematic approaches to achieving efficient and flexible electricity demand. Digital technologies such as smart meters, management systems, trading platforms and systems to collect and share data are also enablers opening up new opportunities. Digital platforms and tools are making it easier to set up co-operatives, engage stakeholders, make investments and exchange electricity.

There are many examples of initiatives worldwide where communities are taking ownership of their energy resources, managing them collectively, and benefiting economically and socially. These global movements of community-owned and managed renewable energy projects demonstrate that they not only contribute to the fight against climate change, but also address social and economic challenges within communities. Specific awareness campaigns and training on community energy management, including for energy community managers, have been established in Canada, France, Spain and the United Kingdom, as well as by ICLEI in Europe.

Community-centred energy projects are also effective vehicles for more inclusive, equitable and resilient energy systems. They are showing clear benefits across the globe by deploying renewable technologies as indicated below, by improving efficiency, supporting reliable power supply, reducing bills and generating local jobs.

Community-focused initiatives and their impacts



IEA. CC BY 4.0.

Interest in community approaches is growing

An increasing number of countries are allocating significant funds to support community-based clean energy projects. The Italian National Recovery and Resilience Plan has allocated EUR 2.2 billion to support energy communities and self-consumption, while the USD 370 billion US Inflation Reduction Act of 2022 offers additional financial incentives for community-based clean energy projects. In January 2023 the US Department of Energy launched a USD 50 million programme to help communities meet their clean energy goals. The programme connects local governments, electric utilities and community-based groups, and provides tools, technical partnerships and peer-to-peer learning. The Australian government launched the AUD 40 million (Australian dollars)[1] Energy Efficiency Communities Programme in 2020, offering grants to small businesses and community organisations to undertake collective efficiency and renewable projects. In Colombia, Las Comunidades Energéticas (the Energy Communities) initiative was launched with the objective of promoting collective actions to improve access to clean and affordable energy for vulnerable communities as well as to decentralise and democratise energy. These communities generate, and efficiently use, clean energy and distributed energy resources. The number of registered communities in Colombia amounts to almost 13 000 as of February 2024.

Levels of interest in participating in energy communities is increasing as new opportunities are created and as awareness rises about the benefits that can be accessed. At least 2 million people in the European Union are involved in more than 7 700 energy community projects. In Australia community energy groups now have more than 44 000 members – a doubling compared to 2015. In the United Kingdom approximately 220 000 people are engaged in community energy projects.

Examples of community-focused approaches for inclusive energy transitions in cities

Local procurement initiatives advance clean energy

Community-led or community-centred bulk clean energy procurement, when effectively planned, is an advanced way of integrating diversity, equity and justice into the community's energy transition, as well as improving the resilience of local energy systems. Community-centred inclusive procurement and ownership yield multiple benefits to the community, including strengthening clean energy investment in the area, enabling local vendors to provide better customised services to the community, creating local jobs, and improving the affordability of technologies and energy. In a pilot project in the Indian city of Lucknow, residents were able to sell their surplus rooftop electricity production to other prosumers and consumers through the use of a peer-to-peer (P2P) digital trading platform. This allowed for surplus production to be sold to peers at a price higher than the

[1] Exchange rate: 1 Australian Dollar (AUD) = EUR 0.61 = USD 0.66 (as of 04 April 2024).

regulated one and for consumers to benefit from local clean energy while also cutting their electricity bills, as the electricity price in the trial was 43% below the central market price.

Community-focused approaches can help reduce the cost of technologies and improve energy access. In the United Kingdom, Solar Together, a group-buying scheme for PV panels and battery storage, is helping bring down technology costs to improve affordability and access in co-operation with local councils. In the city of Liverpool, this approach reduced average installation costs by 26%. Other UK community energy projects targeted energy storage, new EV charge points and a mixture of solar, wind and hydro generation, producing over 500 GWh of electricity – enough electricity to satisfy the demand of almost 175 000 homes. They also resulted in GBP 3.35 million of savings on energy bills in 2021 – equivalent to the annual average energy bills of more than 2 500 households in that year – and created more than 180 new full time equivalent jobs.

In the United States, a recent study indicated that a community solar pilot project in Ohio could yield earnings of almost USD 2.5 billion, with local tax revenue of and around USD 410 million over its lifetime. Community solar subscribers in the US generally save 10-20% on their monthly energy costs, lowering the energy burden that many low-income households experience. In the United States, local solar development can create five more jobs on a per-megawatt basis than utility-scale solar generation. Integrating, optimising and growing local solar and power storage could create 1.4 million US jobs by 2050, increasing to 2 million if supported by clean electricity targets. Creative and conscious procurement, although not directly operated by the community itself, ensures more equitable energy transitions for local communities. These procurements are done by large buyers, mostly leveraging corporate renewable energy purchases to enhance local communities' engagement and benefits. For example, the Clean Energy Buyer Institute aims to support climate-resilient communities, focusing on communities of colour, rural communities, and coastal and island communities.

A local approach can deliver social benefits

Community-focused projects can also enhance access to energy and increase resilience. Peace Renewable Energy Credits (P-RECs) are an extension of Energy Attribute Certificates, which are an internationally traded virtual commodity representing 1 MWh of renewable energy generated to include environmental and social benefits from projects in fragile settings. Governments, utilities, companies and individuals can purchase credits to meet mandatory or voluntary sustainability goals. The funding stream can provide developers with an additional revenue stream, enabling access to term finance that may not otherwise be available. The major ICT company Microsoft secured two investments in the Democratic Republic of the Congo, the first in 2020 and the second in 2022. One of the funded projects installed night-time street lighting connected to the neighbourhood solar mini-grid, which enabled 70% of businesses to operate longer hours in the evening. Another expanded support on energy access, such as first-time electricity connections for the community and contributing a new 3.7 MW solar metro-grid to benefit almost 20 000 people.

Community microgrids can also enable prosumers to exchange and trade energy via P2P energy sharing. This sharing co-operation within communities minimises energy imports from other suppliers outside the community while also minimising the energy cost. The Community Microgrid Initiative in the United States aims to provide indefinite renewables-driven backup power to critical facilities. It focuses on enabling disadvantaged groups to meet emergency power and instant recovery needs, and even to build back better after disasters such as wildfires and heavy rain.

Also in the United States, the Valencia Gardens Energy Storage project was designed to support low-income and senior housing facilities consisting of around 260 units in San Francisco. It is expected to deliver multiple benefits such as reducing peak loads, enabling ancillary grid services, and enhancing grid resilience and security. Over 20 years, it is estimated that the project will save USD 1.3 million off electricity bills and achieve USD 4.6 million in economic stimulation.

In Adjuntas, Puerto Rico, some residents were without power supply for almost a year after Hurricane Maria in 2017. A new co-operatively owned solar microgrid project harnessing 700 solar panels in the town centre and a 187 kW battery storage system will enable 14 local businesses to produce their own electricity and to run for about 10 days, even when disconnected with the main grid. In Bawley Point and Kioloa, two small, remote coastal towns in Australia prone to bushfires and strong storms, are in the process of developing self-contained microgrids where approximately 100 homes would purchase rooftop solar and/or a battery with subsidies from the USD 5.3 million project.

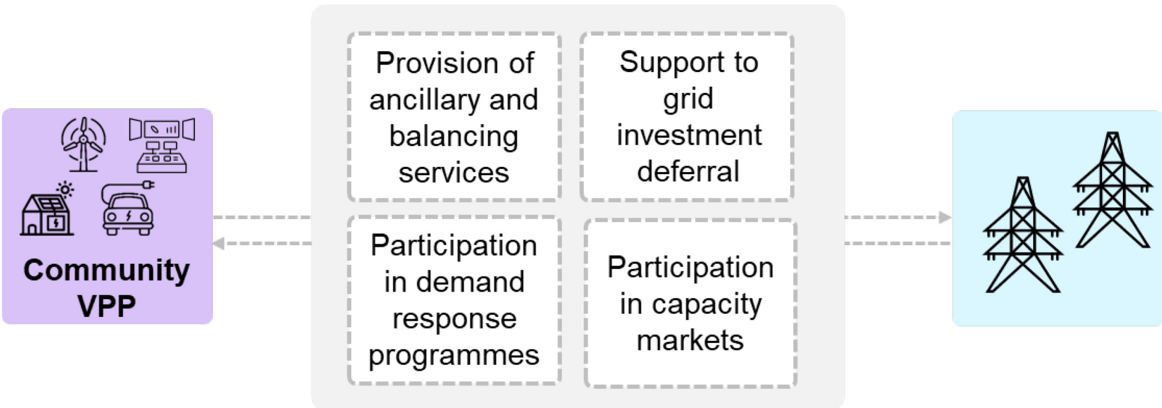
Community energy initiatives can support power system reliability

There are obvious direct benefits to the local communities, as demonstrated, but supporting community-based projects also offers wider grid benefits. Consuming electricity close to the generation source can help avoid power system losses and enhance energy efficiency and can also provide additional grid balancing services, further improving grid resilience. For example, in northern Perth, Australia, a battery resource shared by around 120 households resulted in collective savings of over AUD 81 000 during a five-year period. The battery also helped ease the strain on the grid by enabling an 85% reduction in consumption of electricity from participating households at peak times.

In Italy, the Magliano Alpi energy community installed solar PV on the town hall roof, and in collaboration with the EU Joint Research Centre has developed digital tools to forecast energy generation and demand and share electricity. This investment has enabled the community to use their solar PV systems more effectively and cover 35% of their electricity needs. Increased reliance on their own generation resources during peak demand periods alleviates grid stress and has helped defer expensive infrastructure upgrades. Based on Magliano Alpi's experience, a local company specialising in solar PV installations and EV mobility created an operational group, GO-CER, to support the creation of renewable energy communities. The network gathers a variety of local professionals and experts to help set up and operate energy communities.

When configured as community-based VPPs, energy communities can further contribute to the provision of flexibility to the electricity system. When coupled with advanced digital technologies such as machine learning algorithms, they have significant potential to improve the economic value to the community and carbon emission reduction performance. A study in the city of Greater Bendigo, the third-largest city in the Australian state of Victoria, showed that one project enabled by advanced digital technologies could halve the carbon emissions within the area in ten years with a probability of more than 70%, and lower the electricity price by up to one-sixth of the current level. In the United Kingdom the Flex Community is bringing together households and businesses to trial new approaches to community solar projects, electricity trading between neighbours and managed EV charging to better match electricity demand and supply.

Flexibility contribution from energy communities



Source: Regulatory Assistance Project (2021), Energy communities with grid benefits: A quest for a blueprint, as modified by the IEA.

Best practice to support inclusive local energy

Policy makers and utilities can support inclusive local energy solutions

Utilities in several countries are providing support to local energy schemes, such as collective self-consumption and energy communities. In Italy, the distribution system operators collaborated with the state-owned energy service system operator, Gestore dei Servizi Energetici, to create an interactive map of primary substations, which allows interested groups to identify the boundaries of self-consumption and energy communities under the agreement (current transitional measures set the boundary at secondary substations).

The French distribution operator, ENEDIS, is collecting consumption and production load curves for collective self-consumption projects. This helps it allocate the quotas for self-consumed electricity among participants for billing purposes (including through a direct interface with energy suppliers) and provides tools for operation and data visualisation.

Municipalities also play a key role in designing strategic public procurement schemes to incentivise communities, as identified in the Procurement Guide for Community Energy from REScoop. Municipalities can assist communities adopt renewable energy and enhanced energy efficiency, supporting the creation of energy communities. The municipality of Strasbourg, France, in its procedure to allocate concessions for rooftop solar, specified that only energy community organisations can participate in the tender.

However, conducive frameworks and support from national governments have a critical role to play in scaling up inclusive local energy solutions. From a technical perspective, it is important to ensure that the right digital technologies are in place. The revised Swiss Federal Act on a Secure Electricity Supply from Renewable Energy Sources requires electricity operators to install smart meters at the request of participants in energy communities, thereby helping to ensure that the right technology enablers are in place.

