DECARBONISING ELECTRICITY:

HOW COLLABORATION BETWEEN NATIONAL AND CITY GOVERNMENTS WILL ACCELERATE THE ENERGY TRANSITION

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Summary

This report is the second of a two-part series, building on the key considerations contained in the first report and providing further policy recommendations. The initial report, *Urban Energy and the Climate Emergency: Achieving Decarbonisation via Decentralisation and Digitalisation*, explores how two megatrends, decentralisation and digitalisation, already are substantially influencing the restructure of energy markets. Decentralisation refers to a growing reliance on small-scale power sources that are distributed throughout an electricity grid. It is increasingly enabled by new digital technologies that allow for the coordinated operation of these power sources, locally as well as across grids. This is especially true in cities, where these megatrends are progressively converging and as urban governments chart multiple paths towards local, distributed, clean power generation.

Decentralisation of power systems in urban areas, aided by digitalisation could be a key strategy for national governments seeking to decarbonise electricity in support of their climate goals. Decarbonisation achieved through decentralisation and digitalisation is referred to as a "3D" transition in the power sector.

Large-scale grid decarbonisation, however, will require the coordination of transitional policies that are centrally led across multiple urban areas. This paper reviews national policy approaches that can enable decarbonisation of the power sector

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Installing solar panels on a rooftop in Jiujiang, East China. © Humphery.

more broadly. It also emphasizes, however, the importance of involving cities and local governments in these approaches. The objectives are (a) to explain why national governments should specifically take into account their cities in the context of power sector transitions, and (b) to specify how policies at the national and city levels can more effectively be integrated for the purpose of of grid decarbonisation.

Common challenges to grid decarbonisation and decentralisation

As the initial report in this series and other studies suggest, the decarbonisation of electricity requires policies and regulations at the national or grid level. To examine how a local government might complement a national effort, it is important to recognise the common challenges of 3D transitions and the relevant national policy and regulatory frameworks needed to address them. Studies of grid decarbonisation identify distinct transformation "phases," where substantial technical, policy or market reforms are called for before further decarbonisation can proceed. Complementary actions at the city level may differ, depending on the phase of larger grid-wide decarbonisation.

For example, the most challenging objective, initially, may be the installation of additional renewable capacity, using policies to mandate or incentivize the deployment of variable renewable energy sources. Subsequent phases could include policies to promote more flexibility as the market develops. Such challenges are interrelated and, as the penetration of renewables gathers momentum over time, greater flexibility will be required, eventually calling for new infrastructure, market restructuring and innovative business models, as well as more deliberate efforts for cross-sector integration.

The interrelationships among these challenges mean that a piecemeal approach to electricity sector decarbonisation – especially if it is achieved through decentralisation – will not work. To be effective, policy-makers must consider a comprehensive "policy mix" to strategically and simultaneously advance multiple elements of a phased approach to grid transformation. While numerous recent studies explore the composition of an appropriate national policy mix, most of these studies overlook the role of local government since, traditionally, it is not involved in power sector planning and regulation.

Cities as the missing link

There are multiple ways by which local governments can complement a national effort to decarbonise electricity, helping to overcome obstacles at various transitional phases. The manner in which local governments contribute will depend on their capacities, resources and governance responsibilities.

All local governments should become **partners in power sector planning**. For example, local governments should participate in national (or utility-level) power sector planning exercises, bringing local knowledge to bear in siting distributed renewables, improving energy efficiency in buildings, and enhancing the flexibility of local grid operations. At a later stage, local governments may provide **advice on local 3D planning** – especially where "prosumer" decentralisation models enable citizens to both produce and consume electricity – and **streamline implementation efforts** through local permits and zoning. Local governments also may establish **community bulk buying programmes** that accelerate adoption of local renewable energy sources.

Local governments with greater resources, capacities, and governing responsibilities will be able to undertake a wider range of complementary measures, including the **adoption of local ordinances that require or enable 3D infrastructure development; provision of financial incentives for local distributed clean energy resources; and installation of distributed clean energy technologies at municipal facilities and buildings.** A further complementary approach is to promote cross-sector integration at the local level, for example by promoting the electrification of urban buildings and transportation. In later phases of a grid transition, local governments with greater capacity may be able to contribute to flexibility and demand response services; encourage local microgrids and neighbourhood-wide renewables deployment; and provide the necessary data and information for efficient local grid planning and operation.

Finally, those local governments that are sufficiently large, and those with municipal utilities, can pursue a range of additional complementary measures, including the **piloting of new regulatory approaches and market structures** and the integration of a variety of municipal operations (including water, waste management, public transit, and ports) in local grid planning.

Enabling local government action

The partnership of local government in power sector transitions is essential; to be effective, it requires support at the national level. A comprehensive national policy mix for power sector transitions should include enabling policies for local governments. Key objectives should include the following:

- **Build local financial and technical capacities.** In the initial stages of planning for grid decarbonisation, national governments (i.e., energy ministries and utility regulators) should conduct skills and finance gap analyses to identify the support that local governments will require to facilitate local implementation of 3D transitions.
- **Facilitate governance reform to improve vertical and horizontal coordination.** It is essential for national governments to determine which levels of government will be responsible for implementing the various elements of a 3D transition, including elements related to physical infrastructure, regulation, and governance. As part of this determination, national governments should assess how best to coordinate national and local efforts, and identify opportunities for improved local government (municipal or metropolitan) cooperation in major urban areas.

- **Build local financial and technical capacities.** In the initial stages of planning for grid decarbonisation, national governments (i.e., energy ministries and utility regulators) should conduct skills and finance gap analyses to identify the support that local governments will require to facilitate local implementation of 3D transitions.
- **Legal and regulatory enabling measures.** Early in the process of grid decarbonisation, national governments should establish data sharing frameworks needed to facilitate 3D transitions, including both physical (infrastructure) and market data. National governments should also map out how national policies and regulations in other domains may be affected by 3D transitions, including policies related to industrial strategy, environment, telecommunications, and innovation.

Conclusion

Decarbonising electricity in line with global efforts to keep global warming well below 2°C – while at the same time ensuring energy access to growing populations around the world – will require a rapid and wholesale transformation in how electricity is generated and delivered. Cities, as major centers of electricity consumption, will be essential players in any such transition. If electricity decarbonisation is pursued through the decentralisation of power grids, local government engagement will be critical in order to streamline and accelerate deployment of necessary infrastructure, including local clean generation technologies, storage systems, robust distribution networks, and digital technology. To be truly effective, therefore, national approaches should explicitly incorporate local governments in a comprehensive strategy for decarbonising electricity involving 3D transitions.

Abbreviations

3D	Decarbonisation through decentralisation and digitalisation
cDER	Clean distributed energy resources
dRES	Dispatchable renewable energy sources
PV	Photovoltaic
vRES	Variable renewable energy sources

1. Introduction: The importance of national and local collaboration to decarbonise electricity

To achieve the deep decarbonisation of electricity around the world will require a transformational change in how it is generated and delivered. Cities are responsible for two-thirds of global final energy consumption, and local governments are increasingly demonstrating immense climate ambition; as such, it is critical to look at electricity decarbonisation through an urban lens. This paper is the second of a two-part series. The first paper provided a framework to better understand urban power sector transitions and the necessary roles of national and local governments in their realisation. An urban angle to the formulation of energy policy is critical when "decarbonisation" of the national grid is pursued through "decentralisation" and "digitalisation" - referred in the initial paper as the "3Ds." Many energy markets already are undergoing decentralisation and digitalisation, a trend that could be harnessed to support larger grid decarbonisation, especially in cities where these megatrends are increasingly converging.

Cities play, for multiple reasons, an essential role in the 3D transition of electricity.

This paper examines the policy approaches needed, at the national level, to broadly steer decarbonisation of the power sector, and the importance of involving cities and local governments in these approaches. In particular, the paper offers policy insight and recommendations for national policy-makers who seek to leverage the capacities of local governments, so as to maximize the value and effectiveness of 3D power sector transitions. It identifies specific ways in which local governments can contribute to these transitions.

Cities play, for multiple reasons, an essential role in the 3D transition of electricity. First, cities **are large electricity consumers**.[2] Any effort to decarbonise the power sector should take into account ways in which to serve the electricity demand of urban areas. In particular, measures to physically redesign power systems should consider urban form, infrastructure and economic activity. Second, local governments at the municipal, metropolitan and county levels frequently have **unique authorities** in these areas that, when exercised, can support (or hinder) grid decentralisation and decarbonisation efforts. Third, local governments are essential **mediators of power sector transition** in their communities; they have access to data and information, for example, that can aid the planning and operation of decentralised power systems.

Most importantly, the responsibility of local governments for, and their proximity to, local communities makes them indispensible partners in the local implementation of power sector reforms, especially for obtaining the buy-in of community members to ensure reforms are durable and sustainable. A transition to renewable electricity can yield multiple benefits for local communities, including socioeconomic development, job creation, air pollution reduction, and health improvement. Such benefits, frequently championed by local governments, are especially important as the world embarks on a path towards recovery from the impacts of the Covid-19 pandemic.[3] In short, local governments are critical actors to ensure successful, sustainable and economy-enhancing 3D transitions in urban areas.

Section 2 of this report describes, in further detail, the elements of 3D power sector transition and why the pursuit of decentralisation with digitalisation is often recommended as part of a national or regional strategy to achieve grid decarbonisation. Section 3 provides an overview of national policy approaches to drive power sector decarbonisation, including aspects relating to decentralisation and digitalisation. Section 4 describes how local governments are able to complement such approaches, as part of a comprehensive policy mix that is implemented at multiple levels of government. Section 5 addresses what national governments can do to better coordinate with municipal governments and enable local action, an essential step to realize the full potential of 3D transition. Section 6 provides conclusions, as well as recommendations for national policy-makers and regulators. The goal is to highlight the need for national governments to include cities in the transition of the power sector, as well as indicate how national and city-level policies can be (more) effectively integrated for the purpose of grid decarbonisation.

2. Decarbonising electricity through decentralisation and digitalisation: What it means, where it is occurring, and why

"Decarbonising" electricity involves reducing the amount of carbon released into the atmosphere when electricity is generated. To avoid dangerous climate change, the world must completely decarbonise electricity generation by the second half of this century. Such "deep decarbonisation"[5] will require replacing conventional power plants with renewable, nonemitting power sources.

One challenge is that power output from many renewable sources is variable and/or intermittent. Although variable renewable energy sources (vRES) are able to be curtailed when their output fails to align with electricity demand, this is not cost-effective for producers or consumers, nor is it aligned with net-zero ambitions. Despite a reduction in demand as a result of Covid-19 lockdowns, for example, electricity costs have increased in countries with greater penetration of vRES due to challenges in balancing supply and demand. The United Kingdom, for instance, saw system balancing costs soar. These challenges confirm that cost-effectively integrating high levels of vRES will require a transformation in how the grid is engineered and operated[6].