Capacity building in communities for socio-economic development

Some projects focus on education, training and awareness campaigns to enable communities to actively participate in managing their energy resources effectively. These initiatives are not only about energy, but also about creating jobs, providing training opportunities and reinvesting profits back into the community to address issues like unemployment and poverty The RevoluSolar energy initiative was the first PV community founded in a Brazilian favela, enabling renewable energy access for many families, with more than 170 kW of solar capacity installed, offsetting 16 tonnes of CO_2, and directly benefiting 2 000 people. The community opted to reinvest the profits from the projects into charities, training 70 residents to tackle rising rates of local unemployment and supporting the education of more than 100 children. This ability to determine where, how and to whom the revenues from the project are distributed, improved overall welfare in the favela while also enabling the community to protect people from rising energy prices, saving them around USD 11 000 to date.

Brixton Energy, the United Kingdom's first community-owned social housing renewable energy project, has evolved into a P2P network, allowing participants to reduce their energy bills by more than 20%, while also creating training and work placement opportunities for residents including young people and unemployed electricians. In 2021 a three-month trial of a smart local flexibility service was implemented, where they integrated new storage with existing solar and helped provide residents with more than 40% of their household electricity needs.

In Italy, the Ministry of the Environment and Energy Security offers grants of up to 40% for energy communities and collective self-consumption projects in municipalities with less than 5 000 inhabitants. The programme has ambitions to achieve at least 2 GW of installed capacity by June 2026. These initiatives can also help rehabilitate suburban and peri-urban areas. The first solidarity local energy community was established in 2021 in the suburbs of Naples, Italy, actively involving, from the design phase, 40 families living in social housing. This energy community was established to increase awareness of energy and environmental issues, to fight energy poverty and to train local young people in clean energy skills. The project is expected to save participants EUR 300 000 over a 25-year period.

Institutional support for community projects

Institutional support and monitoring, in particular at the start of local energy projects, is also important to accelerate progress and to ensure the right rules and incentives are in place and opportunities are leveraged. Best practice policy solutions are starting to emerge. For instance, the European Parliament has recently provided funding for the creation of an advisory hub and support service to help collect and disseminate best practices and provide technical assistance to community initiatives across the European Union. The European Commission has published a short guide with examples of how to set up community energy one-stop shops to facilitate the process, and digital tools for energy communities, with practical examples of how these are used in projects across Europe.

From a financial standpoint, instruments to channel national and international funding can help further facilitate the creation of local energy projects. The EU-funded COMPILE Project designed a guide to support municipalities in choosing the most appropriate funding mechanism for energy communities, and has produced five pilot projects, of which four are in urban locations. In Spain, the Community Transformation Offices have been established to support the creation of energy communities through the empowerment of new energy actors such as residents, small and medium-sized enterprises and local authorities, providing technical, financial, legal and administrative advice, and education and training.

In Chile a platform called Comuna Energética has been established to support municipalities and local actors in implementing replicable and innovative clean energy projects. Comuna Energética supports the creation of local energy strategies, helps strengthen capacity in municipalities and ensures alignment with other national initiatives and instruments. It has implemented around 50 projects to date. In Italy the Energy Communities' Observatory has been established to identify persistent challenges and to support the creation of conducive policies, to promote a national roadmap for the development of energy communities and to help local governments and residents setting up and managing such initiatives.

Further mapping of initiatives and benefits is underway as part of the IEA People-Centred Clean Energy Transitions Programme and the Digital Demand-Driven Electricity Networks Initiative (3DEN). The IEA User-Centred Energy Systems Technology Collaboration Programme, through its Global Observatory on Peer-to-Peer, Community Self-Consumption and Transactive Energy Models, is tracking developments across the world in the area of local energy models, mapping their implications for energy systems and collecting policy insights.

Chapter 4: Systemic approaches for a sustainable urban energy future

Key takeaways

- Agile, integrated planning processes are essential for meeting renewable energy targets and addressing grid infrastructure challenges while aligning with urban development needs, avoiding delays and integrating distributed generation effectively. More than 3 000 GW of renewable power projects are currently awaiting connection globally.
- Given the increasing complexity of urban energy systems and the urgency of meeting clean energy transition objectives, urban and energy planners and operators need more granular real-time insights. These can be derived from analysing an increasingly wide range of data sets as the number of connected sensors and devices rises from 13 billion today to exceed 25 billion by 2030.
- Better alignment of energy system and urban planning processes and supportive policy action to help anticipate future changes and investment needs can result in reduced costs and assist energy efficiency implementation. In China, integrated planning enabled a reduction in investment of USD 13.5 billion.

The case for change in urban energy planning

Rapid and large-scale changes require more agile and integrated planning

It will be necessary to move fast to implement projects at scale to stay on track with international clean energy transition commitments. Many regions are already facing challenges at the planning stage, which is leading to delays in deploying renewable energy, with around 3 000 GW of renewable power projects currently in the queue for connection to the grid, alongside reports of energy efficiency schemes stalling. Analysis suggests that due to outdated grid planning in some countries in the European Union, more than 200 GW of new solar capacity is being planned than accounted for by national grid plans, with a potential shortfall in planned infrastructure investment of at least EUR 5 billion.

With the global pledge to triple the capacity of renewables and to double annual energy efficiency gains by 2030, it is imperative that governments – both local and national – overcome the current barriers and deploy new streamlined and integrated planning processes.

Power systems must be expanded to manage the demand for increased capacity, reinforced to increase stability, and hardened to withstand extreme weather conditions with a combination of both adaptation and mitigation measures. One challenge is that grid planning must now consider more diverse future operating conditions than historical data allow, so as to be resilient by design. When looking specifically at infrastructure requirements in urban areas, it is also important to recognise the density aspect, which offers potential but may also create engineering challenges. While in general rural grids prioritise accommodating power generation, urban power grids focus on meeting the high electricity demand of cities, driven by multiple customer connections and dense loads.

Managing the intersection between power systems and urban planning

With the dramatic growth in distributed generation and electrical equipment, such as distributed solar PV installations and EV charging stations, urban power systems are increasingly required to manage dynamic multi-directional electricity and data flows, necessitating additional infrastructure. Given these profound changes to the energy landscape, realising the potential for the intersection between power systems and urban planning is imperative to support successful clean energy transitions.

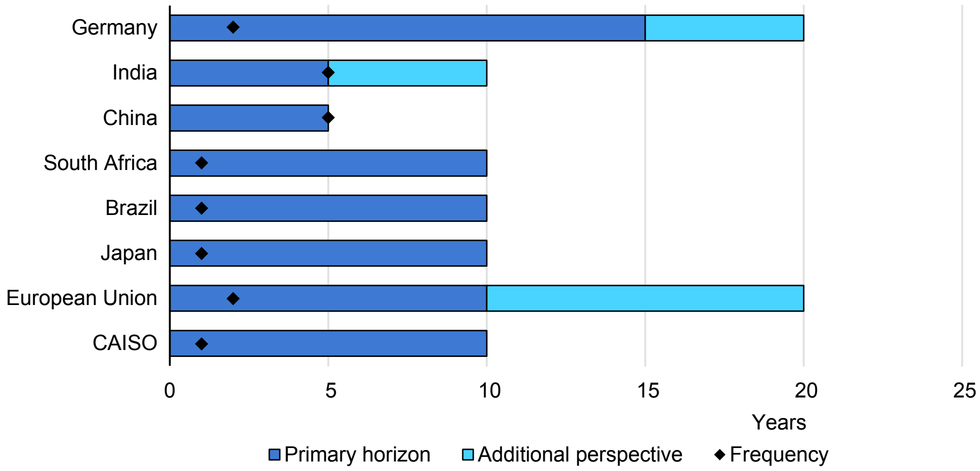
As emphasised by the 2023 IEA Special Report Electricity Grids and Secure Energy Transitions, governments need to further align and integrate planning for transmission and distribution grids with broad, long-term planning processes. Deploying new power grid infrastructure often takes 5 to 15 years to plan, permit and complete, compared with 1 to 5 years for new renewables projects and less than 2 years for new loads such as EV charging infrastructure, housing developments and industrial facilities. Better planning can help ensure that these contrasting timescales do not lead to a logjam in bringing projects to fruition.

Cities are increasingly turning to integrated planning approaches to sustainable urban development, focusing on integrating policies and actions across sectors, multi-level governance and stakeholder involvement in implementation. Integrated energy planning is the systematic analysis of all the factors that influence the evolution of energy systems. It facilitates problem solving and makes it possible to explore linkages, evaluate trade-offs and compare consequences, thereby helping countries to develop an effective energy strategy that supports national sustainable development goals. It increases transparency and provides information to stakeholders, informing project developers, grid operators and authorities and helping co-ordinate investment in generation and grids. It is also useful for foreseeing the potential outcome of changes and events.

Integrated planning plays a pivotal role in identifying and implementing energy-efficient technology policies, ultimately enhancing the overall performance of the urban power system. The benefits of a co-ordinated approach extend to improving urban resilience in the face of disruption and ensuring a reliable response during emergencies. As cities anticipate increased energy demands due to urbanisation, population growth and shifts in consumption patterns, integrated planning becomes instrumental in addressing the associated challenges. Efforts can be geared towards avoiding excessive power system redundancy, optimising resources and identifying synergies to provide cost-effective solutions.

Short-term action is required to deliver long-term vision

Length of planning horizons and update frequency for grid planning studies



Notes: Horizons are based on the main transmission planning study for each region, noting that some have additional longer-term studies used to inform the main plan. CAISO = California Independent System Operator.

Sources: IEA analysis based on Electricity Grids and Secure Energy Transitions; data from National Transmission Needs Study for the United States; Ten-Year Network Development Plan for the European Union; Electricity Supply Plan for Japan; Plano Decenal de Expansão de Energia for Brazil; Transmission Development Plan for South Africa; Five-Year Plans for China; National Electricity Plan Volume II (Transmission) for India.

Challenges arise in meeting clean transition needs as rapid renewable energy and technology deployment may outpace infrequent grid updates. Additionally, the planning horizon for urban development is often shorter than high-level climate targets, hindering efficient alignment with longer-term ambitions.

A recent study showed that strategic grid planning based on a longer-term vision enables existing low-voltage grids to support new charging infrastructure for EVs and heat pumps, addressing budgetary constraints. Dynamic load management can partially mitigate or postpone investments in transmission and distribution systems, proving cost-effective in about 90% of cases. Additionally, a study on East China found that introducing integrated planning in a wider regional area – rather than focusing on local problem solving – could avoid infrastructure investment of USD 13.5 billion while maintaining a robust power system.

Main characteristics of traditional and integrated planning for power grids

	Traditional resource planning	Integrated and co-ordinated planning
Electricity grid context	Large, centralised conventional electricity plants, unidirectional electricity flow	Increasing shares of variable renewables including distributed PV, demand-side resources and bidirectional flow, transforming the energy landscape
Leader	A company that owns the assets	A selected entity with a neutral role, ideally with no conflict of interest
Objectives	Meet legal requirements (reliability, sustainability) and balance sheet constraints or shareholders return	Meet climate and energy policy objectives and maximise overall market benefits at reasonable risk
Planning process (transparency)	Top-down, transmission-distribution system planning with limited interactions; assumptions and details may be restricted, with only headlines made public; public consultation at the end of the process	Participatory and transparent process; continuous engagement with relevant stakeholders to develop scenarios, select sensitivities and challenge assumptions; results made public and open to debate
Resources considered	Centralised generation, transmission and distribution	Generation, both centralised and distributed, transmission and distribution, demand-side resources and system flexibility
Input parameters and estimation tools	Approximation, reserve margin calculations	Multi-dimensional analysis, including environmental and social aspects
Outputs	A plan focused on investments	Several outputs to guide decisions of policy makers and market players

Sources: IEA (2022), Steering Electricity Markets Towards a Rapid Decarbonisation, and US Aid (n.d.), Best Practices Guide: Integrated Resource Planning for Electricity, as modified by the IEA.

Collaboration is central to aligning planning with cities' needs and timelines

Collaboration between local governments and utilities is important to ensure that the grid is expanding and decarbonising in line with each city's needs and timelines. Municipalities can engage directly with electric utilities and promote new solutions, or influence utility strategy by providing long-term plans, updating them on a multi-year basis while acting as representatives of their communities. Such collaborative initiatives enable utilities and cities to leverage resources, improve infrastructure reliability and reduce costs, thus resulting in a higher quality of service. In the United Kingdom, for example, the Infrastructure Coordination Service under the auspices of the mayor of London was able to identify short-, medium- and long-term solutions to enable new housing developments to proceed on a faster timeline by working closely with the grid operators.

Some local governments have partnered with utilities to develop renewable energy, efficiency programmes and joint working to enhance energy metering and data access. In the United States, the city of Denver developed a Strategic Energy Plan with the local utility to lay out a plan to achieve 100% renewable electricity by 2025. Through this partnership the utility supported the local government by providing analysis based on energy data and plan strategies, and staff training. Another US city, Charlotte, created a strategy for co-operation with the local utility, aimed at developing a plan to advance the Low Carbon, Smart City Collaboration, and recently announced a High Energy Use Pilot to provide homeowners incurring high energy usage with energy-efficient retrofits.

The newly formed international Cities Technology Collaboration Programme aims to optimise urban energy planning for improved living standards. It will focus on gathering energy-related data, sharing knowledge, promoting data-driven planning, and discussing legislative and socio-economic factors. This collaboration has potential to guide national policy implementation to support cities utilise data for more efficient planning.

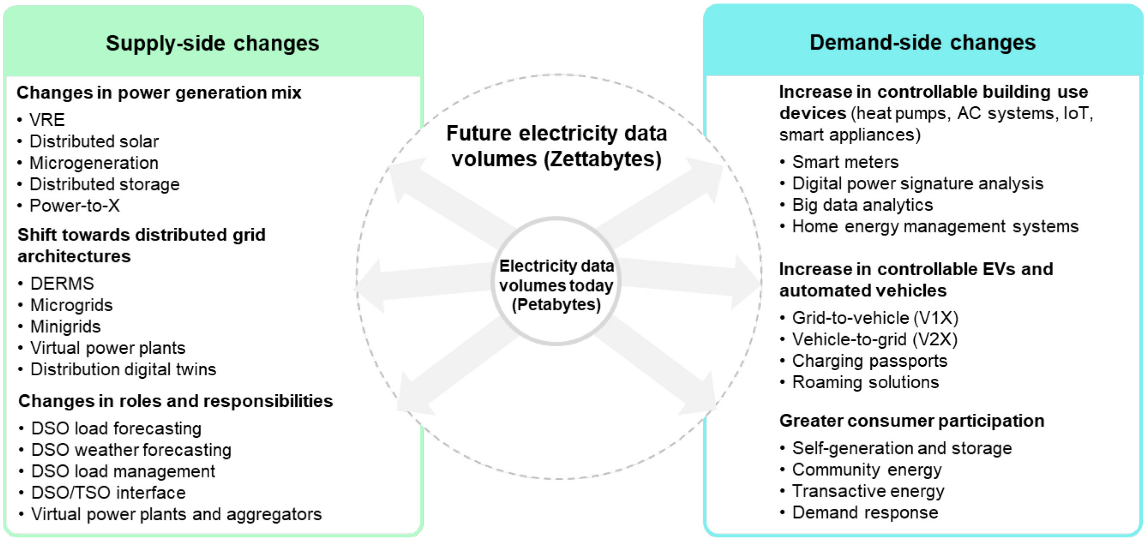
The benefits and challenges of more data

Managing increased data complexity and volumes has become a priority

As the energy access sector undergoes deep transformation, a pressing need remains to better inform decision makers with actionable and targeted tools for integrated electricity planning. This is especially important in locations where data availability is suboptimal. The IEA has collected geospatial models and datasets that are crucial for stakeholders across the African energy sector looking to deliver an effective path towards universal electricity access.

The growth in data, both quantity and type, can be a powerful asset in effectively managing the evolving power system, but only when it is accompanied by enhanced data accessibility, utilisation and sharing, along with more robust analysis tools.

Drivers of electricity data volume and increasing complexity



Notes: AC = air conditioning; DERMS = distributed energy resources management system; DSO: distribution system operators; IoT = Internet of Things; TSO = transmission system operator; VRE = variable renewable energy.

With technology adoption varying immensely in every location, each energy system faces unique challenges. A major challenge for system operators is that they lack visibility of customer-owned equipment and its impacts on electricity demand, known as "seeing behind the meter". This currently necessitates tailored visibility solutions that also consider the urban context due to the density of energy demands, where most utilities today still have limited visibility and have to rely on bespoke digital tools such as DERMS. As many regions are seeing decentralised energy systems grow at different rates, regulators can prioritise addressing system reliability, especially in urban environments, by increasing visibility and data availability. The Australian Energy Market Operator established a distributed energy resource register in 2020 that provides visibility on the location and capacity of devices installed in customer premises thereby supporting power system planning and operation. In 2024 India has initiated a consultation process towards developing a national registry.

Paving the way for innovative planning solutions

Leveraging data from technological advancements, such as smart meters and digital communication, is a key aspect of integrated planning. Insights based on data and advanced analytics and improved data and information sharing can help forward planning for periods of high demand, lessening reliance on costly peak generation sources and enhancing grid reliability.

Misaligned planning timelines could increase the risk of power outages due to power system resource adequacy issues (i.e. the ability of a power system to supply enough electricity at the right locations during all hours of the year), and the inability to provide new electricity connections for renewable generation assets, data centres or housing developments. Misaligned planning can delay the deployment of renewable energy, constrain the achievement of increased energy efficiency and lead to higher electricity costs for consumers.

There are means to better manage these risks. Data sharing mechanisms allow policy makers to design more efficient power systems. For example, in the Netherlands, central government, local governments, utilities and planning agencies work closely together to share data on power systems. Since 2022 data have been publicly available on electricity consumption and production by province and municipality, which allows planners to anticipate grid needs and adjust capacity installations accordingly. To help municipal planners, a specific data tool shows on customisable maps the annual energy consumption by household, the energy label of the house and the capacity of its renewable production that can be fed back into the grid.

Towards resolving data challenges

Integrated planning fosters stakeholder co-ordination, but regulatory constraints and data management challenges persist. Cities and power systems generate complex data in varying formats, with much of the data currently unused or unreliable, presenting untapped potential. Establishing a common protocol and reference architecture for digitalisation and assumed open data sharing could contribute significantly to reducing costs, help drive rapid innovation and expedite the energy transition across diverse systems. This could help reduce the friction caused by the increased system complexity.

Governance gaps and digital skills gaps persist and impede data utilisation, preventing the development of innovative tools and methodologies. Power system data that are proprietary and fragmented across utility departments or entities hamper data interoperability, and access to data is also sometimes constrained by data protection. Simplifying information sharing, co-ordinating markets and establishing robust data governance are essential for data interoperability. Standards for data interoperability are key to achieving these outcomes.

Examples of standards and norms to control and monitor equipment

Region	Name	Description	Type
European Union	Norm EN 50631-1:2020: European Norm	Describes the necessary control and monitoring for household appliances.	Norm
United Kingdom	PAS 1878:2021	Requirements and criteria for electrical appliance to be classified as energy smart.	Norm
Australia	AS 4755 – Demand Response Standard	Demand response capability and modes of appliances and smart device.	Standard
United States	ANSI/CTA-2045	Specifies a modular communications interface to facilitate communications with residential devices for applications such as energy management.	Standard
International	IEC 62746-10-1	Open automated demand response system interface between the smart appliance, system or energy management system and the controlling entity.	International standard
United States, California	Senate Bill 49 – The Flexible Demand Appliance Standards	Authorises the Energy Commission to adopt standards for appliances to facilitate the deployment of flexible demand technologies.	Bill
International	OpenADR 3.0	Open automated demand response system that provides two-way information exchange between utilities and customers' smart appliances.	International standard

Regulations can define access rights, data formats and consent mechanisms, ensuring consumers have control over their data. Cybersecurity guidance and standards, such as the Cyber Assessment Framework, can help utilities mitigate risks, and policy makers should remain vigilant about emerging technology cybersecurity gaps.

Connecting the dots: Overcoming interoperability challenges to support clean energy transitions

One of the main reasons that renewable projects are facing permitting delays is the bespoke nature of each agreement. These permitting processes are highly manual and involve co-ordination across many different authorities at local, regional and national level. The lack of standardisation of the process and the poor visibility of data and project tracking, together with the high volume of manual input, risk missing the global pledge to triple renewable capacity by 2030 if they are not remedied. There is, however, the potential to overcome many of these hurdles by leveraging digital solutions.

In the European Union, the large ICT company, Amazon Web Services, has sought to overcome this impasse whereby around 80 GW of renewables are awaiting permitting. It is working with permitting staff across several EU member states to develop a digital platform to:

- Reduce processing time.
- Automate data management to reduce manual input.
- Standardise the process using automated checklists and workflow triggers and notifications.
- Collect, manage and process all documents in a single repository.
- Increase transparency on progress throughout the permitting process.

Several pilot projects are underway, connected to the Horizon Europe programme, to develop solutions that the tackle data interoperability challenges facing increased power system digitalisation. The Interconnect project brings together 50 European partners across 11 countries to develop a data and communication architecture to connect homes and buildings to the electricity sector. To identify ways to leverage flexibility, the OneNet project is developing a communications architecture for demand response, storage and distributed generation. PLATOON focuses on smart grid services, increasing renewable energy consumption, greater energy efficiency and optimised energy asset management. Other projects are exploring ways for the private sector to create new business models. To lay down the groundwork in understanding the state of the market, BD4OPEM is developing products and services to improve the planning, monitoring, operation and maintenance of distribution grids towards an open innovation marketplace. Denmark has implemented DataHub, a digital platform that centralises electricity consumption data and clearly defines use cases for access by third parties.

Data analytics can enhance the efficiency, resilience and sustainability of urban energy systems

Access to data is only the first step. It is then necessary to understand what the data infer, for example by using advanced analytics such as artificial intelligence (AI) or machine learning models. Other means of data analysis are the creation of digital twins, which are virtual models of real-world systems. The coverage of digital twins varies from an individual building or site to entire districts, systems and cities. They can help identify where interventions are needed, for example by identifying areas likely to become heat islands. They can identify where energy efficiency interventions can bring greatest positive impacts by mapping heat losses and income levels. And they can be used to trial different options and understand possible outcomes to help inform planning processes and optimise investment.