In particular, there will be a need for new technologies to store electricity (daily as well as seasonally), investments in transmission and distribution as a means to manage intermittency and, especially, improvements to grid flexiblity so as to shift or curtail demand and reduce system balancing costs.[7] It is possible for deep decarbonisation to be achieved in the context of a traditionally structured system in which electricity is generated at centralised power stations, such as photovoltaic (PV) fields and wind parks, and distributed to consumers over long distances.[8] This may continue to be the dominant model in many countries. Around the world, however, decarbonisation is increasingly taking place in the context of two mutually reinforcing trends in the power sector: decentralisation and digitalisation.

In a power sector context, decentralisation refers to a shift towards the generation of electricity from small-scale power sources distributed throughout an electricity grid, often co-located with particular loads (i.e., sources of electricity demand).[9] Rooftop PV systems, for example, can help meet the electricity needs of buildings where they are installed as well as neighboring buildings. As noted in Webb et al. (2020),[10] decentralisation is largely driven by the falling cost of small-scale renewable energy technologies, such as solar PV and wind; the availability and decreasing cost of new technologies for storing electricity (e.g., batteries); and the increasing feasibility of incorporating energy efficiency and demand response into grid and distribution system operations. Together, these clean distributed energy resources (cDER) can potentially and dramatically shift the way in which electricity is produced and consumed.

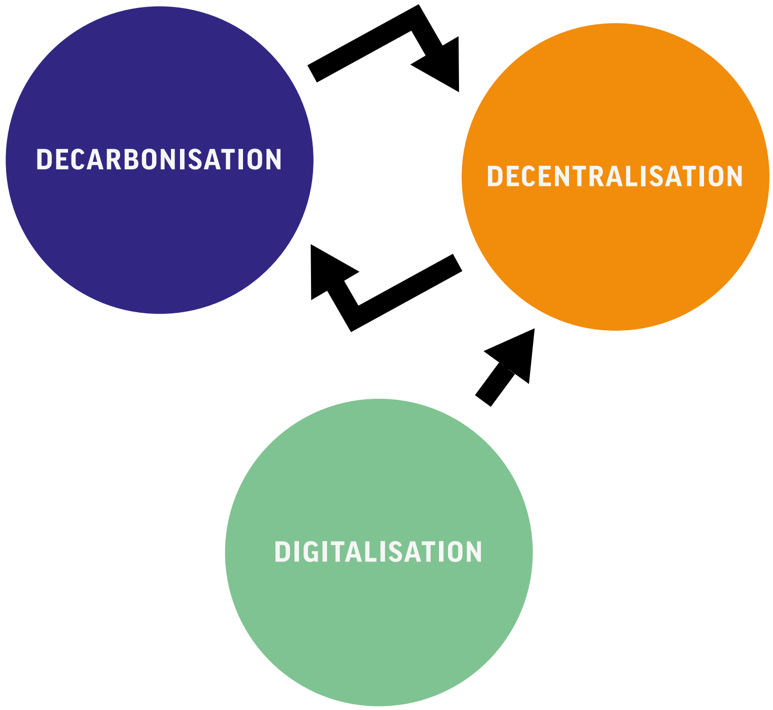
Decentralisation is taking place in a multitude of areas due to its cost effectiveness, even without factoring in the avoided costs of pollution and health impacts that come with the use of fossil fuels. In many developing countries, for example, the primary reason to adopt distributed generation is to serve areas where grid electricity is unavailable or unreliable.[11] In those cities and countries with wider grid-connected electricity access, decentralisation may also be driven by cost efficiencies and, to some extent, consumer demand (in many places, for example, rooftop solar now can be bought at home improvement shops). However, decentralisation involving cDER can also make sense as an explicit strategy used by grid planners to achieve decarbonisation, offering cost advantages; improved grid resilience through the redundancy provided by local networks able to operate independently from the main grid; and other benefits. Decentralisation and decarbonisation, therefore, can be part of a virtuous cycle, where one helps to push or enable the other (Figure 1).

Decentralisation and decarbonisation can be part of a virtuous cycle, where one helps to push or enable the other.

One reason decentralisation is increasingly cost effective is the advance of another trend: the progressive deployment of digital information technology. ”Digitalisation” refers to the use of advanced communication technologies to facilitate system management, including such things as time-of-use electricity meters and other “smart grid” technologies that allow real-time adjustments and more efficient operation of the local grid, community energy resources, and buildings. Sixty percent of electricity demand growth in the past 25 years is attributed to buildings, but smart thermostats and lighting, for instance, could cut building energy consumption by 10% by 2040.[12] Overall, digitalisation makes it possible to know, in real time, the status of the energy system - even to the level of individual buildings - with a high level of temporal and spatial resolution. This allows the coordinated operation of cDER on local distribution grids, as well as a real-time balance of supply and demand across larger grid areas. Where there is large-scale penetration of vRES, digital technologies can support grid flexibility, enabling large-scale distributed “demand response” measures (e.g., lowering power demand in buildings during peak load times or during shortfalls of variable renewable power).

While digitalisation is not a prerequisite for decentralisation, it nevertheless remains a strong enabler for it (Figure 1), allowing efficient and flexible management of distributed generation assets at a local scale.[13] Recent data show that digitalisation of power systems has been proceeding at a fast pace; between 2014 and 2016, global investment in digital electricity infrastructure and software increased every year over 20%, a higher pace than investment in gas-fired power generation.[14]

Figure 1. Inter-relationship between decarbonisation, decentralisation, and digitalisation (3D)



WHERE 3D TRANSITIONS ARE ALREADY OCCURING

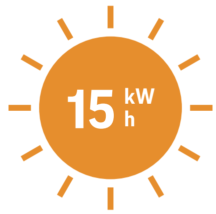
Together, decarbonisation, decentralisation and digitalisation often are referred to as the "3Ds" of a larger electricity sector transition that already is occurring in a number of developed and developing countries.[15] Table 1 illustrates, in practical terms, what forms the 3D transition may assume in different national contexts, with countries having been selected to demonstrate the diversity of starting points. Wherever possible, indicators have been selected to illustrate the degree of the 3D transition in each country, with (a) the share of electricity supplied by renewables[16] used as a proxy for the status of decarbonisation; and (b) the per capita amount of electricity generated from solar used to indicate the status of decentralisation. In addition, two indicators – mobile cellular subscriptions and the share of the total population using the Internet – provide a broad picture of the overall status of digitalisation in each country.[17] For each of the indicators, the latest available data are used; various indicators may therefore refer to different years. Finally, additional information is provided on the specific policies of each country as well as regional or national developments that may be relevant to understanding where the "3Ds" currently are in a given country, or what the perception around their development is among practitioners and policy-makers. There is no single 3D pathway towards grid decarbonisation;[18] as Table 1 illustrates, most countries today are at differing starting points, with a greater or lesser degree of decarbonisation, varying levels of decentralisation and digitalisation, and at different levels of policy emphasis on all three.

Table 1: Examples of power sector decarbonization, decentralization, and digitalization in select countries

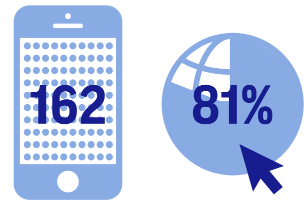
KEY	DECARBONISATION	DECENTRALISATION	DIGITALISATION	
	Share of electricity generation supplied by renewables, 2019	Per capita electricity generation from solar (kWh), 2019	Mobile cellular subscriptions (per 100 people), 2018	Share of individuals using the internet, 2017 – 2018
AUSTRALIA				
	21%	561 kWh	111	87%
	A highly varied renewable portfolio (with traditionally dominating hydro resources having been complemented over the last 10 years by massive solar and wind deployment) places the country in a good position with respect to the decarbonisation status of its power system (Burger et al. 2020).	The highest rate of per capita domestic photovoltaic installations in the world, amounting to nearly 25% of households (Burger et al. 2020) makes Australia quite advanced in terms of decentralisation of its power system. Also, due to the dominance of its rooftop PV market, Australia has been the obvious choice for the introduction of residential storage (Burger et al., 2020). This highly decentralised model, however, is posing important challenges, among them the so-called 'utility death spiral' caused by the increasing number of customers switching to onsite generation and leaving the supplier, with consequent higher grid costs to be shared among the remaining customers (Burger et al. 2020).	The high penetration of rooftop solar, its deregulated electricity retail markets, and the grid stress due to extreme temperatures and high electricity demand are opening up significant entrepreneurial opportunities in solar optimisation, grid balancing, and customer engagement. However, AI and Blockchain applications are still very much at proof of concept or pilot stage (Bumpus 2019).	
CANADA				
	67%	114 kWh	93	91%
	Increased integration of renewables is driven by policies throughout Canada. For example, the government of Alberta targets 30% of generation from renewables by 2030, and neighboring Saskatchewan aims for 50% by 2030. Ontario is one of the largest jurisdictions in the world to have eliminated coal-fired generation (World Energy Council 2018).	Utilities are integrating electricity storage in their current systems using a variety of technologies. Ontario's Independent Electricity System Operator has contracted for 56 megawatts of new storage capacity to enhance frequency regulation, provide ancillary services, and to store off-peak generation, supporting increased grid reliability and efficiency (World Energy Council 2018).	Digitalisation as part of the power system transition appears to be still a challenge (World Energy Council 2018).	

COSTA RICA

The country's Decarbonisation Plan contains a 100% renewable electricity production target by 2030 (GoCR 2018).

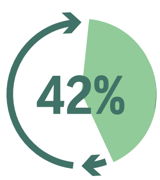


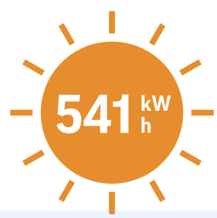
Very limited data availability makes it a challenge to understand to what extent the current renewable production is decentralised.

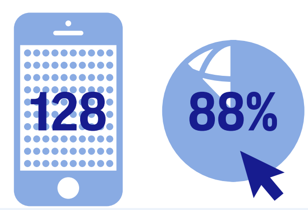


Digitalisation in the power system transition appears to be still at an initial stage; however, a "3D" ambition is explicitly adopted and the main challenges ahead are summarised in the country's Decarbonisation Plan, "The country must advance in processes of digitalisation, digital connectivity, smart cities and telecommuting. For this, it requires the development of tools for analyzing and using digital data and the availability of infrastructure in data centers, fiber optics and submarine cables. It also requires interconnection with the region." (GoCR 2018)

GERMANY







COSTA RICA

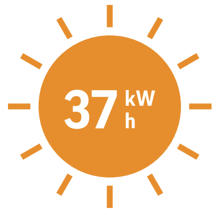
Decarbonisation with respect to the electricity consumption has seen important advancement over the last decade: at the end of 2017, renewables accounted for 38.5% of electricity consumption and the country aims to obtain 60% of its final energy consumption from renewables by 2050 (Burger et al. 2020).