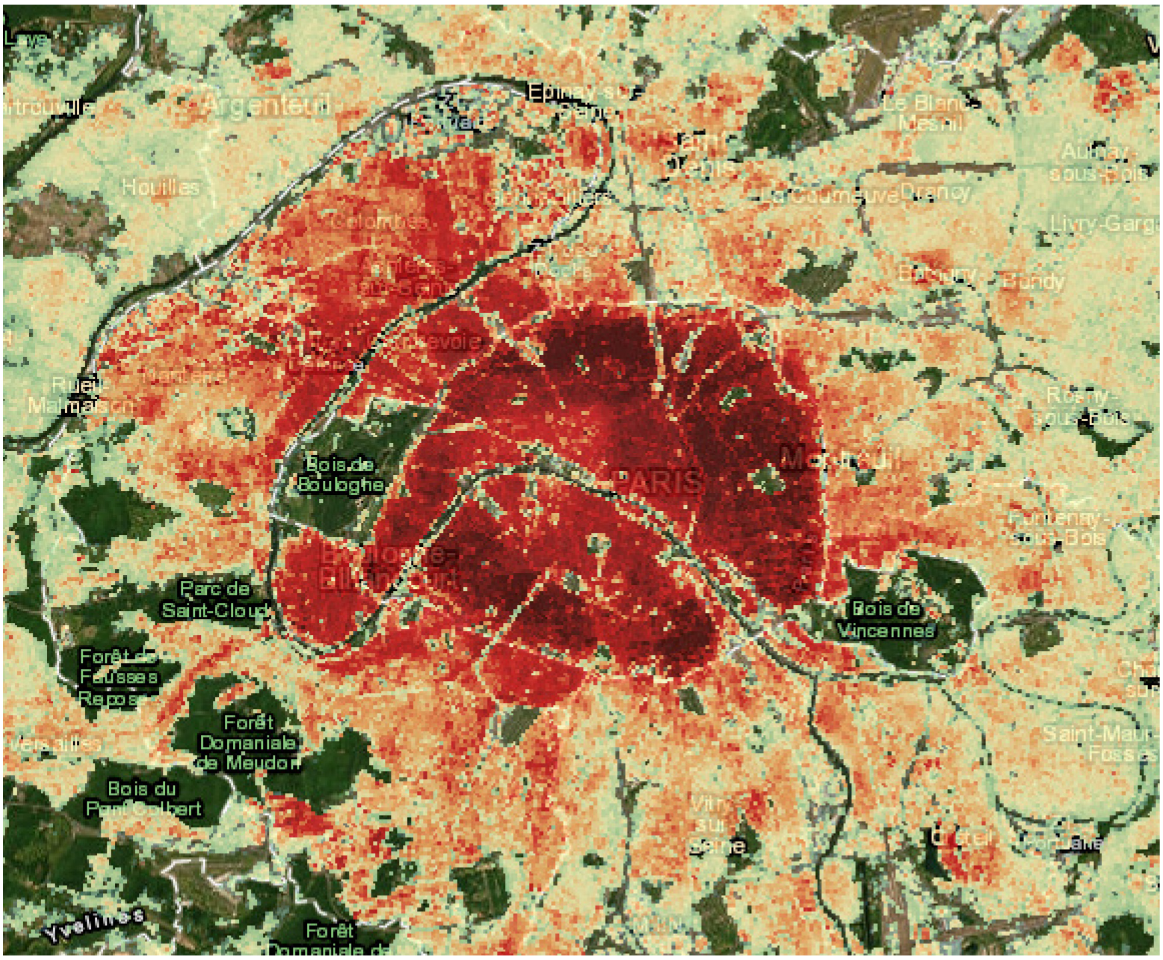
Singapore, for example, started developing a 3D representation of the city in 2012 in order to identify areas that were most at risk from flooding. The digital twin is now shared across different government agencies and has many practical uses around green space management, urban planning, network coverage and transport flows. A project to map EU-based local digital twins has been funded by the European Commission, both to consider the current state of the digital twin ecosystem and develop a roadmap towards use of data and advanced analytics for enhanced planning and operation of urban systems. The cost savings from using digital twins to make data-driven decisions in cities globally have been estimated at up to USD 280 billion globally through to 2030 from improved planning.

Data-driven insights and advanced digital controls can contribute to enhanced grid efficiency in urban locations by reducing power system losses, reducing curtailment of renewables, and providing more control, greater resilience, improved reaction times and consequently lower system costs. In the United States, a recent study by the Department of Energy simulated the grid conditions resulting from a 70% share of renewable sources by 2030. It found that deploying advanced digital hardware and software could result in increased efficiency and a reduction in curtailment of between 23% and 43% through grid optimisation.

For urban and power system 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 communication network-connected provides data. Datasets can cover air quality, weather, energy consumption patterns in buildings, geospatial data and traffic control systems. The ability to provide more insight through data visualisation is an emerging tool to aid decision makers – it can simplify complex data by displaying large data sets in various ways that can reveal patterns or trends or identify areas that need further attention.

In European Union, under the Horizon 2020 funding programme, the Hotmaps geographic information system (GIS) toolbox has been developed as an open-source platform for mapping heating and cooling demand in European countries to support authorities and energy planners in the development of a strategic heating and cooling plan for their region.

Total heat density of buildings in Paris, France



Source: Reproduced from Hotmaps.

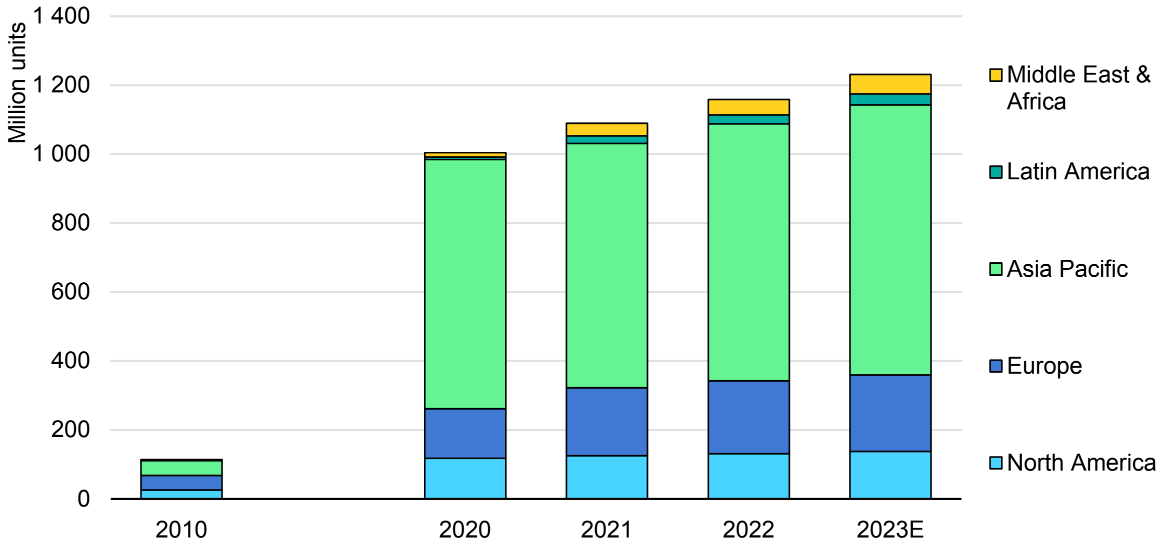
Advanced analytics can be used to merge diverse datasets to improve decision making in urban energy planning, enhancing asset efficiency and service provision. Advanced spatial energy planning, with GIS and digital twin modelling, maps local potential and measures impacts before implementation. The VESTA-MAIS model in the Netherlands is a spatial energy planning model that forecasts the energy use and CO_2 emissions of the built environment until 2050. The potential benefits and costs of building measures such as insulation and heat pumps, and spatial measures such as district heating, geothermal and heat exchangers, can be calculated integrally. Effects on avoided CO_2 emissions, energy use, investment costs and financial benefits can be identified to improve planning. The model is open source, so municipalities, utilities and others can also access it.

Planning models like these aid in locating high-value energy efficiency interventions and planning mixed-use zones to flatten demand curves and reduce CO_2 emissions. Areas needing efficiency interventions in urban planning can be identified by mapping heating and cooling demand and combining weather and demand data. There are an increasing number of assets that can provide granular and more real-time data for decision making.

Data challenges can be overcome by leveraging AI and machine learning

As increasing numbers of digitally enabled technologies come online offering data points from nodes all across the grid, the analytical methods traditionally used become overburdened by the sheer volume and speed of data availability. However, technological advances in the fields of AI and machine learning in recent years are presenting the potential not only to overcome data bottlenecks, but also to make great leaps towards new applications not thought possible even up until very recently. The major advancements are that AI drives down the time taken to perform big data analytics and repetitive tasks can be done with the help of machine intelligence, reducing human input and error, and improving the degree of precision.

Global stock of smart meters, 2010, 2020-2023



Note: For 2023 data "E" indicates estimated total.
Sources: IEA analysis based on data from Guidehouse and BloombergNEF.

Previously, insufficient volume and quality of industry data hampered efforts to attain better insight, but modern digital transformations have driven progress, with emerging uses of AI beginning to be considered. 2023 marked a significant milestone as the global count of smart meters exceeded 1.2 billion, representing a remarkable tenfold increase compared to 2010. In a wider context, the number of connected devices equipped with automated controls and sensors to monitor and measure energy use and flows is projected to exceed 13 billion in 2024. Projections further indicate that this figure could soar to 25 billion or more by the year 2030. This extensive deployment of smart meters and advanced sensor technology is already generating large volumes of data. Making use of these data necessitates the deployment of cutting-edge storage and analytical tools.

Additionally, there is a trend towards increased consumer engagement in energy systems. Given greater data availability, and the will to capitalise on the data, there is also a need to manage increasingly large and complex data sets and to ensure strong data governance. However, many energy utilities currently do not have analytics departments, suggesting that these organisations are missing out on the opportunities better data offer. There is also a growing need for organisations to increase collaboration between departments on data and data management.

AI could be a useful tool to leverage consumption data, while preserving consumer trust and safety. AI-generated synthetic datasets can produce realistic profiles for each consumer archetype, not attributed to specific individuals. In the United Kingdom, the Centre for Net Zero has developed Faraday, a generative AI model trained on existing smart meter data and capable of providing realistic synthetic consumer profiles. This allows for protection of customer data while enabling policy makers, planners and operators to model impacts of changes such as new types of tariffs, uptake of EVs, new building developments, and extreme weather.

It is also possible to examine power system resilience. In Ireland, the state electricity distribution system operator has partnered with an AI modelling platform to mitigate the impact of extreme weather events on energy supply, with results of the digital twin analysis available in weeks rather than months of manual input.

The Building Energy Efficiency (BEE) Pilot is a project developed in the cities of Helsinki, Finland, and Stavanger, Norway, to shift energy consumption to times of high availability of renewables. The system is linked to the building management system (BMS), where it gathers data on energy consumption as well as indoor air quality data. The AI-based system forecasts the next day's energy grid mix and weather conditions, and adjusts how energy is used in the building. Based on the initial simulations, a 10-20% increase in use of renewables and 15-20% energy savings through optimised control are possible.

While the use of AI in energy systems is still at a nascent stage, applications are emerging – from power generation through to supply, transformation and end use.

Use of AI for urban energy system applications

Application	Impact
Texas utility ONCOR uses machine learning and AI technologies to identify overloaded equipment to target for predictive maintenance, and identify geographic areas where vegetation poses a safety risk to transmission lines.	In 2019, 2 000 power quality issues detected before causing an outage, avoided 5 000 potential outages from overloaded or damaged transformers.
E.On's self-learning algorithm predicts when medium-voltage cables on the grid need to be replaced, using data on power flows and weather.	E.On research suggests the technology can reduce the number of outages by 30%.
Hepta Airborne uses a machine learning platform in combination with drone footage of transmission lines to analyse images of the line for defects within 15 minutes.	250 km of lines analysed in 5 minutes, and on average 11 more defects per line-km identified.
Nokia AVA Energy Efficiency – an energy management system – uses a range of AI applications to reduce power demand in telecommunications networks.	Up to 30% energy savings and lower CO_2 emissions from telecommunications radio network.
Octopus Energy's Kraken is a software platform, based on advanced data and machine learning capabilities, that allows management and optimisation of resources.	40% reduction in cost to serve customers, according to Octopus Energy.
The United Nations Innovation Technology Accelerator for Cities (UNITAC) developed an AI-based tool to identify rooftops and evaluate structure footprints in the city of eThekwini, including a focus on informal settlements.	Help develop solutions for informal settlements through ability to map rooftops across the entire city in 72 hours.

Increased use of AI warrants efforts towards monitoring and counteracting risks, including potentially increasing energy demand. Appropriate data safeguards also need to be in place to ensure privacy and security. Furthermore, increased use of automated and self-learning software raises questions about who is responsible for the outputs or outcomes of these systems – if noncompliance with regulations occurred due to the failure of the analytical model, or if there was a privacy leak, for example. In an effort to address some of these issues, the OECD AI Principles – adopted by OECD member governments and many non-member governments – provide guidance on pursuing a human-centric approach to trustworthy AI. Efforts are also underway to understand and assess the impacts of AI in the urban context, map risks and explore governance considerations.