Good degree of decentralisation, not only in the form of solar photovoltaic and wind, but also energy storage in the form of batteries (World Energy Council 2018). Interestingly, a good number of the decentralised renewable energy projects were initiated and are currently operated by small private investors, including individuals, households, and energy cooperatives (Burger et al. 2020).

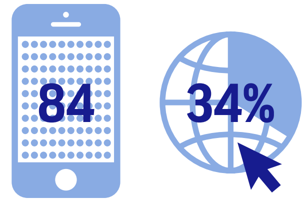
Digitalisation in the form of smart meters not very successful but currently pilot projects are being trialed as part of the ´Digital Agenda', mainly aiming at targeting SMEs to encourage them to use digital technologies at the intersection between energy and business (Bumpus 2019).

INDIA

The 3D trends are fragmented in India. Rooftop solar is a challenge to finance in cities where skylines change often; it remains at 21% of total installed capacity (Mercom India, n.d.).

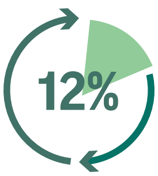


State level policy means there are very different implementation opportunities across the country for electric vehicles and other “smart” solutions (Burger et al. 2020).

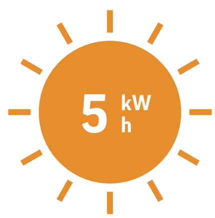


Smart metering is held back due to the structure of tariffs that make it more expensive for Commercial & Industrial customers to buy power, and therefore more likely to seek alternative (solar) backup (Burger et al., 2020). Going forward, greater penetration of digitalisation through smart grid/smart metering/pre-paid meters and the ongoing electrification of 2 and 3-wheeler transport is expected (Burger et al. 2020).

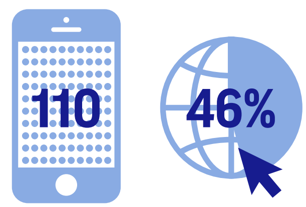
SENEGAL



Latest IEA data (IEA, n.d.) show that around 10% of 2018 total electricity generation in the country came from renewable energy sources.



Decentralisation appears to be advanced, with Senegal emerging as a leader in microgrid deployment: 30 microgrid projects are in operation with hundreds in the pipeline; a well-regulated, two-prong concession approach has been adopted for private sector involvement in microgrids; 80% upfront investment subsidy was granted for private investors for grid extension and off-grid electrification; and mini-concessions were granted for private micro-utilities for stand-alone microgrids in remote communities as part of Local Initiative for Rural Electrification projects (Frost & Sullivan 2018).



Digitalisation trends have been progressing in the context of the power system transition to allow the decentralisation development to happen (Frost & Sullivan 2018).

Note: IEA = International Energy Agency. Sources: Bumpus, A., 2019.[19]; GoCR (Government of Costa Rica), 2018.[20]; Frost & Sullivan, 2018.[21]; IEA, 2020.[22]; Mercom India, 2020.[23]; World Energy Council, 2018.[24]

THE BENEFITS OF DECENTRALISATION

From a national perspective, decentralisation in urban areas can be advantageous for multiple reasons. These include the following.

Lower system costs

Distributed energy systems offer advantages in densely populated areas (i.e., towns and cities), where it may be difficult to find the space to install large renewable power plants or where there is limited public acceptance for the extension of transmission infrastructure.[25] One study suggests electricity cost reductions of up to 50% are possible using cDER, even after factoring in social and technical complexities, such as the intermittency of renewable energy supply, heterogeneity and uncertainty of consumer demand and the sometimes considerable system balancing costs.[26] Global analyses suggest that up to 5% of urban electricity demand in 2050 could be met cost effectively with rooftop PV (with technical potential up to 32%)[27]. Many utilities increasingly are considering "nonwire alternatives" – including efficiency and cDER investments – as cost-effective ways to relieve grid congestion and defer or avoid the need for upgrading power lines, thereby accelerating decentralisation trends. For example, the Brooklyn/Queens area of New York city has avoided US$1 billion in upgrades with a US$200 million investment in demand management, a nonwire alternative.[28]

Flexibility management

The technical challenges that come with managing a system with many participants on electricity grids include moving to more two-way flows of electricity, allowing decentralised generation to feed into higher voltage systems; and dealing with new technology in the hands of consumers who are able to change the timing and magnitude of peak electricity demand.[29] Local governments undoubtedly will have competing policy priorities alongside energy system optimisation, including siting homes or electric fleet charging near where they are needed most, reducing traffic to city centres and alleviating acute fuel poverty. Where opportunities are provided to monetise local investment in them, however, properly coordinated cDER (including storage) can provide valuable flexibility services that will help to balance electricity systems and manage variability at small and large scales.[30] For instance, distribution network operators in the United Kingdom are procuring "flexibility" to manage local constraint areas, and these aggregated fleets of buildings that can shift demand rapidly, or batteries, also could provide services directly to the National Grid's balancing mechanism.

Greater grid resilience

"Resilience" refers to the capacity of an electricity system to tolerate disturbances while retaining its structure and function. Resilience is a crucial aspect of the electric service quality. A resilient energy system is one that can recover quickly from large shocks by providing various means to supply energy whenever there are changes in external circumstances,[31] such as extreme weather or other natural disturbances as well as cyber or physical attacks.[32] Decentralised grids can be valuable resources for community resilience, particularly if they are able to operate independently (in "island" mode) from the main grid during times of grid stress or failure.[33] Even where the 3D model is not the least-cost approach "on paper" for providing electricity, resilience and risk management can tip the balance and help achieve local buy-in for a larger energy transition, thus making it more sustainable and contributing to multiple sustainable development goals.[34]

Greater energy access

In countries where energy access is a key priority, including many developing countries, decentralised energy provides the fastest and most cost-effective solution. This is particularly true for rural areas, although decentralised solutions also may be as cost effective in many urban areas, including those rapidly expanding.[35] In wealthier countries, 3D solutions may prove effective at relieving so-called fuel poverty – defined as the inability of a household to maintain adequate heating and cooling at a reasonable cost given its income. Lloyd (2018)[36] illustrates a useful example of how a UK social housing estate was provided with solar panels, thanks to the intervention of the social housing provider as part of a pilot project, and how this generated significantly positive results in terms of fuel poverty reduction for the affected households.

3. 3D transitions at the grid level: The keys to a successful national approach and implications for local government engagement

As the initial paper in this series and other analyses suggest, decarbonising electricity – even if the focus is on urban electricity consumers – requires national- or grid-level policy and regulation.[37] To understand how local governments can complement national efforts, it is important first to understand the common challenges associated with 3D transitions at the national level, as well as the associated policy and regulatory frameworks to address them. This section provides an overview of the common themes and challenges, and introduces the concept of applying a comprehensive policy mix at multiple levels of government, in order to achieve grid transformation. Section 4 then outlines the roles that local governments may play in a national policy mix, based on their relative resources and capacities.

Decarbonising electricity - even if the focus is on urban electricity consumers - requires national - or grid-level policy and regulation.

To date, only a handful of countries have experienced deep penetration of grid-based vRES – including cDER – and none have completely decarbonised their grids. This obviously requires an enormous shift in policies, markets and technologies.[38] A growing body of literature, however, is beginning to chart what transformative decarbonisation of electricity grids could look like, and how such transformations may be enabled and managed through public policy.[39] Although a full review of the technical and policy challenges associated with deep decarbonisation is beyond the scope of this analysis, there are nevertheless some common themes that are of note. They include the need for a phased approach, with various types of policy to address the unique challenges that may arise as a result of increasing vRES penetraton levels; the tailoring of solutions to national and local circumstances; and application of a comprehensive mix of complementary policies, within multiple agencies and at multiple levels of government, to drive a successful transition.

MATCHING POLICIES TO DIFFERENT PHASES OF GRID DECARBONISATION

As greater vRES penetration is achieved on an electricity grid, the most serious challenge is how to balance electricity supply and demand. Low levels of vRES penetration are usually fairly easy to manage. High penetration of intermittent resources requires greater attention to potential supply and demand imbalances, including flexible grid management, investment in electricity storage capacity and development of more robust transmission and distribution systems. An accompanying growth in small-scale cDER requires greater digitalisation (i.e., deployment of "smart grid" technologies); upgrades to distribution networks; changes in electricity regulation and pricing; and policy and market reforms that enable new actors and business models to come to the fore (including aggregation of cDER generation and demand response).

The unique types of challenges associated with the various levels of vRES and cDER penetration have led several studies to distinguish different phases in the process of decarbonising electricity grids. The International Energy Agency, for example, identifies six different phases associated with various operational characteristics and challenges that arise with greater vRES integration.[40] An analysis by De Vivero et al. (2019)[41] adopts this same convention and identifies specific common grid operation challenges associated with each phase, from <5% to >85% vRES integration. IRENA et al. (2018)[42] take a similar approach and delineate four phases. Finally, an analysis by Burger et al. (2020)[43], which focuses more specifically on transitions for decentralised grid operation, groups the challenges into three distinct phases (Table 2).

Table 2: Phases of 3D grid transformation

PHASE	CHARACTERISTICS
Phase 1	Grid-based and centralised system, with decentralised renewables as a niche phenomenon (contribution to total power generation less than 10 percent)
Phase 2	Decentralised renewables growing in importance (contribution to total power generation up to 40 percent)
Phase 3	Decentralised renewables as dominant player with fully autonomous solutions not connected to a central grid

Source: Burger et al. (2020).[44]

The boundaries between the phases in all of these studies are somewhat arbitrary; however, they generally indicate where significant technical, policy or market reform is necessary before greater vRES integration can proceed without disrupting grid reliability and safety, imposing higher costs or leading to unintended outcomes (e.g., higher CO^2 emissions from ancillary and backup power). For the purpose of examining the role of local government in 3D transitions, Burger et al.'s more general phase definitions are adopted, representing a helpful guide to identifying relevant city-level approaches (Section 4).