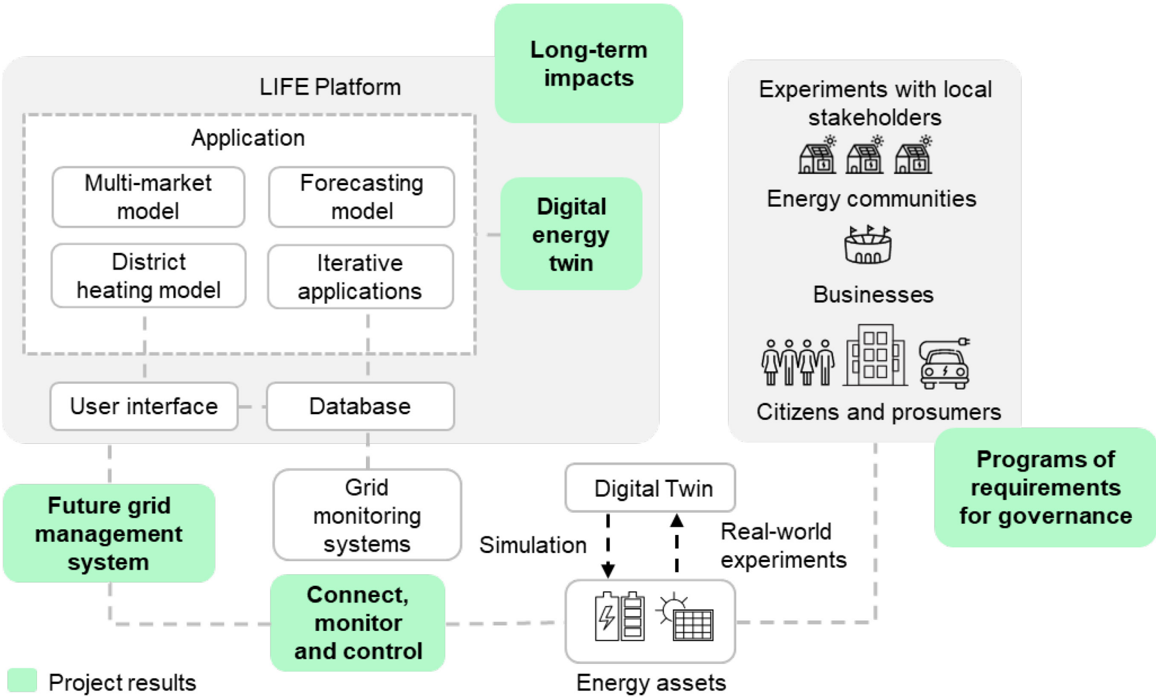
Smart, integrated infrastructure investment planning

Many regions have understood the need to invest in power grids to enable economies to continue to flourish, expanding and reinforcing them to anticipate future demand. The European Union, for example, recognised the need for anticipatory investment and is introducing regulatory incentives for forward-looking grid build-out as part of the Action Plan on Grids announced in 2023.

Substantial investment is needed for the transformation of the energy system, and planning at the national and urban level plays an important role in managing this investment to maximise benefits. Urban grid planning should extend beyond the grid to consider the changing shape of customer load profiles and the increased demand for electrification of transport, heating and cooling.

Smart planning solutions are being tested in many locations, where decision makers are taking a more inclusive approach to the energy transition decision-making process. The Local Inclusive Future Energy (LIFE) City platform in Amsterdam is testing innovative solutions for the clean energy transition. Focusing on Amsterdam Zuidoost, the project aims to reduce the need for grid expansion through smart energy management. A digital twin covers charging stations, solar panels, buildings, heat pumps and a mobility hub, digitally interconnected to explore system optimisation using data and AI.

Local Inclusive Future Energy City Platform, Amsterdam



Source: Spectral Energy (2021), LIFE: A Holistic View on Energy Innovation, as modified by the IEA .

In Italy, the Bologna Digital Twin project was deployed with the aim of optimising existing datasets, infrastructure and other solutions that were available but not fully utilised. The municipality is placing a strong focus on ensuring that the tool provides value for people and communities, including improved local social policies through better insights and using data to enhance services to inhabitants. In the United States, the New York State Public Service Commission has initiated a process towards an Integrated Energy Data Resource that securely collects, integrates and provides access to a large and diverse set of energy-related data and information on one state-wide platform. It is expected that this data will be available to support urban and energy planning processes towards higher levels of clean energy and demand-side flexibility, as well as to facilitate the development of new business models such as community solar and demand-side flexibility aggregation. Also in the United States, in California, efforts are underway to explore electricity price-based grid co-ordination and an associated reference data model. The objective is to develop a simple system for data flows that make it possible for consumers to have their devices react to changes in price – the changes in price would be based on the grid's need for flexibility.

Smart grids in Latin American cities: São Paulo and Bogotá

Enel's Urban Futurability project in Vila Olimpia, São Paulo, represents the combination of ground-breaking technologies for the power grid and the proactive engagement of local stakeholders and communities in a "living lab" to co-design and create an open data platform. This will help stakeholders to contribute to and potentially co-finance new solutions by providing better understanding of energy and other resource use, efficiency and savings opportunities, environmental risks and mitigation options. The technologies applied include self-healing grid capabilities, safer and more resilient underground cables, smart lighting and electric mobility initiatives. The project features South America's first network digital twin, a 3D model using 5 000 sensors for real-time communication. It supports grid resilience, a reduction in the duration and frequency of outages, and enhanced future power system flexibility by leveraging the potential of grid-connected buildings and electric mobility.

More broadly, Enel has installed 500 000 smart meters in the São Paulo metropolitan area, one of the largest deployments in Latin America, investing a total of BRL 470 million (Brazilian reals [2]; USD 95 million). A third of the investment was supported by the Brazilian Regulator, ANEEL, as part of its R&D programme, aimed at stimulating innovation in the Brazilian electricity sector to improve security of supply and reduce environmental impacts. Smart meters act as grid sensors, bringing benefits to the system and the consumers, such as operational efficiency thanks to remote operation, reductions in energy losses, shorter outage durations and more accurate billing. Tariffs based on time of use and dynamic tariffs can also be easily implemented allowing for energy use cost savings and service differentiation.

A similar Urban Futurability approach has been replicated in Bogotá, where Enel is implementing a digital circular city model as part of the Progresa Fenicia Project led by the University of Los Andes. This is a participative urban renovation project implemented under the municipality's Urban Renovation Partial Plan and will assist the municipality to improve the quality of life of residents from a social and environmental standpoint, strengthening the offer of affordable housing and supporting the economic rehabilitation of the area. Currently, the digital twin of the Fenicia project is being developed, connecting and analysing data from buildings, roads and public spaces, streetlights, and weather and air quality sensors.

[2] Exchange rate: 1 Brazilian Real (BRL) = EUR 0.18 = USD 0.20 (as of 05 April 2024).

Using sound frameworks for data-driven urban planning

There are many examples of good practices at the local and regional level that focus on data-driven urban planning. These case studies highlight urban planning that incorporates data ecosystems, data sharing and innovation, and which has the potential to be scaled up, sustained and further developed.

Clear data governance frameworks are essential for efficient data management, protection and transparency. Data visibility, including well-described metadata, is crucial for effective use. The open source Energy Transition Model is one such tool for national and local agencies to perform energy simulations to enable informed decision making.

The Energy Digitalisation Taskforce, commissioned by the UK government, Ofgem and Innovate UK, published a report with recommendations on modernising the energy system. The taskforce outlined the first step as unlocking smart meter data and initiated a study to examine the opportunities, risks and potential architectures. Additionally, a feasibility study has been carried out to establish a "digital spine" for the energy system in support of delivering interoperability across the energy sector, through defined governance roles and responsibilities that will enable the secure exchange of energy system data.

The European Union is monitoring the progress of cross-border interoperable data services, to give priority to reuse of existing data and to initiate automated data collection to reduce the reporting burden on member states through the Interoperable Europe Act proposal. Efforts are also underway to create a common data space for smart and sustainable cities and communities, with the development of the Common European Energy Data Space to design a mechanism enabling data sharing across energy and non-energy domains.

India has developed a Data Smart Cities framework in collaboration with city-level governments to enable cities to better handle data and solve complex urban challenges. The Indian government launched an open data platform to centrally collect datasets from cities. While it is continuously expanding, the platform currently contains over 3 500 data catalogues. The India Smart Cities Mission has also developed a strategy and roadmap for data smart cities and a data maturity assessment framework.

In Australia, the scale and growth of rooftop solar has already exposed the complexities and challenges of operating a power system that sources a substantial portion of its energy from individual homes. The Australian Energy Market Operator, in collaboration with several key organisations, is currently implementing several projects to develop the data exchange, modelling and monitoring tools to ensure better visibility of distributed energy resources and their impacts on the electricity system. Australia's Project EDGE, developed in collaboration with utilities, the system operator and the regulator, defines clear guidelines for data ownership, access, quality and completeness.

In New Zealand the FlexTalk platform has been designed using Open Automated Demand Response (OpenADR) to trial how flexibility from EVs could be accessed and scaled up to include further demand-side assets.

Platforms, tools and regulation can help policy makers use city data effectively

A range of initiatives and pilots are seeking to address part of the data challenge and demonstrate that the technical prerequisites for power system data ecosystems already exist. In recognition of the escalating complexity, various jurisdictions have embarked on different approaches, acknowledging that entrusting utilities with developing bespoke solutions is insufficient. Instead, they are looking for comprehensive and collaborative solutions to tackle this evolving challenge head-on. Over the past two decades, a wide range of national and international bodies have been developing interoperability standards for energy system assets, including customer-owned assets.

To ensure sufficient communication network stability, security and coverage to support data-driven planning and processes, it is also important for cities to bring together telecommunication network operators and grid developers to build communications and data resilience. The International Telecommunication Union, the United Nations specialised agency for information and communication technologies, is working with countries to improve access to digital technologies to underserved cities and communities. They additionally develop technical standards that ensure that networks and technologies interconnect seamlessly, to support climate change adaptation and mitigation actions in cities.

Developing interoperable data registries is essential for effective electricity market functioning. Regulators can establish rules regarding data formats, exchange protocols, governance and consumer consent mechanisms. Initiatives like the Norwegian Elhub data hub and the Green Button Data service in the United States demonstrate effective centralised and decentralised data management. Cape Town's SmartFacility platform integrates smart meter data for decision making. International co-operation, like the Data4Cities Initiative, fosters data access and standardisation.

Steps are being taken to enable better access to energy data. In June 2023 new EU rules were adopted to regulate access to electricity metering and consumption data. These rules aim to protect consumers, empower them in the energy transition and establish common reference models for data in EU countries, allowing consumers to permit third-party data access. In the United Kingdom, the regulator Ofgem has established that data best practice includes a requirement for aggregated smart meter data to be presumed open as part of the Digitalisation Strategy and Action Plan Guidance.

Increasing focus is being placed on developing platforms and tools for more effective use of city data. For instance, the Global Covenant of Mayor's Data Portal for Cities is an open data platform that helps communities fill critical information gaps by providing estimates of previously unavailable data drawn from national and regional sources.

Additionally, moving from a one-off project mindset towards a planning approach driven by key performance indicators (KPIs) can also enhance the effective deployment of smart grid and city solutions. This shift involves moving beyond isolated initiatives and embracing a systematic framework that emphasises performance metrics and how to leverage existing open-source or new data to build such metrics. Building on international best practices, the OECD is developing harmonised indicators for smart cities across the dimensions of well-being, inclusion, sustainability and resilience. The United for Smart Sustainable Cities (U4SSC) Initiative's KPIs are a consistent and standardised method to collect data on a wide range of economic, environmental, societal and cultural factors "to assess the achievement of sustainable development goals". Over 200 cities worldwide are already implementing these KPIs.

Chapter 5: Creating the conditions for implementing smarter urban energy systems

Key takeaways

- A range of barriers are constraining large-scale implementation of smarter urban energy systems.
- The lack of an enabling policy and regulatory environment can constrain action and the development of new business models.
- Without additional efforts in capacity building, reskilling and upskilling and attracting new talent, there is a risk that the implementation of new solutions and approaches will stall and that the full range of benefits from digitalisation will not be captured.
- Cities and utilities are still facing significant challenges in accessing finance for smart project implementation; policy makers can remove obstacles and promote the development and use of new approaches.
- Solutions to these challenges are starting to emerge and there is a growing body of promising approaches that are being developed and tested.

The challenges facing smart cities

Despite some progress, implementation is lagging

While some progress has been made in areas such as smart grids, smart urban solutions and demand response, the widespread adoption of clean energy strategies is lagging. Ongoing challenges are preventing large-scale implementation despite a growing evidence base on the need for and benefits of smarter urban energy systems.

Pilot and demonstration projects have great potential, but may not always lead to faster diffusion due to a lack of mechanisms to further develop a scalable solution. Often there is a lack of skilled personnel with knowledge of moving from demonstration to larger deployment. Frameworks for data governance, data sharing and interoperability may be missing, and complementary infrastructure may not be in place. Funding gaps are also a key blockage, reflecting the lack of a transparent financial ecosystem.