TAILORING POLICY INTERVENTIONS TO NATIONAL AND LOCAL CIRCUMSTANCES

A clear message from existing studies is that there is no single, one-size-fits-all approach to decarbonising electricity grids. Instead, multiple pathways are possible, depending on a country's physical geography and grid infrastructure; availability and adoption rates of relevant digital technologies; and policies, regulations and institutions governing a country's power sector.[45] De Vivero et al. (2019)[46] identify five key characteristics that may help or hinder a country's adoption of vRES: availability of dispatchable renewable resources (e.g., hydroelectric power); prevailing patterns of renewable generation over time (e.g., changes in daily or seasonal output of solar and wind resources) and how well these correspond to patterns of electricity demand; population trends and load growth; population density and distribution; and interconnections to neighbouring countries and their grids.

Although the De Vivero et al. (2019)[47] study does not exclusively examine decentralisation, these same characteristics may help to determine the extent to which decentralisation is a cost-effective or preferred strategy in decarbonising electricity which, in turn, may influence the role that local governments play in this transformation. For example, countries with few dispatchable renewable resources; limited grid interconnection with their neighbours; relatively dense and growing urban populations; and solar or wind resources well-matched to seasonal loads may find urban-centered 3D strategies to be particularly advantageous (Table 3). This is because decentralised systems in urban areas -when effectively implemented and coordinated -can function as a resource for load balancing, generation and storage services that might otherwise be difficult or costly to realize with centralised vRES and storage technologies.[48] What "decentralised systems" in urban areas look like in practice will differ depending on the location; they can include such elements as microgrids on campuses, in industrial areas and in neighborhoods, where significant generation is feasible (and especially where resilience is valuable); aggregation of demand response measures in commercial and residential buildings alike; and increased deployment of vRES within cities on rooftops or on available open land.

Table 3. Characteristics that affect variable renewable energy source integration and the implications for urban 3D transitions

CHARACTERISTICS		IMPLICATIONS FOR VARIABLE RENEWABLE ENERGY SOURCE INTEGRATION	IMPLICATIONS FOR DECENTRALISATION	IMPLICATIONS FOR THE ROLE OF LOCAL GOVERNMENT
GEOGRAPHY	**Availability and potential of dispatchable renewable energy sources (i.e., hydro, geothermal, biomass, waste)**	The more dispatchable renewable resources (dRES) a country has in its system, the less variable renewable energy sources (vRES) are needed to decarbonise the power sector. Countries with a high dRES capacity can facilitate the integration of vRES by providing flexibility and exploiting seasonal complementarities between dRES and vRES.	Low dRES capacity could make decentralised approaches to decarbonisation relatively more attractive, where local storage and demand-response options are deployed to achieve flexibility.	Countries with low dRES capacity may need greater involvement from, and coordination with, local governments to pursue decentralisation and decarbonisation efforts.
	Patterns of renewable resources in time (i.e., seasonal ratio of solar and wind)	With high vRES penetration, the matching of seasonal fluctuations of vRES with typical load patterns becomes a key challenge. Additional measures may be required to manage the security of supply in periods when high levels of demand coincide with low vRES availability (e.g., winter for some countries with large penetration of solar power).	Low alignment between vRES and seasonal load patterns could require use of more centralised, long-term storage options. Decentralisation may still be an effective strategy, but complemented by more centralised system elements.	Urban clean distributed energy resources may be easier to implement where loads align with seasonal fluctuations in output. 3D transitions in urban areas, nevertheless, may be important (e.g., as a solution for managing flexibility).

POPULATION AND ECONOMY	**Trend of load growth**	Countries with significant load growth may favour the expansion of vRES capacity to meet growing demand. At the same time, significant load growth leads to increased energy flows in the network. In response, countries need to reinforce networks to cope with congestion. This can be a win-win situation for vRES, if the grid reinforcements are well aligned with vRES integration .	Decentralisation may be a cost-effective strategy to address load growth in urban areas, especially if this avoids costly new transmission investments.	Population growth frequently goes hand in hand with greater urbanization, creating opportunities for implementing clean distributed energy resources in urban areas as part of a broader grid decarbonisation strategy.
	Density and distribution of population	In densely populated areas, it may be difficult to find the space to install large renewable energy generation plants, but electrified communal heating or e-mobility becomes more economic. Limited public acceptance for extension of the transmission infrastructure regularly causes delays and uncertainties in network planning and implementation. At the same time, smaller distances between new generation sites and load centres may limit the need for additional transmission infrastructure.	All else equal, countries with dense urban populations may find decentralised vRES to be an advantageous approach to decarbonisation, for the reasons described.	Countries with denser, more urban populations may need greater involvement from, and coordination with, local governments to pursue decentralisation and decarbonisation efforts.
POTENTIAL FOR INTERGRID CONNECTIVITY	**Direct interconnection to neighbouring grids**	Interconnections are an important source of flexibility. On average, a grid with high interconnection capacity can more easily cope with the variability and uncertainty of vRES while demanding less flexibility from its dispatchable generation assets. A grid with limited interconnection capacity, in contrast, faces greater challenges to balance power generation from vRES.	As with the availability of dRES (above), fewer interconnections could make decentralised approaches to decarbonisation relatively more attractive, where local storage and demand-response options are deployed to achieve flexibility.	Fewer interconnections may mean that decentralisation offers a more cost-effective approach to integrating vRES than transmission investments. In this case, greater involvement from, and coordination with, local governments may be needed to pursue decentralisation and decarbonisation efforts.

Source: (a) De Vivero et al. (2019),[49] Column 1, Column 2, and Column 3; and (b) authors' own assessment, Column 4 and Column 5.

APPLYING A MIX OF COMPLEMENTARY POLICIES TO DRIVE THE TRANSITION

While every country most likely will face unique circumstances, there are some common challenges that policy-makers must address for any transition to a decarbonised electricity grid. As described in the first paper,[50] these include the following:

- **Achievement of greater vRES penetration.** For electricity grids in the early phases of transition, a basic challenge is the simple addition of more vRES to the grid. For centralised generation, this is relatively straightforward; low levels of centralised vRES power can be accommodated without significant disruption to grid operation. Nevertheless, various kinds of mandates or incentives may need to be adopted to drive greater adoption. Later stages may be even more challenging, especially as greater penetration is achieved through cDER deployment.
- **Flexibility management.** Greater vRES penetration inevitably leads to greater challenges in balancing electricity supply and demand. On traditional grids, flexibility is needed to accommodate exogenous fluctuations in demand, and is achieved through the operation of dispatchable power plants. As the proportion of variable renewable generation grows, fluctuations in supply will occur as well, and new approaches to flexibility will be necessary. These can include distributed demand response (i.e., shifting or curtailing demand to better match patterns of generation), deployment of (dispatchable) storage technologies and more robust distribution networks and transmission systems -all assisted by greater deployment of digital technologies to provide better visibility and control of grid resources. While high penetration of cDER can increase the variability of supply, decentralisation and digitalisation can allow demand to be better managed, thus enabling greater flexibility in grid operation.
- **Accommodation of new business models and a "value shift" within the electricity sector.** As explained in the first paper, 3D transitions make it possible for economic value associated with electricity services to accrue to new participants in the electricity system. The challenge for regulators is to maintain system reliability and consumer protections, even as the status quo is rapidly evolving and requires new technologies and business models to be rapidly de-risked and adopted. The tendency will be for regulators to move slowly and prudently, which is at odds with the pace of sector transition needed, and could delay change that benefits the energy system and citizens. Development of new kinds of services will add to the economic importance of urban electricity markets, in particular, and will expand policy and regulatory options for managing urban electricity systems.[51] A full transition to a decarbonised grid -especially one that incorporates decentralised systems -will require a range of institutional and policy changes to enable new actors and business models.

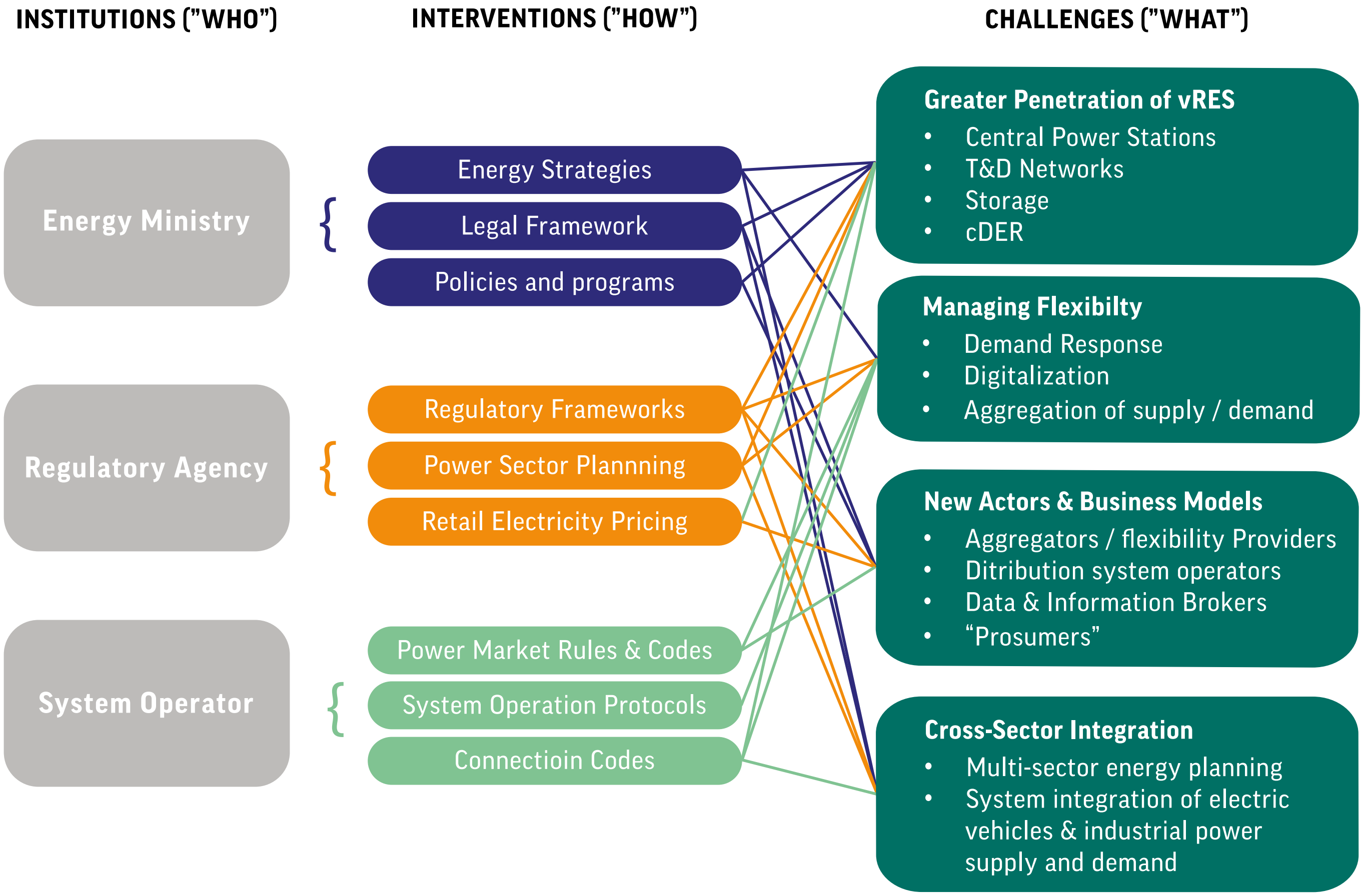
- **Cross-sector integration.** A major strategy for decarbonising energy economy-wide is to decarbonise electricity generation as well as to "electrify" end uses that traditionally rely on the direct consumption of fossil fuels (e.g., space heating, transportation and some industrial processes). Electrification of end uses would substantially increase electricity demand, requiring greater investment in carbon-free generation sources and grid infrastructure. Electrification, however, also can be leveraged to facilitate greater penetration of vRES. With proper integration, for example, electric vehicle batteries could serve as an aggregate reservoir of electricity storage, providing critical load balancing and reserve services in urban areas with high cDER penetration.[52] Likewise, heating or cooling networks in dense urban areas may be a much more efficient way to balance vRES than backup fossil fuel plants, particularly if electrification of these end uses creates new opportunities for demand response services. Leveraging such opportunities for cross-sectoral "coupling" will require comprehensive planning frameworks, as well as policies and regulatory approaches that enable new services and market actors.[53]

The relative prominence of each of these challenges will depend on which phase of the transition a power grid is in. Initially, the biggest challenge may simply be the installation of more renewable capacity, with policies focused on appropriate mandates or incentives to encourage vRES deployment. In later phases, issues of flexibility and market restructuring may come to the fore, where dynamic or agile pricing passed through to retail rates could play a role. These challenges are inter-related, and greater vRES penetration over time will lead to a greater need for flexibility management which, in turn, will require accommodation of new infrastructure, market structures and business models, along with more deliberate efforts at cross-sector integration.

The inter-relationship among these various challenges implies that a piecemeal approach to electricity sector decarbonisation especially if it is achieved through decentralisation -will not work. Instead, policy-makers should consider comprehensive policy mixes that strategically and simultaneously advance multiple elements of a phased approach to a "smart energy system," of which grid transformation is a key part.[54] Various analyses explore what such policy mixes can or should look like at the national level. De Vivero et al. (2019)[55] and IRENA et al. (2018),[56] for example, identify the need for a combined set of technical, policy, and system operation and market design interventions to address a range of electricity system planning and management issues that arise in different phases of vRES penetration.

The International Energy Agency usefully distinguishes the institutions ("who"), policy, market, and regulatory interventions ("how"), and the hardware and infrastructure ("what") needed to support greater power system flexibility.[57] This framework is adapted here to consider policy mixes for power system transformation more broadly – including 3D transitions. Figure 2 schematically illustrates how a policy mix approach, involving interventions at multiple governance levels, can address the four common challenges for 3D grid transformation identified above. The sequencing and timing of interventions will correspond to the challenges a country may face at different phases of the transition to full decarbonisation which, in turn, will depend on country-specific characteristics (as described above).

Figure 2. Schematic policy mix approach for driving 3D grid transitions



Source: Adapted from IEA (2019).[58]
Notes: T&D = transmission and distribution;
cDER = clean distributed energy resources;
vRES = variable renewable energy sources.

Missing from this picture is the role of local governments, which traditionally are not involved in power sector planning and regulation. Nevertheless, there are multiple ways in which local governments can complement nationally led efforts to decarbonise electricity, filling in key parts of the policy mix needed to address challenges at various phases of the transition.

4. How local governments can complement national efforts to decarbonise electricity: A framework for different city types

Many cities around the world are taking action to address climate change with or without the support of national government. As part of these efforts, local governments are increasingly setting targets for decarbonising city-wide electricity supply, including at least 250 cities worldwide with 100% renewable energy targets.[59] A large body of research, therefore, has studied what local governments should do to promote the expansion of renewable energy.[60] Most of these studies examine how cities can decarbonise their own electricity supply, although some also highlight the role that local government could play in broader grid decarbonisation -especially since local governments have limited authority to achieve full clean energy transitions on their own.[61] This section focuses specifically on the question of what kinds of city- or metropolitan-level interventions could complement national grid decentralisation and decarbonisation policies.

At the broadest level, the primary role of local government in a coordinated 3D transition is to help accelerate – and ensure the success of – national decarbonisation efforts.[62] This can be accomplished through a full spectrum of policy instruments, including regulatory interventions, economic instruments, information provision and innovative governance.[63] Thus, depending on the city and its circumstances - and the relative capacity and autonomy of its local government - a typical local policy mix could include such elements as the following:

- **Regulation and incentives** that make it easier and more cost effective to deploy local cDER and associated digital technologies, and that facilitate power system flexibility and new business models.[64] These local regulations and incentives can (and should) actively complement power sector regulatory frameworks instituted by higher-level regulatory agencies (Figure 2). In some cases, local governments may play a critical role in the enforcement or implementation of national-level regulations and incentives.
- **Investments in cDER infrastructure**, including adoption of cDER and demand-response technologies in municipal facilities, as well as financial support for community vRES, efficiency and demand-response projects.[65] Again, these investments can (and should) complement power sector planning and operation strategies at the level of central regulatory agencies and system operators by, for example, enabling local consumers and investors to realize the economic value associated with them.
- **Data collection and reporting** to enable more effective planning of local 3D infrastructure development. Data is often fragmented or outdated at the

local level, and it can be an important element of national planning. Local data collection – for instance, about where new developments are planned or on the levels of congestion on low voltage networks – can feed into centrally-led system planning efforts. Likewise, sharing these types of data with market actors, within a broader national framework for energy data governance, would facilitate new market models and improve operating conditions. Greater access to city-level data also will allow energy transition goals to be measured and managed in the context of related policy goals, such as air quality, waste management and access to public transit.

- **Advising and facilitating** to ensure community input into 3D decision-making; and coordinating urban planning, vertically (working with the national and subnational levels of government) as well as horizontally (across local government departments), to ensure effective deployment of cDER and related technologies and facilitate cross-sector integration.[66]
- **Aggregation and coordination** – especially in the later phases of transition -that enable the cost-effective operation of local, decentralised distribution grids for the benefit of city residents, including through local distribution system operation.[67] This often may be done more cost effectively at the local level than through a central system operator, where small interventions using cDER or building efficiency and flexibility can avoid higher-cost network upgrades.

The remainder of this section identifies various ways in which local governments can contribute to nationally led 3D transitions. Many of the local policy options described below may be pursued – and actually are being pursued in many cities around the world – by local governments seeking to boost the share of renewables used to meet their community electricity demand. While some proactive local governments are able to pursue these types of actions at (nearly) any time, large-scale grid decarbonisation definitively will require coordination with central government transition policies across multiple urban areas. The mix of local policies will evolve over time as transition progresses, entailing a transition pathway that is unique to each city or urban area.[68] In the following subsections, therefore, it is indicated:

- how local actions can help address the four common challenges for a nationally led 3D transition – achieving greater penetration of vRES; managing flexibility; supporting new actors and business models; and cross-sector integration; and
- when local policy actions would be most useful from the standpoint of complementing a national transition, based on the phase of the transition (earlier or later).

Finally, because different local governments have varying capacities and legal authorities, policy options have been grouped according to the relative capacities (technical, financial, or legal) they have for action. Section 4.1.1 describes a mix of actions that every local government – including those of smaller municipalities with fewer resources – should be able to undertake to complement national transition efforts. Section 4.1.2 describes measures that larger local governments, including metropolitan governments, could take in addition to those in Section 4.1.1. These include financial incentives, infrastructure investments, regulatory approaches and service provision, requiring more vertical coordination (with national regulatory authorities) and horizontal coordination (among different local agencies and jurisdictions). Section 4.1.3 identifies an approach that larger, more sophisticated local governments can undertake to help accelerate 3D transitions: the piloting of new regulatory approaches and market structures. Finally, Section 4.1.4 describes the unique complementary actions that municipally-owned electric utilities can undertake at the direction of local governments to assist in implementing 3D transition strategies.

ALL LOCAL GOVERNMENTS

Not every municipality can be at the forefront of efforts to decarbonise the electricity grid. Smaller municipalities, in particular, may lack the required financial resources and regulatory and technical capacities. Furthermore, they may lack the density and economies of scale needed to support some of the more sophisticated implementations of a decentralised system architecture. On the flip side, smaller towns and rural communities often are well-suited to a decentralised approach, and "prosumer" market models are currently more prevalent in these communities than in dense urban areas.[69] Regardless of circumstance, local governments of all sizes can take steps to complement and ease implementation of all phases of a nationally led 3D transition. A critical role – even for local governments that are small or under-resourced – is to act as a facilitator and mediator of national transitional efforts within their jurisdictions. Key actions include the following (summarised in Table 4):

Important for all transition phases

- **Partnering in power sector planning.** A successful transition to a decentralised grid requires an expanded role for local governments in effective power system planning. Local governments can participate in national (or utility-level) power sector planning exercises (Box 1), in particular by providing a detailed understanding of local barriers and opportunities for siting vRES (including cDER), improving energy efficiency in buildings[70] and identifying opportunities for enhanced demand-side flexibility. Local governments also can aid in identifying options for developing distribution network infrastructure.[71] Such participation will help inform national decision-makers about appropriate or desirable levels of decentralisation, as well as clarify the expected contribution of cities to system-wide decentralisation efforts. Local governments also can help to identify critical loads within their jurisdictions, along with opportunities to improve efficiency and, in later transitional phases, to provide demand response services, thus improving local resilience.[72] In addition, participation in national planning efforts will assist local governments to integrate cDER energy access solutions into urban development strategies, aid local planning for cross-sector integration, and develop local institutional capacities to coordinate implementation efforts within their communities.[73]

BOX 1 **Partnering in power sector planning: Beyond efficiency to nationally aligned climate action planning**

Ireland's Climate Action Plan in 2019 will require a retrofit of hundreds of thousands of homes to achieve high efficiency standards by 2030. The plan additionally sets out changes for national urban planning and electricity grid connections to allow local authorities to more effectively contribute to national targets (a detailed sectoral roadmap creates targets for 2021–30). All local authorities have established Climate Action Regional Offices to carry out the delivery of action plans. The intention is that regional implementation will contribute to national implementation and, in turn, will reinforce the delivery of targets at the level of the European Commission. In practice, this should allow differing approaches at the local level to address critical issues, such as electrification of heat and transport, by taking into account local density and economic conditions.