Three key interrelated areas need addressing:

- Enabling regulatory environments that allow for testing, investing in and deploying new solutions.
- Skills and capacity to develop projects and leverage new technologies.
- Access to finance.

Solutions to address these challenges are being developed and tested around the world, as discussed in the following sections.

Overview of challenges facing smarter sustainable cities

Regulatory barriers

- Market regulations that disincentivise deployment of digital solutions.
- Stringent regulatory frameworks, which can hinder private-public partnerships.

Skills and capacity building

- Lack of digital and traditional skills.
- Insufficient human and infrastructure capacity to develop smart city initiatives.
- Lack of infrastructure for collecting, storing and analysing data.

Access to finance

- Lack of methodologies to quantify benefits, affecting perceived risk and cost of finance.
- Missing connections between different funding sources.
- Lack of instruments for financing low-carbon projects in cities.

Navigating regulatory challenges in energy innovation

Nurturing innovation in the energy sector encounters various challenges. They encompass intricate regulatory environments, a dearth of clear guidance for innovators, restricted access to resources for smaller entities, risk aversion among regulators and policy makers, fragmented collaboration among stakeholders, and challenges in assessing the impact of projects. But policy makers and regulators have options for overcoming these hurdles, in particular:

- Simplifying regulatory procedures.
- Offering transparent guidance and resources.
- Fostering collaboration.
- Encouraging a culture of experimentation and risk-taking to cultivate a supportive environment for energy innovation.

Regulatory experimentation can be instrumental in overcoming barriers and can be pursued by using regulatory sandboxes, regulatory pilot projects and pilot regulation. These may often be necessary to reduce the potential for exposing bill payers to cost uncertainty. When developing new regulations, policy makers can hold public consultations and establish regulatory sandbox programmes to facilitate temporary rule exemptions for innovators to trial promising new solutions that require regulatory adaptations.

In the United Kingdom, the regulator Ofgem has established a policy instrument called the Future Regulation Sandbox to test and trial changes to its energy rulebook in a controlled environment before implementing amendments. Among recent developments to facilitate smart grid deployment, Brazil is testing new tariff structures on more than 40 million customers across the country. The European Union has recently established a regulatory sandbox to test blockchain applications, Portugal is currently focusing on local energy community pilot projects, and Spain has just closed a first tender for projects to inform regulatory innovation in support of flexibility.

City-level sandboxes provide further opportunities to test innovative solutions that do not fit into pre-existing regulation and policy landscapes. In Brazil, Rio de Janeiro has developed a sandbox to help innovation and the deployment of technology, and to understand what changes are needed to create receptive regulatory frameworks. All projects will undergo an impact assessment to determine what further actions are needed. In Korea, the Smart City Sandbox programme has been in place since 2020 under the Smart City Act, allowing the testing of new technologies and services.

To facilitate experimentation options, policy makers can create specific co-ordination and information offices at the national level to provide guidance to regulators on experimentation across different sectors, such as the Canadian Centre for Regulatory Innovation, and create resources for this purpose, as Germany has done.

Toolkits and one-stop shops can also be created to help innovators understand regulation and options for experimentation and facilitate participation from smaller entities. Examples include Australia's Energy Innovation Toolkit and Japan's single point of contact for applicants at the Cabinet Secretariat. This need also emerged in the United Kingdom, where innovators applied for regulatory sandboxes to receive clarification and regulatory advice, finding out that in most cases a sandbox was not necessary for them to test innovation. This resulted in guidance for innovators and a point of contact to support them.

Regulatory experimentation in Italy

Since 2010 the Italian energy regulator, ARERA, has been implementing a variety of innovative regulatory approaches for learning purposes and to adapt incentive-based regulation in support of decarbonisation and power system transformation. This has taken place across several distinct phases:

- Phase one (2010-2012) focused on testing smart grid technologies, storage and dynamic thermal rating in critical portions of the grid, to design appropriate incentives for mass adoption.
- Phase two (2017-2021) introduced system-level experimentation through pilot regulation, adopting new and transitional regulatory schemes.

Several notable examples of pilot regulation include the following:

In 2017 demand-side resources began being able to provide flexibility services for grid stability through virtual aggregation. Around 1.3 GW of aggregated resources have been made available and lessons learned so far are informing new regulation on dispatching, with implemented anticipated from 2024.

In 2020 pilot regulation allowed new tariffs and business models for self-consumers located within the same building or multi-apartment block, enabled by smart meters. Lessons from this transitional phase were reflected in the integrated text for self-consumption, adopted in 2023.

In 2021 pilot regulation was introduced to incentivise private EV charging during off-peak hours. In parallel, the Italian committee for electrotechnical standards has been working on interoperability in the communication between aggregators and smart wallbox EV chargers.

During this phase, stakeholder engagement and public consultations were also strengthened.

- Phase three (2022-2025) continues to promote innovation, focusing on the opportunities offered by digitalisation to empower consumers and improve services, and on the innovative regulation of ancillary services, self-consumption and energy communities. Further experimentation will assess whether the current regulatory model sufficiently allows distribution system operators to take greater responsibility for ancillary services and grid management. This will take place alongside several pilot projects carried out by Italian distributors, testing the use of distributed energy resources in local flexibility markets and a range of planning tools (see Chapter 2 for further details).

Developing digital skills and capacity for smart urban energy systems

While digital technologies create far-reaching opportunities for cities and the energy sector, there is a risk that the lack of skills, including skills related to data and technology and soft skills, will constrain urban power system modernisation and may lead to investments in digital technologies being underutilised. Updating education programmes and vocational training, designing tailored capacity building, widening access to expertise and guidance, and ensuring inclusivity can all help address this risk.

The new foundational skills of the digital economy

Human skills	Business enablers	Digital building blocks
• Communication • Creativity • Critical thinking • Collaboration • Analytical skills	• Managing and analysing data • Software development • Computer programming • Digital security and privacy	• Communicating data • Digital design • Project management • Business process

Source: Burning Glass Technologies, Center for Innovative Technology, The Business-Higher Education Forum (2019), Future Skills, Future Cities, as modified by the IEA.

The demand for the digital skills needed for smart cities is predicted to increase twice as fast as the overall national level. Implementation may stall because municipalities and critical organisations lack digital as well as traditional skills and the necessary human and infrastructure capacity to develop comprehensive smart city initiatives. This particularly relates to integrating systemic approaches to urban services in municipal administrations, which are frequently structured in siloes. Also, as cities evolve they will host increasing numbers of data flows, but many local governments do not yet have the skills and the infrastructure for collecting, storing and analysing such data. In the energy sector, data science skills will become more important, and AI and machine learning understanding will become increasingly necessary to fully achieve net zero ambitions.

Key actions to fill the skills and labour gap in urban power system modernisation

1	**Creating guidance and tools to develop grid modernisation strategies**
2	**Anticipating, fulfilling and monitoring the skills demands of the energy sector**
3	**Addressing the skills mismatch**
4	**Co-designing training programmes with industry to reflect market demand**
5	**Developing complex cognitive, interpersonal, entrepreneurial and cybersecurity skills**

Some cities and national governments are offering training to city officials. For example, in South Africa a skills training programme was provided to Johannesburg city officials to support them in effectively implementing national and city-level policies in energy efficiency and green energy codes. Egypt has trained more than 12 000 government employees to build the digital skills needed to move to the New Administrative Capital, with programmes on digital project management as well as digital transformation to combat corruption. In 2020 the Cities Today Institute, a global collaborative network for cities, launched an education and training non-profit, the Urban Leadership Foundation, to support chief technology officers, chief information officers and their teams prepare for a digitised future. In Colombia the Ministry of Information and Communications Technologies launched training to close the digital skills gap of professionals in the ICT industry, where up to 90% of the tuition costs are covered.

Sharing knowledge and providing guidance and technical support drives urban energy transformations

Several initiatives are underway to develop toolkits and initiatives geared towards assisting cities and communities adopt and implement smart city solutions, digital transformation and sustainable practices. In Canada, a smart city toolkit has been developed to provide guidance on a range of smart city applications and technologies with a focus on how data and technology can be applied to existing and new types of municipal services.

With a view to promoting open-source data sharing, the Digital Cities Toolkit developed by UN Habitat is a policy toolkit to help develop people-centred, sustainable smart cities. It covers policies, data for the public good and technology procurement. Other capacity-building tools look to regions undergoing change. The UN entity the International Telecommunication Union has developed the Toolkit on Digital Transformation for People-Oriented Cities and Communities to provide a comprehensive guide to the digital transformation of cities and communities, aimed at local government leaders, urban planners and city officials.

One proven method of improving collective knowledge is sharing best practice advice, highlighting successful projects that have tested new innovative methods, and also providing technical assistance in the early stages. Mission Innovation's Urban Transitions Mission works to support cities to scale up innovative people-centred solutions such as distributed renewables, digital solutions and zero-emissions mobility, and by collaborating with national governments, international organisations, the private sector and financial institutions. There is also benefit in learning not just what worked, but also understanding what prevented wider or more rapid success. The European Union has set up the Smart Cities Marketplace, which provides a map of European smart city projects, including an overview of results achieved, barriers encountered and lessons learned. It also provides resources and support for implementation, including technical assistance.

To achieve the change that is necessary, and at the pace needed to stay on track with a pathway consistent with achieving net zero by 2050, it will be necessary to test many new solutions and technologies in many different regions and find what works well in diverse locations. The Mission Innovation Green Powered Future Mission aims to demonstrate that power systems in different geographies and climates can effectively integrate up to 100% renewable energy and maintain a cost-efficient, secure and resilient system. The initiative is implementing 80 pilot projects across different geographies, with an approach that avoids duplication and is focused on scalability and replicability. Other projects such as the EUR 345 million EU Horizon 2020-funded project, the Scalable Cities initiative, brings together 18 smart cities and communities to identify and promote energy solutions and business models that can be scaled up and replicated and lead to measurable outcomes. It has implemented more than 550 demonstrations of technological and social innovations in the areas of mobility and logistics, buildings, urban data and digital infrastructure, people's engagement and urban governance.

Inclusive programmes for skills development can break down barriers to clean energy opportunities

Targeted programmes and initiatives can help ensure that underrepresented groups benefit from clean and digital energy transition opportunities. The UN Development Programme and the Union of Municipalities of Türkiye have announced an EUR 8 million four-year digital vocational training initiative targeting a first round of 4 000 students and youth in cities across the country, while also upskilling municipal employees and working with youth-focused NGOs. In South Africa, in a larger-scale project, the city of eThekwini has recently set the target to train 1 million young people with IT skills in the next three years.

Several cities have identified the potential for the new energy economy and are developing green jobs programmes to train people, focusing on supporting underrepresented, low-income and unemployed people. In Brazil the city of Belo Horizonte, in collaboration with the United States, has launched the Coding Dreams in Vilas and Favelas initiative to foster digital inclusion by providing vocational training to residents of the vilas and favelas. Since 2019 the Coding Dreams programme has trained over 1 000 people. In the United Kingdom, the Green Skills Academy was launched in 2022 by London City Hall to provide training in green jobs to underrepresented groups, and aims to support 3 000 learners into jobs and 3 700 people into new training and learning.

Strategies and solutions for financing urban energy innovation

While both cities and electricity utilities face challenges in using their budgets to invest in digital technologies and new solutions, they can also face challenges in accessing finance and participating in projects and partnerships. Risk perceptions and lack of methodologies to quantify the full range of benefits from projects can further limit access to finance.

Public funding can help de-risk projects and attract private financing

Public funds can be used to de-risk and attract private financing. In the United States, as a result of the US Infrastructure Investment and Jobs Act, funding of more than USD 1.2 trillion will be available to help cities and communities build a range of smart city projects, such as the deployment of vehicle-to-grid technologies or the development of transport planning tools. In Europe, the Next Generation EU recovery plan allocated EUR 5.4 billion to its research and innovation Horizon Europe programme, which will contribute to funding the Climate-Neutral and Smart Cities Mission. This aims to create 100 climate-neutral smart cities by 2030, which would serve as pilots to enable all European cities to follow suit by 2050.