India's Energy Efficiency Services Ltd. is the government-run energy services company tasked with deployment of building energy efficiency and energy efficient technologies on a national scale. It sets targets for efficient devices (e.g., fans and lighting), and then encourages local distribution and deployment through various tender programmes and partners. While the Smart Cities Mission is officially tasked with more innovative "smart city" capabilities, Energy Efficiency Services Ltd. has begun to partner with local governments to roll out electric vehicle charging infrastructure while continuing to deliver solar pumping, photovoltaic and smart meter programmes.

Important for later transition phases

- **Advising and facilitating local 3D planning.** As numerous studies note, local governments are uniquely positioned to enable and facilitate dialogue around the local adoption of renewable energy and energy efficiency strategies.[74] Local governments can enhance the success of 3D strategies, in particular, through participatory planning at the local level and thus ensure that citizens have a say in shaping their energy systems.[75] This is particularly true for the success of "prosumer" decentralisation models, where the majority of citizens transition to becoming producers as well as consumers of electricity.[76] Provision of information and consultation also can raise citizen's general awareness about the benefits of decarbonisation and energy conservation (Box 2), allowing for better planning around associated economic transitions (e.g., fall-offs in traditional manufacturing and construction jobs).[77]

BOX 2 **Advising and facilitating local 3D planning: Durban and Johannesburg, South Africa, and Dublin, Ireland**

Durban and Johannesburg, South Africa: Durban has developed a geospatial map to allow residents to identify cost and savings opportunities in relation to the installation of rooftop solar photovoltaic, in part to support the city in dealing with resource adequacy problems facing the country. Johannesburg has used geospatial mapping in the first instance to improve climate action planning, by identifying existing solar photovoltaic and solar hot water heating.[1]

Dublin, Ireland: Dublin's energy agency, Codema, has developed a spatial energy demand analysis, and is building on this to create a Dublin Region Energy Master Plan to facilitate the city's climate action plan and encourage citizen engagement.[2]

[1] For further information, see http://gis.durban.gov.za/solarmapviewer.

[2] For further information, see https://www.dublincity.ie/residential/environment/dublin-city-councils-climate-change-action-plan-2019-2024f.

- **Streamlining local implementation efforts.** The ability to develop and deploy city infrastructure — including cDER and the digital technologies necessary for a 3D transition -depends on local permit rules, municipal procurement policies, zoning ordinances and other bylaws. These measures, while crucial to facilitate energy transition in urban areas, are often overlooked in broader policy studies.[78] For those local governments unable to adopt and enforce more sophisticated regulatory approaches -such as "whole-building" energy codes or other requirements for developing cDER (Section 4.1.2) -investing in better permitting procedures and the staff to conduct inspections will be essential to speed local transition efforts.[79] Local governments also can aid with cross-sector integration by, for example, streamlining the siting of electric vehicle charging infrastructure (Box 3). Other complementary measures may include running ongoing public awareness campaigns and maintaining registries of cDER certified installers.[80]

BOX 3 Streamlining local implementation efforts: Kitakyushu City, Japan, and Shenzen, China[1]

Kitakyushu City, Japan: The city was one of 29 local authorities selected by the Government of Japan to establish local sustainability initiatives in line with the country's 5th Basic Environment Plan Japan 2018. This has led the city to invest in its own power generation and innovative smart building infrastructure.

Shenzhen, China: The city has benefited from national government support to rollout electric vehicle infrastructure, starting with buses and taxis - the subsectors easiest for government to influence. It has supported construction costs for charge-points, thus lowering operator costs.

[1] Webb, M., A. Scott, I. Gencsu and D. Broekhoff, 2020. Urban Energy and the Climate Emergency: Achieving Decarbonisation via Decentralisation and Digitalisation. Washington, DC: Coalition for Urban Transitions. Available at: https://urbantransitions.global/en/publication/urban-energy-and-the-climate-emergency.

- **Accelerating deployment of cDER through community bulk buying programmes.** Bulk buying programmes for cDER (sometimes referred to as solarise campaigns) can achieve economies of scale in deploying cDER and energy efficiency technologies across a local community.[81] Local governments with sufficient resources are able to run these programmes on behalf of residents and businesses, such as Community Choice Aggregation programs found in states in the United States, and/or participate in them as a means to increase cDER adoption in municipal buildings. Such programmes not only realise volume discounts in the purchase of cDER resources, but can include access to certified installers, guarantees that high-quality products will be installed, free site evaluations and simplified permit and inspection requirements.[82] Coordinated programmes such as these also will ensure that cDER is deployed in conjunction with the necessary digital technologies to enable local flexibility management and facilitate "prosumer" models of electricity supply. Programmes can be structured in various ways, including through public-private partnerships or arrangements where local governments act as financial backstops or intermediary purchasers.[83]

Table 4. 3D Complementary actions for all local governments

CITY ACTION	RELEVANT PHASE OF 3D TRANSITION*			TRANSITION CHALLENGES ADDRESSED			
	1	2	3	Greater penetration of variable renewable energy sources	Managing flexibility	New actors and business models	Cross-sector integration
Partnering in Power Section Planning	✓	✓	✓	H	M	M	H
Advising and facilitating local 3D planning/ implementation	✓	✓		H	L	M	M
Streamlining local implementation efforts	✓			H	L	L	H
Accelerating deployment of clean distributed energy resources through community bulk buying programmes	✓	✓	✓	H	M	L	L

* As indicated in Table 2 of this paper, decentralised renewables in Phase 1 contribute <10% of total power generation; in Phase 2, decentralised renewables contribute 10-40%; and in Phase 3, decentralised renewables dominate generation. Notes: H = high relevance for addressing this challenge; M = medium relevance; L = low relevance

LOCAL GOVERNMENTS WITH GREATER RESOURCES, CAPACITY, AND AUTHORITY

Some local governments have greater resources, regulatory capacity and legal authority to undertake 3D-enabling policy interventions. Legal authority will vary by country and jurisdiction. In many areas, however, local governments (municipal or metropolitan) will be able to pursue a range of regulatory measures -including adoption of building codes and siting requirements -that will facilitate the deployment of cDER and related infrastructure. In later phases, they also may be able to actively assist in managing flexibility and support new business models for local power provision (e.g., through public provision of data and information). Key actions include the following (summarised in Table 5):

Important for all transition phases

- **Adopting local ordinances requiring or enabling 3D infrastructure development.** Local governments that have the necessary regulatory authority can adopt a range of measures to accelerate the deployment of local cDER, storage, energy efficiency and digital technologies needed for a 3D transition. A particularly effective approach is to tighten, expand and enforce building codes to support greater energy efficiency and cDER adoption. "Whole building" or performance-based energy codes, for example, may require a combination of efficiency and onsite generation (cDER) as a means to improve building energy performance.[84] At the level of new commercial or residential development, local governments can require distributed energy system feasibility studies that encourage adoption of cDER, promote development of a robust distribution network and assist with overall system planning.[85]

  Local ordinances can also address important market and nonmarket barriers to greater adoption of efficiency measures and cDER. Building codes and other measures can address so-called "split incentives," where developers fail to invest in efficiency and onsite generation because they do not have to pay a building's electricity bills (and short-term tenants lack the incentive to invest in long-term upgrades). Local "solar access" ordinances can ensure that new buildings and developments do not compromise the ability of surrounding buildings to generate onsite solar energy.[86] In New York City, the revision of fire codes has made it easier to adopt distributed battery storage in buildings. All of these kinds of measures can be particularly effective if adopted sufficiently early in rapidly growing cities, driving the incorporation of decentralised electricity systems into new development and avoiding the need for more costly future retrofits or power system investments.

- **Incentivising local cDER adoption.** Local governments with sufficient resources can provide direct financial incentives for community adoption of cDER technologies (Box 4). An increasingly common approach is to establish Property Assessed Clean Energy programmes, which provide upfront financing for residents and businesses to acquire cDER (or make related clean energy investments) and repay loans through an increase in their municipal tax assessments.[87] These kinds of programmes also have the ability to reward adoption of associated "smart grid" technologies that deliver onsite generation, efficiency and demand response capabilities.[88] Finally, local governments also can indirectly incentivise development of decentralised local power systems by making public land available for key infrastructure, including electricity storage facilities or larger-scale vRES.

BOX 4 **City-wide clean distributed energy resource incentives and co-benefits**

Solar City Seoul's 2022 target of 1 gigawatt in rooftop solar includes all municipal buildings and 1,000,000 homes. The scheme, partly funded by government subsidies, is expected to create 4,500 jobs (C40 2020).[1]

[1] C40, 2020. "How to Install Solar Panels on City-Owned Property and Lead by Example." Implementation Guide. March. New York: C40 Cities Climate Leadership Group, Inc. Available at: www.c40knowledgehub.org/s/article/How-to-install-solar-panels-on-city-owned-property-and-lead-by-example?language=en_US.

- **Deploying cDER and digital technologies in municipal facilities and buildings.** Local governments themselves often are significant electricity consumers in urban areas, and their own internal clean energy policies can have an outsized impact (Box 5).[89] By investing in cDER (including storage) for their own facilities, local governments will be able to achieve economies of scale and assist with overall market development for cDER and associated digital technologies. Government procurement can be combined with community bulk buying programmes (see above) to further leverage local government buying power. In the later phases of 3D transition, adoption of municipally owned distributed energy systems can enable local governments to provide demand response services at scale, as well as act as aggregators of local electricity supply and demand (including, for example, by aggregating data to assess how cDER might be shared among local government buildings behind the meter).

BOX 5 **Santiago makes use of its own buildings for clean distributed energy resources**

With the primary driver of addressing pollution, Santiago invested US$5 million to develop solar photovoltaic projects on public schools, hospitals, and other symbolic buildings, totaling over 1 megawatt in capacity.

[1] For full case study, see Sustainia 2017, Cities 100, Available at: https://www.c40.org/case_studies/cities100-santiago-slashing-smog-with-public-building-enhancements.