Sharing financial knowledge and skills, offering direct financial aid for capacity development and facilitating connections between different funding sources can help improve access to finance. Robust methodologies to assess the full costs and benefits of options can help alleviate risks and facilitate access to finance. The International Smart Grid Action Network has developed a smart grid evaluation toolkit that helps identify smart grid planning options through a techno-economic assessment that integrates cost-benefit analysis within a multi-criteria framework. Similarly, cities can benefit from tools to better assess the full set of costs and benefits.

To overcome investment barriers and leverage the impact of public resources, an increasing number of public green banks and green bank-like entities have emerged, offering green financial products to leverage public and private capital that unlock access to funding for projects aiming to reduce emissions, improve efficiency and provide resilience. There are examples of many successfully funded projects in the United States, India, Indonesia and France.

International and multilateral financial institutions can provide funding and tools to support urban-led action. The European Bank for Reconstruction and Development launched its Green Cities Framework in 2016 to systematically promote sustainable urban development in more than 50 cities in 25 countries, with more than EUR 5 billion invested across around 90 projects, saving 4.6 million tonnes equivalent of CO_2, equivalent to removing over 1 million cars from the road.

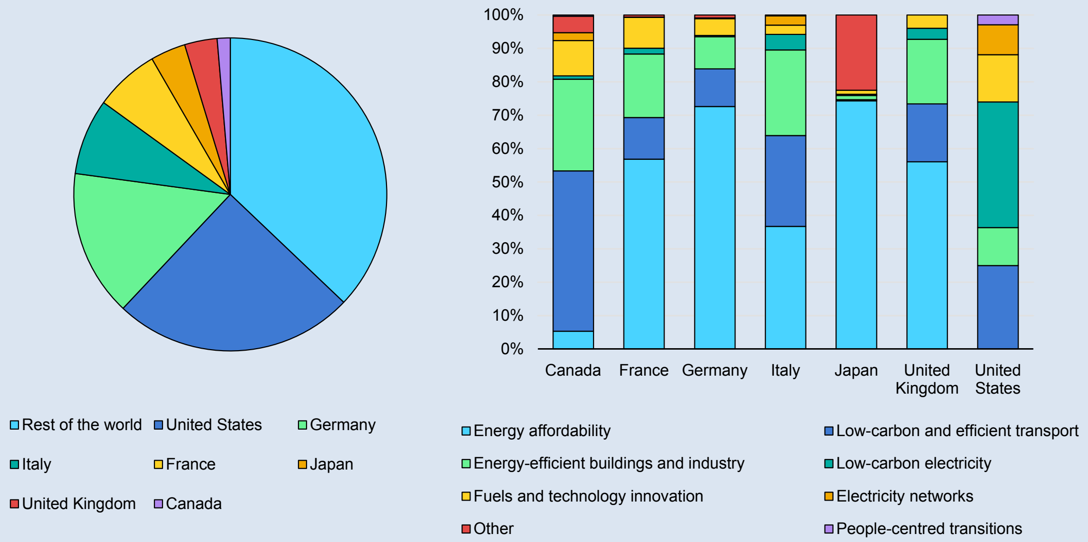
Analysis of G7 investment and priorities reveals trends in government energy spending

Total energy-related government spending, as monitored by the IEA's Government Energy Spending Tracker, has risen significantly since the start of the Covid-19 crisis. As of June 2023 governments globally had spent more than USD 2.2 trillion since April 2020, with G7 countries accounting for 63% of total investment. Germany and Japan spent around 73% of their total energy-related spend on supporting energy affordability, followed by France and the United Kingdom at around 60%.

Energy efficiency-related investment – including spending on efficient buildings and industry and low-carbon and efficient transport – accounted on average for around

33% of spending, approaching 53% and 75% respectively in Italy and Canada. The United States also spent 3%, equivalent to USD 16.3 billion, supporting people-centred transitions programmes.

Government energy-related investment support (left) and spending areas in G7 countries (right), April 2020-June 2023



Source: IEA (2023), Government Energy Spending Tracker: Policy Database, accessed February 2024.

Green, social and sustainable bonds create economies of scale

Some cities, with support from national governments, the private sector and international organisations, are addressing barriers and developing new business models and approaches to fund sustainable energy projects and implementation. Green, social and sustainable bonds are becoming an attractive instrument to finance low-carbon projects in cities. By bundling into one investment multiple projects that otherwise may have difficulty attracting investors due to low value, or uncertain returns, bonds can provide economies of scale and attract new investors. According to a recent market update by the World Bank, local governments have to date issued USD 21 billion in green bonds. Funds raised are being used for many different applications. In Canada, the city of Toronto has issued green bonds for investment in renewables, energy efficiency and green building projects. The city of Reykjavik, Iceland, has issued a green bond framework focusing on the low-carbon economy, such as buildings energy efficiency, clean transport and adaptation measures. Navigating financial markets can be challenging, but some governments are providing detailed guidance. Colombia produced a comprehensive guide for municipalities on co-financing smart cities, which delineates national and local-level financial resources, as well as international co-operation and private funding, that can be used according to the type of project, including smart grids and renewables in cities.

Mixing and matching public and private funding creates scale

Private capital can help fill the investment gap, but challenges inherent in smart grid and smart city projects may impede private investment, including the risk associated with new technologies, difficulty in monetising socio-economic benefits, and the lack of a clear path to return on investment. Analysis by the European Commission has determined that more than 40% of European smart city projects were financed from both combined public and private funds. In Rio de Janeiro, Brazil, public–private partnership investment of almost USD 190 million was used to replace more than 450 000 public lights with high-efficiency LEDs as part of the Smart Luz project. Around 70% included IoT sensors, enabling efficient operation through remote monitoring and control, with an additional 20 000 sensors providing data such as rainfall levels.

As part of the US Smart Cities Challenge, Columbus, Ohio, received a USD 40 million Department of Transportation grant, along with USD 10 million in philanthropic support, which enabled the city to attract more than USD 100 million of private sector investment. The municipality used the finance to transform the city's transport system, including deploying a digital tool and promoting ride sharing to reduce fuel usage and improve mobility for lower-income communities. The initiative has reduced traffic congestion, has seen EV adoption above regional averages, and has created or induced more than 2 300 jobs. In Spain a model was developed in Barcelona to combine clean energy and efficiency with rooftop solar PV and building energy retrofits. This pilot project has led to a strong pipeline of projects for implementation, with around 1 500 individual participants registering their interest in hosting PV installations on their buildings.

The C40 Cities Finance Facility, funded by the German, UK and US governments, facilitates access to finance for climate change mitigation and resilience projects in urban areas. Similarly, the City Climate Finance Gap Fund is supporting cities in emerging market and developing economies to design urban growth scenarios, and prioritise what sort of policies and investment mechanisms can support implementation. The EU Smart Cities Marketplace provides support in developing projects and matchmaking for the financing of urban projects and intensification of partnerships with existing initiatives. Since 2018, this initiative has been able to match approximately 130 projects with a value of more than EUR 600 million in investment.

Chapter 6: New approaches to pilots and experimentation for large-scale implementation

Key takeaways

- Pilot projects can be useful for testing and de-risking early-stage digital energy solutions in emerging markets. They reduce subsequent costs and time while providing valuable evidence and insights. The involvement and innovation of non-traditional actors in regulatory aspects also support successful outcomes.
- Strengthening international collaboration and knowledge sharing is crucial for developing common practices and standards. Collaborative projects can accelerate urban energy transitions at a lower cost, providing evidence for the value of digital solutions.
- The 3DEN/UNEP pilot projects in India, Morocco, Brazil and Colombia showcase the benefits of advanced digital technologies. They aim to improve energy management, enhance affordability and manage grid flexibility, with quantifiable outcomes like energy savings and CO_2 emission reductions.

Accelerating implementation in emerging markets and developing economies

Emerging economies require further investment in early-stage digital energy solutions to leverage renewable resources, enhance supply security and increase energy access. Pilot projects can help de-risk such initiatives by testing technologies in limited areas, reducing implementation costs and time. New approaches such as demand response and community initiatives need not only new technologies, but also involvement from non-traditional actors and innovation in regulatory, institutional and social aspects. Pilots offer real-life evidence and adaptability insights, while international collaboration and capacity building facilitate best practice sharing and project scaling.

Strengthening international collaboration and knowledge sharing is vital to developing common practices and standards and identifying areas where innovation can be leveraged jointly, accelerating progress in urban energy transitions at a lower cost. Collaborative demonstration projects can provide valuable lessons on how to manage digital technologies on a larger scale and create evidence for the value created by digital solutions and technologies, which can, in turn, help de-risk future investments.

To accelerate action, UNEP and Italy's Ministry for Ecological Transition are teaming up to support the digitalisation and development of flexible and resilient energy systems for the urban context and beyond. They have developed a novel smart grid pilot programme that is providing insights and evidence for the IEA's Digital Demand-Driven Electricity Networks (3DEN) Initiative, on the policy, regulatory, technology and investment context needed to accelerate progress on power system modernisation and effective utilisation of demand-side resources. Four pilot projects are currently underway, which together aim to test new approaches to demand-side and distributed energy resources across a range of contexts, revolving around the principles of replicability and scalability.

Digital twin for enhanced electric distribution grid operation and management (India)

A pilot project, led by Panitek Power, is implementing digital twin technology for the first time in a fast-changing low-voltage distribution network in a southern part of New Delhi, India. Digital twins can efficiently integrate diverse data sources, offering distribution companies valuable insights for effective grid operation and management, and strategic planning for optimal asset deployment and upgrades. At the same time, the increasing penetration of rooftop PV and EV charging points presents additional challenges in grid operations. This initiative aims to provide crucial visibility on the network, empowering utilities to make real-time informed decisions on the one hand, and on the other to help defer the need for substantial investment in grid infrastructure, which is particularly significant considering the escalating number of electricity consumers in India. In the 19 months preceding January 2024, 29 million new household connections were added to the existing residential customer base of 267 million in 2022.

The distribution sector in India is grappling with financial and operational sustainability issues, with significant technical and commercial losses in parts of the Indian distribution network. Pinpointing the sources of these losses is crucial for remediation efforts.

The project covers 3 600 residential and commercial consumers, and measures various metrics, including implementation, performance, environmental impact and cost savings. The goal is to establish the tangible value of digital twin technology and provide recommendations for best practices. This comprehensive approach generates high-quality evidence that can guide policy makers in supporting the widespread implementation of this technology across India and beyond.

Implementation of advanced digital industrial and energy monitoring systems (Morocco)

Decarbonisation of industry is a strategic priority for Morocco and the country is targeting a 20% reduction in energy consumption by 2030. However, current energy management systems only display consumption in real time, without storing and analysing data for decision making or providing energy performance indicators. This hinders the effective identification of opportunities to reduce energy usage. The pilot project, implemented by Les Eaux Minérales d'Oulmès (LEMO), addresses these issues through digitalisation and the use of AI modules at two bottling sites to forecast energy consumption (by location and by production line), identify energy losses and predict maintenance actions to reduce energy consumption.

The two lead project bottling sites alone have an electricity consumption of almost 56 GWh (2021), with a peak capacity of 10.25 MW (Tarmilat) and 7.5 MW (Bouskoura). Such high energy consumption, combined with the current state of the equipment, requires more advanced and intelligent solutions for measuring energy in real time and analysing large amounts of data to produce tangible savings. The project should result in energy savings of at least 30%.

The data generated by the project will be used to develop energy efficiency action plans. These will serve as a roadmap for the entire sector. The project is intended to contribute to reducing CO_2 emissions in line with the LEMO low-carbon strategy, which aims to achieve a 50% reduction in greenhouse gas emissions by 2030 compared to business as usual. This would contribute to the national emissions reduction target of 45.5% by 2030.

The project will also address the sector's infrastructure gap, specifically smart and interconnected energy metering systems, and the limited levels of awareness, funding and technical assistance.

Digital districts for flexible energy services (Brazil)

An estimated 96 000 new affordable houses will have to be built every day globally by 2030 to meet growing housing needs. At the same time, low- and moderate-income households are less likely to adopt rooftop PV. They may face barriers to actively participating in and reaping the benefits of the energy transition.