- **Promoting cross-sector integration.** Local governments with greater resources can be key partners in initiating and accelerating cross-sector integration as part of a 3D transition. Specific measures will vary by sector and local regulatory authority. Electrification of end uses in buildings, for example, can be achieved through building code requirements. Alternatively (or in conjunction), some local governments are contemplating "gas bans," prohibiting the use of natural gas in new residential and commercial buildings.[90] Furthermore, local governments can play a key role in accelerating the adoption of electric vehicles.[91] Houston, Texas, for example, offers waivers on registration fees, and Portland, Oregon, offers free public charging infrastructure. Finally, local governments can identify opportunities for integrated energy system operation, including distributed thermal energy applications.[92] Uppsala, Sweden, aims to improve the flexibility of demand, integrating district heating to improve the integration of renewable sources into the energy system.[93] In Johannesburg, South Africa, C40 recently provided technical assistance to the city to identify existing solar thermal and solar PV resources in order to effectively baseline and design policies to improve the deployment of these technologies for water heating and electricity.

Important for later transition phases

- **Providing flexibility and demand response services.** One basic role for local government in the later phases of a 3D transition could be the coordination of demand response efforts across municipal operations, public transportation services (Box 6). Depending on the energy footprint of municipal facilities, implementing demand response measures could provide a significant source of local distribution grid flexibility. These can take time to develop, because they may require new business or operating models between the public and private sectors. The cities of Hamburg in Germany and Kitakyushu in Japan have programmes underway to provide demand-side response services to local network operators.[94]

BOX 6 **Flexibility: A technical and market transition**

Electrification of public transport will not only increase the load on distribution networks in cities, but it also will create opportunities for vehicle batteries to serve as flexible capacity that can alleviate grid congestion and accelerate decarbonisation. City buses provide predictable charging schedules based on known routes. In practice, however, a number of technical or market barriers may emerge. For instance, electrifying London's 9,000 buses is equivalent to the energy requirements of 150,000 homes, and it is critical that these do not all charge at once to avoid costly grid upgrades or higher-carbon sources of backup power. Furthermore, companies that run the buses (there are franchises for bus depots and route operations, usually for five years) need to ensure that any up-front investment in buses or charging infrastructure would have to be paid back over a very short time period. London recently announced "Bus2Grid," a three-year innovation project whereby an energy services and communications provider, a bus franchisee, and the Transport for London system will test the technical operation of 100 buses to provide over 1 megawatt of energy to the national grid balancing market, along with the business models that would allow for commercialization following trial.

- **Encouraging local microgrids and neighbourhood-wide** cDER deployment. Encouraging local areas (e.g., university campuses, hospitals, science parks and new developments) to create resilient microgrids can help enable greater deployment of cDER, reducing customer acquisition costs and helping utilities better plan for changes to aggregated customer load shapes.
- **Providing critical system planning and operation data**. Local governments often have access to information and data that can help to optimise generation, storage and demand-side response across a community's distribution network.[95] The City of Glasgow, for example, has collaborated with its local distribution systems operator to develop a detailed assessment of energy use in buildings, local energy sources and options for a low carbon energy system.[96] While all local governments, to some degree, are able to aid in planning efforts relating to 3D transitions, and have demonstrated their ability to steer new development towards lower-carbon alternatives, those with greater resources should be able to play a more active operational role. As noted in Webb et al. (2020),[97] for example, local governments can actively promote the development of new business models and market structures by providing real-time access to data, including on the carbon performance of local generation assets. In addition, local government data can contribute to cross-sector integration, indicating, for example, where best to deploy electric vehicle charging infrastructure to meet demand and avoid grid congestion.

Table 5: 3D Policy actions for local governments with greater resources and authority

CITY ACTION	RELEVANT PHASE OF 3D TRANSITION*			TRANSITION CHALLENGES ADDRESSED			
	1	2	3	Greater penetration of variable renewable energy sources	Managing flexibility	New actors and business models	Cross-sector integration
Adopting local ordinances requiring or enabling 3D infrastructure development	✓	✓	✓	H	L	L	M
Incentivising local clean distributed energy resource adoption	✓	✓	✓	H	L	L	M
Deploying clean distributed energy resources and digital technologies in municipal facilities and buildings	✓	✓	✓	M	M	M	L
Promoting cross-sector integration	✓	✓	✓	L	L	L	H
Providing flexibility and demand response services	✓	✓		L	H	L	L
Microgrids and neighbourhood coordination	✓	✓		H	H	H	M
Providing critical system planning and operation data	✓	✓		M	M	M	L

* As indicated in Table 2 of this paper, decentralised renewables in Phase 1 contribute <10% of total power generation; in Phase 2, decentralised renewables contribute 10-40%; and in Phase 3, decentralised renewables dominate generation.

Notes: H = high relevance for addressing this challenge; M = medium relevance; L = low relevance

GOVERNMENTS OF LARGER CITIES AND URBAN AREAS

Local governments in very large cities (e.g., megacities with metropolitan areas of over 10 million residents) perhaps are best positioned to aid in national efforts towards a 3D power system transition. In general, their greater resources will allow them to undertake more robustly all those actions that smaller municipalities are able to, including more sophisticated regulatory interventions and more extensive procurement strategies, financial incentive programmes and community investments (e.g., bulk buying programmes). Large metropolitan and municipal governments may be better able to undertake efforts "in-house," engage in service provision and/or engage in joint ventures and partnerships with community enterprises.[98] Seoul in the Republic of Korea, for example, has established a special agency, Seoul Energy Corporation, to oversee implementation of local energy policies that include a range of incentives, subsidies, leasing schemes and loans designed to achieve ambitious solar PV targets.[99] In short, the potential role of governments of large urban areas is similar to that of smaller local governments, only at greater breadth and scale.

One role that may be more suited to large-city governments -and which could be a critical element of a 3D transition in its early phase -is to assist with the piloting of new regulatory approaches and market structures (Table 6). Larger cities, in particular, can be instrumental in accommodating local innovation zones and "regulatory sandbox" approaches in specific districts. As described in Webb et al. (2020),[100] for example, London has benefited from regulatory experiments involving peer-to-peer energy trading, thus developing an important knowledge base for further development of decentralised electricity markets. Moreover, these experiments can also involve models for cross-sector integration; for example, incorporating electric vehicle battery storage into local grid flexibility management.

Table 6: 3D policy actions for local governments of larger cities

CITY ACTION	RELEVANT PHASE OF 3D TRANSITION*	TRANSITION CHALLENGES ADDRESSED			
	1 2 3	Greater penetration of variable renewable energy sources	Managing flexibility	New actors and business models	Cross-sector integration
Helping pilot new regulatory approaches and market structures	1, 2	L	L	H	M

* As indicated in Table 2 of this paper, decentralised renewables in Phase 1 contribute <10% of total power generation; in Phase 2, decentralised renewables contribute 10-40%; and in Phase 3, decentralised renewables dominate generation.

Notes: H = high relevance for addressing this challenge; M = medium relevance; L = low relevance

POLICY OPTIONS FOR MUNICIPALLY OWNED UTILITIES

Some local governments directly administer local electric utilities. Municipal utilities are common, for example, in Europe, Japan, the Philippines, South Africa and the United States.[101] Allowing municipal control of an electricity service is a complex decision, with legal and governance implications that go beyond mere engineering and cost optimisation. Where decentralisation is pursued as a path towards grid-wide decarbonisation, however, municipalisation can have its advantages as a governance strategy. Local governments in charge of municipal utilities may play a more expansive role in 3D transitions, further tailoring 3D strategies to local circumstances (Box 7). For example, they can act as local distribution system operators, aggregating and coordinating local cDER dispatch and demand response; and engage in a wide range of planning and decision-making relating to vRES penetration, flexibility management, new business models and cross-sector integration (Table 7).

Municipal ownership of electric utilities is not an either/or proposition. Different models are possible, with varying levels of ownership and control (Figure 3). Regardless of the ownership model, municipal utilities retain certain regulatory powers, which means they are able to undertake the same kinds of reforms and interventions that would typically fall to a national (or state-level) regulatory agency (Figure 2). This allows them to make decisions about the resource mix serving local electricity consumption, and pursue regulatory frameworks enabling the deployment of cDER and associated new market models (e.g., "prosumer" participation in local electricity supply and demand). Furthermore, municipal utilities may serve as system operators, or stipulate the rules, codes and protocols that a privately owned system operator must follow regarding local power market participation and interconnection.

Figure 3. Ownership possibilities for municipal utilities

Full municipal ownership			No ownership
100% municipal ownership	Partial municipal ownership	Privately owned, but still structured as a municipal utility that the city can influence as a key "city stakeholder"	No municipal energy utility; all customers buy their energy from a regional, national or other local supplier
Examples: Barcelona (Spain); Munich (Germany); Nottingham (UK); Olongapo (Philippines); and 1,843 utilities in the United States including in Austin (Texas), Burlington (Vermont), Oak Ridge (Tennessee) and Sacramento (California)	Examples: Freiburg (Germany)	Examples: Boulder (Colorado, US); Metro Manila (Philippines)	Examples: Denver (Colorado, US); Chicago (Illinois, US); Nairobi (Kenya); Tunis (Tunisia); London (UK)

Source: REN21 (2019).[102]

BOX 7 Examples of municipal utilities engaged in 3D transition strategies

- Hamburg has developed an integrated strategy that includes the use of a wide range of renewable technologies in an increasingly interconnected regional energy system. The city and surrounding areas already produce sufficient renewable power to meet approximately 160% of regional electricity demand, and they have connected local district heating.

- Austin's latest strategy (to 2027) includes a comprehensive set of goals for decarbonisation, energy efficiency, demand-side response and technology and storage, including increasing the share of renewables in the electricity mix from 38% in 2018 to at least 55% by 2025, and 65% by the end of 2027.

- Cape Town has sought to challenge national power company ESKOM in the constitutional courts to allow the city to increase the direct purchase of renewable electricity from independent power producers and increase adoption of rooftop solar photovoltaic.

Finally, many municipal utilities have responsibilities that go beyond the power system, including water, waste management, public transit and ports (maritime and aviation).[103] This makes them ideally positioned to develop and pursue cross-sector integration strategies involving electrification, demand response and renewable generation across city operations (Box 8). Pumping systems used in water treatment and waste water processing, for example, can be excellent sources of demand-side flexibility.

BOX 8 Cross-sector integration in Munich

Munich owns and operates its utilities jointly across telecommunications, transportation, energy, water and waste. It is able to retain revenues and invest in the future of these businesses, setting up new task forces, for instance on electric vehicles, to ensure operational silos are prevented.

* As indicated in Table 2, decentralised renewables in Phase 1 contribute <10% of total power generation; in Phase 2, decentralised renewables contribute 10-40%; and in Phase 3, decentralised renewables dominate generation. Notes: H = high relevance for addressing this challenge; M = medium relevance; L = low relevance

Table 7: Municipalization of electric utilities

CITY ACTION	RELEVANT PHASE OF 3D XTRANSITION* (1 2 3)	TRANSITION CHALLENGES ADDRESSED: Greater penetration of variable renewable energy sources	Managing flexibility	New actors and business models	Cross-sector integration
Local regulation, development, and operation of city power systems	1, 2, 3	L	L	H	M

* As indicated in Table 2, decentralised renewables in Phase 1 contribute <10% of total power generation; in Phase 2, decentralised renewables contribute 10-40%; and in Phase 3, decentralised renewables dominate generation.

Notes: H = high relevance for addressing this challenge; M = medium relevance; L = low relevance.

5. National policies to enable local government action

In the first paper of this series, examples were provided of a number of cities around the world that are at the forefront of efforts to transform urban power grids, and emphasis was placed on the role that local governments can play in accelerating low-carbon energy transitions.[104] At the same time, the importance of national government engagement in urban power sector transitions was stressed. Effective governance and strong supporting institutions -across all levels of government -are essential for any transition.[105]

To be effective in their role, many local governments will need national government support. Thus, a comprehensive "national" policy mix for 3D power sector transitions should include enabling policies for local governments. The scope of what national policy-makers can do is quite broad, including governance reform, financial support and various types of information provision and capacity building.[106] At the broadest level, national governments can use regulatory measures and fiscal incentives to stimulate private and civil society investment in cities.[107] More focused measures can be applied to contribute to the building up of local financial and technical capacities, supporting and improving local governance relating to the power sector, and creating legal and regulatory environments that enable local government action.

Building up local financial and technical capacities

As noted in Webb et al. (2020),[108] local governments for larger, wealthier cities may have the necessary resources and regulatory capacity to play an active role in enabling 3D transitions at the local level. In most countries, however, the large percentage of urban residents in medium-size and smaller cities means that these urban areas should not be neglected.[109] In many parts of the world, local governments lack the financing and technical capacity to effectively drive renewable energy adoption, or to actively assist with nationally led transition efforts.[110] Thus, even to assist with local power system planning and implementation (Section 4.1.1), these cities will call for assistance. Such aid can begin with national ministry- or regulatory agency-led efforts to engage local governments in system planning, while providing financial and technical assistance for them to engage. Technical assistance may also take the form of model rules, building codes and siting requirements that enable accelerated adoption of local 3D infrastructure -including cDER, distributed storage and digital technologies -along with the training, knowledge transfer and resources to effectively implement them.[111] Such assistance is especially essential as national and local governments, alike, begin the process of post-pandemic economic recovery.[112]

Key actions: Early in the planning process for grid decarbonisation, national governments (i.e., energy ministries and utility regulators) should conduct a skills and finance gap analysis to identify where local governments may need support to perform new responsibilities relating to locally implemented 3D transitions. Such an analysis, however, should not delay making technical assistance available where needs are already evident, especially as a means to enlist local governments in post-Covid19 recovery.

Facilitating governance reforms to improve vertical and horizontal coordination

In addition to financial and technical support, leveraging the participation of local governments may require governance reforms to align national and local efforts. New governance structures may be necessary along two dimensions: vertical and horizontal. The first, enhanced "vertical" coordination between national (or mid-level) and local governments, allows local governments to play an active role in power system planning and development efforts. At a minimum, vertical coordination requires that energy ministries and regulatory agencies have offices devoted to coordinating with local governments and, in parallel, ensuring that local governments have the staff and resources to effectively collaborate on power system development. For larger municipalities, vertical coordination entails having clear lines of communication between local public works or energy offices and power system regulators.

The second dimension, "horizontal" coordination, ensures that different municipal agencies, within a single jurisdiction and across multiple jurisdictions within a greater urban area, are able to work effectively together (e.g., Climate Action Regional Authorities in Ireland; or using Munich's "Task Force" approach). It also means devoting resources to engage with local citizens and surrounding communities in planning and development processes[113] (e.g., Citizen Climate Assemblies in the United Kingdom and France). Creating local "power system coordinating offices" within local government will help to address the vertical and horizontal governance challenges. As Ireland's example illustrates, the national government can be instrumental in helping to establish these coordinating bodies.

The manner in which a national government assists local governance will depend on the nature of the country's governing system.[114] A country with a unitary system, for instance, may directly institute local governing reforms, whereas under a federal structure, a national (and/or mid-level) government could establish funding and training programmes to assist local governments in establishing appropriate governing structures.

Key actions:

- National governments should assess sufficiently early which levels of government must be responsible for implementing the various aspects of a 3D transition (e.g., physical, market, and governance aspects, addressing both supply and demand for electricity). They should identify what is needed to bring about effective vertical coordination with local governments, as well as opportunities to improve local government (municipal or metropolitan) cooperation in major urban areas. Nationally convened task forces or other informal working groups can facilitate multilevel collaboration across departments and sectors.

- National governments can convene local governments and 3D market stakeholders to help overcome potential market and policy barriers.

Legal and regulatory enabling measures

In many situations, the challenges that a local government faces are due to a lack of legal authority rather than (or in addition to) a deficit in financial or technical capacity.[115] Depending on the context, local government simply may not have the authority, for example, to adopt fiscal and regulatory incentives for 3D infrastructure, engage in bulk buying programmes, help coordinate local system operation or undertake other measures described in Section 4. In these cases, the most effective enabling action may be to provide local government with these authorities, accompanied by supportive national governing frameworks[116] -up to and including the municipalisation of electricity services (Section 4.1.4).

Decentralisation of the power system does not necessarily require decentralisation of governance. Sometimes, the most effective approach is to establish national-level policies that enlist local governments in their implementation. Property Assessed Clean Energy programmes, for example, generally require enabling legislation at the national or state level, but often are best administered at the local level.[117] In Hamburg, Germany, local efforts to promote digitalisation are being aided by Germany's national digitalisation law, which covers technical specifications and data security requirements.[118] Enabling legal frameworks also are generally needed for local governments to experiment with new regulatory and market structures as a way to inform national transition strategies (Section 4.1.3 and Section 4.1.4).[119]

Key actions:

- Early on, national governments should establish data sharing frameworks that provide clarity on which data relating to 3D transitions (e.g., physical and market) should be made public, shared, or be proprietary.
- National governments can map the relevant domains for national policy and regulation that may be affected by 3D transitions, including industrial strategy, environment, telecommunications and innovation.

6. Conclusion

Decarbonising electricity in line with global efforts to ensure global warming remains below 2°C, while ensuring energy access to growing populations around the world, will require a rapid and wholesale transformation in how electricity is generated and delivered. Notwithstanding the systemic challenges posed by the Covid-19 pandemic, this goal is not out of reach. Declining costs of renewable energy and electricity storage, together with the growing use of digital technologies in power system design and operation, are making this kind of transformation increasingly possible and cost effective -as well as an essential strategy for post-pandemic economic recovery.[120] Transformation cannot take place on its own, however. Policy actions at the national level will be critical to enable and accelerate it.

One pathway towards decarbonising the power sector is through greater decentralisation of electricity generation. Decentralisation, including in urban areas, affords several potential advantages, including lower costs for delivered electricity (where circumstances are conducive); possibilities for more flexible grid management; greater power system resilience, especially at the local level; and improved options for energy access. Decentralisation is now proceeding "organically" in many countries due to steady advances in technology. It also can be pursued deliberately, however, as part of a comprehensive strategy to decarbonize electricity; that is, to achieve decarbonisation through decentralisation and digitalisation (a "3D" transition).

The degree to which a 3D approach is preferred will depend on national and local circumstances; it may also vary between different parts of the same country or grid. National governments will have to assess not only the physical and institutional requirements for implementing a 3D approach, including infrastructure development, but also how to enable and accommodate new market actors and business models. To date, decentralisation has been successfully pursued in many rural areas as a means towards greater energy access. The 3D model is increasingly being pursued in cities, especially as new technologies evolve.

As major centers of electricity consumption, cities are essential players in any transition to decarbonised power supply. Where a 3D transition is pursued, the role of local government will be critical. Because a decentralised power system requires extensive deployment of infrastructure at the local level (including clean generation technologies, storage systems, robust distribution networks and digital technology), it is important for local governments to actively facilitate this transition by streamlining and accelerating local implementation.

At a minimum, this can include assisting national ministries or regulatory agencies with power system planning, and adopting measures to streamline local installation of 3D infrastructure. For local governments with greater resources and capacity, local efforts may include adopting regulations and incentives to promote the purchase of clean distributed energy resources; deploying decentralised systems in municipal facilities; engaging in community bulk buying programmes; providing data and information for system planning and operation; and, in some cases, contributing to the management of local system operation. In addition, large cities and those with municipal utilities can help to pilot the new regulatory and market models necessary to maximise the value of a 3D approach, including "prosumer" models, where city residents become producers as well as consumers of grid electricity. More broadly, engagement of local government is essential to attract the "buy in" of community members needed for a 3D transition to be durable and sustainable.

To be truly effective, therefore, national approaches to power sector decarbonisation should explicitly include local governments, ensuring they are part of a comprehensive policy mix to drive the transition. This includes taking appropriate steps to coordinate and enable local government action. A key element of any nationally led approach should include the financial and technical assistance that local governments require so that they are able to pursue local 3D enabling actions.[121] This is especially true today, given the essential role that local government can play towards a successful, sustainable and "green" recovery from Covid-19.[122] Over the longer term, national governments should consider legal and governance reforms that will empower local governments to take the necessary actions, including the establishment of local agencies and institutions with appropriate implementation authority.

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ABOUT THE COALITION FOR URBAN TRANSITIONS

The Coalition for Urban Transitions – launched in 2016 at the Climate Leaders' Summit in New York – is a major new international initiative to support decision makers to unlock the power of cities for enhanced national economic, social, and environmental performance, including reducing the risk of climate change. The Coalition provides an independent, evidence based approach for thinking about 'well managed' urban transitions to ensure that the growth of urban areas, and the accompanying process of economic, social, and environmental transformation, maximises benefits for people and the planet.

The initiative is jointly managed by the C40 Cities Climate Leadership Group (C40) and World Resources Institute (WRI) Ross Center for Sustainable Cities. Members include over 20 major institutions spanning five continents, including research institutions, city networks, international organizations, infrastructure providers, and strategic advisory companies. The initiative will be overseen by a Global Urban Leadership Group to steer and champion the work.

ABOUT LSE

The London School of Economics and Political Science (LSE) is one of the foremost social science universities in the world. LSE Cities is an international centre at the LSE that carries out research, graduate and executive education and outreach activities in London and abroad. Its mission is to study how people and cities interact in a rapidly urbanising world, focusing on how the physical form and design of cities impacts on society, culture and the environment. This research was commissioned via LSE Enterprise.

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