The Digital Districts for Flexible Energy Services (D2FX) project, led by Planet Smart City, aims to demonstrate how digital solutions can improve housing affordability by optimising energy usage and reducing the associated costs. It intends to demonstrate how digital solutions can seamlessly integrate distributed energy resources with energy storage systems and orchestrate dispatchable loads at consumers' premises to support the grid and avoid disruptions. This can enable consumers to actively participate in the electricity system and benefit from remuneration schemes for energy production and for providing ancillary services.

The project is optimising demand response and load-shifting mechanisms while providing seamless services and enhanced comfort for residents in the large-scale, affordable housing neighbourhoods of Aquiraz and Laguna near Fortaleza, Brazil. The project Smart City Laguna is expected to involve 18 000 residents and to benefit around 10% of the resident population. More than 60 houses out of 623 will be equipped with solar PV (1.1 kWp) and home storage system (5 kWh) and each house is expected to produce and consume respectively 1 970 kWh and 1 570 kWh per year. The innovation hub of Smart City Aquiraz will be equipped with solar PV with a nominal power of 80 kWp and a storage system of 15 kWh, and is expected to produce 140 MWh per year. A digital layer of sensors connected to the Energy of Things Platform seamlessly gathers real-time data from distributed renewable energy production plants, energy storage systems and smart meters at the housing unit level. The platform optimises energy use and identifies the best actions the community can implement to maximise the use of local renewable sources. It also relays crucial insights to residents through an app. This direct communication channel empowers residents to tailor their energy consumption to individual needs, reducing waste and curbing expenses.

By harmonising technological innovation, environmental stewardship and societal well-being in energy usage and urban planning, the project aims to provide evidence of the profound environmental, social and economic benefits that digital technologies can unlock across smart affordable districts globally.

One of the project's goals is also to support the scaling-up of these solutions and their potential use in affordable housing programmes, such as Brazil's Minha Casa Minha Vida, to allow low-income consumers and other stakeholders in the value chain to benefit from clean energy transitions.

Distribution system operator's grid flexibility project (Colombia)

This pilot project, led by Enel Grids, aims to implement a flexibility scheme strategically designed to alleviate grid congestion and guarantee the reliability of services in the Sabana Norte region, within Enel's concession area in Colombia. The anticipated impact extends to over 320 000 customers.

The region is currently grappling with congestion events, resulting in outages, exacerbated by the surge in electricity demand resulting from a major expansion of the industrial and commercial sectors, with a potential for further future growth. To address these circumstances, the project laid out plans to reinforce the affected grid, to be completed in the medium term.

The project's digital solutions will facilitate near-real-time dispatching and seamless interactions between customers and the distribution system operator. Industrial and commercial entities with significant energy consumption will be empowered to adapt their consumption through monitoring and control devices and an app for bidirectional communication, and they will be remunerated for contributing substantial demand response.

This project leverages available demand-side flexibility and the smart grid capabilities of the distribution system operator to maximise the utilisation of distributed energy resources and contribute to the overarching goal of digitalising both the network and end users, thereby advancing the decarbonisation agenda in the energy sector.

This project will test innovative methods for fault prediction and loss reduction within the electricity distribution system. It will provide policy makers with a blueprint for potential mechanisms to activate demand-side flexibility in similarly congested areas nationally and beyond.

Approaches to maximising the value of pilots

These pilot projects have been designed to provide valuable data and insights to inform policy making and future projects. Further implementation in different locations will enable the development of strategies to adapt to local circumstances and demonstrate how projects can be tailored to achieve more successful outcomes. An important aspect related to scaling up and replication is that the conditions need to be right for projects to realise their ambition, particularly in EMDE regions where persistent barriers to finance exist due to the high cost of capital. Co-ordinated international support and mechanisms to enable international sharing of learning and insights offer the prospect of achieving scale and speed, and lower costs.

Chapter 7: Conclusions

National policy makers have an essential role to play in implementing new approaches and leveraging human, technological and financial resources to achieve net zero energy transitions in cities. This report looks at four priority areas for national policy makers when approaching their own climate action plans. These key areas **place people at the centre** of clean energy transitions in cities, support **data-driven integrated planning**, create a **supportive environment** for innovation and change, and foster **international co-operation**. By paying attention to these essentials, national policy makers can craft inclusive policies, prioritise efficiency and empower communities.

Four priority areas for national policy makers

Placing people at the centre, building for the future

- Supporting community-led initiatives for sustainable development.
- Promoting integrated urban planning with stakeholder involvement.
- Designing benefit-sharing mechanisms for clean energy access.

Supporting data-driven integrated planning

- Integrating energy and climate objectives into urban planning.
- Aligning grids with urban objectives.
- Incentivising optimisation of grid infrastructure and demand-side management.

Creating a supportive environment

- Enhancing data accessibility and utilisation for effective power system management.
- Promoting interoperability and digitalisation for informed decision-making.
- Supporting innovation and financing for sustainable urban development.

Fostering international cooperation

- Disseminating knowledge and accelerating innovation.
- Supporting financially for scaling up smart energy technologies.
- Replicating successful pilot projects for wide adoption.

Placing people at the centre, building for the future

Social licence, consisting of people's acceptance, approval and trust, is essential for advancing clean and equitable energy transitions at the necessary scale and pace to achieve climate and energy goals. Community-centred clean energy initiatives play a crucial role in securing this social licence by enabling individuals and communities to actively participate in adopting more efficient and sustainable practices and investing in clean energy technologies. These initiatives offer several benefits, including providing demand-side flexibility, reducing costs, promoting affordability, equity and inclusion, and generating local employment opportunities.

By prioritising a people-centred approach to urban net zero transitions, national policy makers empower cities to champion local and community-centred clean energy efforts while investing in education and capacity building.

National policy makers can **promote equitable measures** through the following actions.

- Supporting community-led initiatives for sustainable development:
- Craft policies that provide financial incentives and regulatory support for community-driven initiatives such as community procurement, people-led renovation, energy communities and positive energy districts.
- Specifically include vulnerable communities to ensure they benefit from these initiatives, promoting inclusivity and equity in urban development efforts.
- Promoting integrated urban planning with stakeholder involvement:
- Integrate multi-dimensional analysis, including environmental and social aspects, into urban planning frameworks.
- Support stakeholder involvement in decision-making processes to ensure comprehensive and inclusive urban development strategies.
- Examine multi-level governance mechanisms to facilitate co-ordination between local, regional and national authorities in urban planning efforts.
- Designing benefit-sharing mechanisms for clean energy access:
- Design benefit-sharing mechanisms such as group-buying schemes and subscription models to reduce the cost barrier for accessing clean energy technologies.
- Provide incentives and support for the implementation of these mechanisms, enabling equitable distribution of clean energy benefits, particularly among underrepresented and vulnerable groups.
- Foster collaboration between governments, utilities and community organisations to implement and scale up benefit-sharing initiatives effectively.

Supporting data-driven integrated planning

Data-driven integrated planning is crucial for transitioning to cleaner energy systems in urban areas. National policy makers can support sustainable energy objectives in all planning phases. City governments can accelerate progress by engaging people, prioritising efficiency and renewables, providing regulatory oversight and aligning utilities with urban objectives to ensure resilience and flexibility in power systems.

National policy makers can **support strategies for data-driven integrated planning** by taking the following actions:

- Integrating energy and climate objectives into urban planning:
- Embed energy and climate objectives into zoning and permitting regulations, infrastructure development plans and urban land use planning frameworks.
- Ensure that energy and climate considerations are central throughout all stages of urban planning and development, promoting sustainability and resilience.
- Aligning grids with urban objectives:
- Encourage electricity utilities to align their planning processes with urban objectives, fostering collaboration and engagement with energy users.
- Promote co-ordination between utilities and urban planners to ensure that energy infrastructure development supports broader urban development goals.
- Incentivising optimisation of grid infrastructure and demand-side management:
- In addition to investments in grid expansion, create incentives to optimise use of current grid infrastructure and leverage demand-side assets to enhance efficiency and flexibility.
- Encourage investment in grid modernisation technologies and demand response programmes to improve grid reliability and resilience.

Creating a supportive environment

Digitalisation empowers data-driven decisions for city-led net zero transitions. Real-time data inform target setting and assist in the identification of opportunities and monitoring of progress. National policy makers can create a policy environment that enables data access, fosters the sharing of best practices and promotes open standards. To address financing challenges, they can incentivise partnerships and innovative mechanisms, transform regulations and foster collaborative financing at the regional level.

National policy makers can **enable data-driven decision making** by taking the following steps:

- Enhancing data accessibility and utilisation for effective power system management:
- Enable city and utility access to relevant data to effectively manage the evolving power system, particularly by increasing visibility of distributed energy resources.
- Facilitate data sharing through trust frameworks and open data standards, ensuring all stakeholders, including government and utilities, can use data to inform decision making and drive innovation in business models.
- Promoting interoperability and digitalisation for informed decision making:

- Build on open data and interoperability principles to establish a common protocol and reference architecture for digitalisation.
- Enable more informed decision making and better integration of new technologies and business models into urban energy systems.
- Supporting innovation and financing for sustainable urban development:
- Reshape governance and regulatory frameworks to promote digital-driven decarbonisation in urban areas, fostering innovation and sustainability.
- Encourage collaboration and experimentation through city-level sandboxes and pilot projects to test innovative business models in electricity grids and other urban sectors.
- Improve access to finance by leveraging public funding, fostering collaborative financing schemes, and building sustainable finance mechanisms to support net zero pathways in urban contexts.

Fostering international co-operation

Implementing effective pilot projects and fostering international collaboration on grid modernisation are important for advancing sustainable energy solutions. Strategies such as knowledge exchange, allocating funding and replicating successful pilots could drive widespread adoption of clean energy solutions in urban settings.

Facilitating international co-operation, sharing technical expertise and mobilising financial resources are essential for enhancing grid modernisation efforts globally. To achieve these goals, it is important to address common challenges. Managing climate change and ensuring energy security require collective action through collaborative research, innovation and solutions. Strong international partnerships will contribute towards establishing resilient and sustainable energy systems that will drive global economic growth and development.

National policy makers can **ensure effective pilot project implementation** through these actions:

- Disseminating knowledge and accelerating innovation:
- Foster knowledge dissemination and learning exchange from urban pilot projects to identify areas for further innovation in urban energy transitions.
- Promote collaborative demonstration projects to accelerate progress in urban energy transitions at a lower cost, leveraging insights gained from successful pilots.
- Supporting financially for scaling up smart energy technologies:
- Allocate supplementary funding for successful pilot initiatives to facilitate the scaling-up of smart energy technologies, particularly in urban contexts.

- Support the expansion of proven solutions to a larger scale, contributing to the widespread adoption of clean energy technologies.
- Replicating successful pilot projects for wide adoption:
- Develop strategies for replicating successful pilot projects to drive widespread adoption of clean energy solutions across diverse urban settings.
- By replicating successful models, ensure that the benefits of clean energy solutions are accessible to a broad spectrum of urban communities.

Potential international actions spearheaded by G7 countries

G7 countries have an important role to play in incentivising and accelerating smart urban clean energy transitions by acting on several different fronts. These countries can provide financial incentives, resources and learning opportunities to help cities fund and implement their smart city initiatives. They can help create common visions for low-emissions transitions, improve co-ordination across government levels, and help deploy enabling technologies and infrastructure.

G7 countries can play an active role in **speeding up the global transition** by enabling developing economies to access the benefits that digitalisation can unlock through knowledge exchange, capacity building, technology transfer, and projects and programmes aimed at developing and trialling innovative approaches and dedicated financing mechanisms.

Moreover, G7 countries can help **set up broad international communities** of practice, support research and development, and enable cities to take advantage of advances in innovation. G7 countries can also provide common resources, frameworks and standards and foster collaboration between cities.

Finally, G7 countries can further strengthen **co-operation with EMDEs**, supporting in particular Africa's clean energy ambitions and advancing progress on inclusive and people-centred clean energy transitions, dovetailing with G20 efforts, namely the Brazilian G20 Presidency's key priorities.

The 3DEN Initiative can play a key role in synergising international collaboration on the topic of urban energy transitions and facilitating knowledge exchange, from policy guidance to on-the-ground implementation. The IEA and the Italian government welcome further countries and organisations joining the 3DEN Initiative and actively contributing to the development of analysis, tools, engagement and guidance in support of clean energy transitions around the world.

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