Centre for Net Zero

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CLEAN ENERGY CITIES

A data-driven framework for the transition to future energy systems

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TABLE OF CONTENTS

Glossary of technical terms

Term	Abbreviation	Definition
Distributed energy resources	DERs	DERs are small-scale electricity supply, storage, or demand resources that can be interconnected to the electric grid.
Distribution System Operator	DSO	Distribution System Operators, are the entities responsible for distributing and managing energy from the generation sources to the final consumers.
Electricity System Operator	ESO	The Electricity System Operator performs several functions, from second-by-second balancing of electricity supply and demand, to developing markets and advising on network investments.
Herfindahl–Hirschman Index	HHI	The Herfindahl–Hirschman Index measures the concentration of land uses in a 125 sq km area that surrounds the centre of the city (calculated as the sum of the square of percent of land covered by one land use). The index is measured in points - the lower the score, the more land uses there are and the more evenly distributed land is between those uses.
Low Carbon Technology	LCT	Low carbon technology is the term given to technologies that emit low levels of CO^2 emissions, or no net CO^2 emissions.
Locational Marginal Pricing	LMP	Locational marginal pricing is a way for wholesale electric energy prices to reflect the value of electric energy at different locations, accounting for the patterns of load, generation, and the physical limits of the transmission system
Private Purchase Agreement	PPA	A Power Purchase Agreement refers to a long-term electricity supply agreement between two parties, usually between a power producer and a customer (an electricity consumer or trader). The PPA defines the conditions of the agreement, such as the amount of electricity to be supplied, negotiated prices, accounting, and penalties for non-compliance.
Renewable Energy Sources	RES	Renewable Energy Sources denotes energy coming from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas
Variable Renewable Energy	VRE	Variable Renewable Energy sources produce energy intermittently instead of on-demand, i.e. these are not dispatchable due to their fluctuating nature.
Low Voltage networks	LV	Low voltage networks are the parts of an electricity system connected to a distribution transformer. Distribution transformers connect to substations and lower the voltage from MV to LV.
Medium Voltage networks	MV	Medium voltage networks are the parts of an electricity system that is connected to a substation. Substations connect to the transmission system and lower voltage from the transmission voltage to MV.

FOREWORDS

November 2022

Cities are major energy consumers. They account for around three-quarters of global final energy use and more than 70% of global carbon emissions.[1,2] As the world's urban population increases, the need to decarbonise the energy use of cities grows by the day - and when you're living in a climate emergency, every minute matters. If we don't take action now to meet the critical goal of limiting global warming to 1.5°C, both people and the planet will pay a devastating price.

The good news is that collective ambition is strong. Cities want to play an active role in the global energy transition. They recognise that they can help the world meet its climate targets whilst delivering the environmental, economic and social benefits of clean energy to local communities.

Yet the 'green cities' space is increasingly saturated. There are numerous, competing voices and recommendations, many of which are place-agnostic. So where can city leaders turn? What steps should they take, and in what order of priority? And how can they leverage their inherent characteristics to accelerate their respective transitions, rather than attempting to build their way out of the problem, or reinvent the wheel?

Clean Energy Cities is a direct response to these challenges. Our intention is to provide a coherent, evidence-driven framework that cities can rely on to accelerate their local energy transitions, in accordance with their characteristics. This detailed piece of analysis is underpinned by real world data, in keeping with Centre for Net Zero's core identity as a research unit. We are proud of our reputation for pioneering research into future energy systems, but have always been clear that our work doesn't stop at the point of publication. Our ambition is to catalyse real world action; our mission is to make the future energy system a reality.

The report maps out the energy system policies, actions and initiatives that cities can pursue to realise people-centred clean energy systems. It is not designed to be a blueprint: *Clean Energy Cities* contains a series of typologies that reflect the different scale and nature of the challenges faced by cities with similar characteristics around the world - and proposes solutions accordingly. These typologies won't fit a single city precisely but can help cities to pinpoint and prioritise the biggest opportunities that their characteristics present.

I would like to thank the World Resources Institute and C40 Cities for their valuable contributions and guidance. We look forward to working with both organisations in the next phase of *Clean Energy Cities* where we'll be collaboratin city leaders to trigger the real-world action we need to take now to hit our net zero targets.

Lucy Yu

CEO, Centre for Net Zero

Many cities have already committed to taking the necessary action aligned with the goals of the Paris Agreement, set science-based targets to guide their progress or otherwise committed to 100% renewable energy. Others are rapidly following.

Their ability to achieve these ambitions relies heavily on decarbonisation of energy, primarily as electricity. This, however, isn't happening fast enough. To remain on track to achieve the Paris goals, the rate at which electricity generation is decarbonising needs to increase by a factor of 6 by 2030.[3]

Although most cities have little direct control over electricity supply, transmission, and interconnection, they play a critical role in shaping and accelerating the transition to net zero electricity systems.

For example, cities can help aggregate demand and manage flexibility on both supply and demand sides, capturing synergies from sector coupling and from integrated action on mobility, heating, cooling and storage, and supporting infrastructure connectivity.

Moreover, cities are nimble and can experiment and pilot innovative solutions and electricity service models.

Clean Energy Cities is a new framework that recognises these opportunities as well as the different contexts of cities around the world. The recommendations are global and can be used by cities to support implementation of their climate commitments.

Michael Doust

Director Urban Efficiency and Climate, WRI Ross Center for Sustainable Cities

1. "Renewable Global Statuts Report", REN21. https://www.ren21.net/reports/global-status-report/ (accessed Nov. 8, 2022) | **2.** "Urban Climate Action is Crucial to Bend the Emissions Curve", UNFCC. https://unfccc.int/news/urban-climate-action-is-crucial-to-bend-the-emissions-curve (accessed Nov. 8, 2022) | **3.** "State of Climate Action 2022", World Resource Institute. https://files.wri.org/d8/s3fs-public/2022-10/state-of-climate-action-2022.pdf?VersionId=2bl20dBlG7Cb (accessed Nov. 8, 2022)

EXECUTIVE SUMMARY

> "Cities are where the climate battle will largely be won or lost."[4]

António Guterres Secretary-General of the United Nations

By virtue of their populations and economies, cities are major contributors to climate change: over half the world's population currently live in urban environments, cities consume 78 percent of the world's energy, and they produce more than 60 percent of greenhouse gas emissions.[5] These challenges are set to be exacerbated by the estimated 2.5 billion people who will be added to urban areas by 2050.[6]

The disproportionate impact that cities have on the environment means that they can play a major role in addressing climate change in the near term. In particular, they can redesign their energy systems in a way that works harder for people and the planet. Yet too often, a decarbonised future energy system, divested from fossil fuels, is framed as a major challenge to make reality, rather than an opportunity to reimagine urban living and build greener, more equitable urban environments.

At Centre for Net Zero (CNZ), we are making the future energy system a reality and ensuring that delivery is fast, fair and affordable. The energy system will move from fossil fuels to renewable sources of energy. It will stop being a highly centralised, top-down system. It will rely on decentralisation and digitalisation. There will be multiple, distributed sources of energy generation and storage. People will be rewarded for using clean energy through intelligent demand. This will be a greener, more equitable and localised system.

The ability of consumers to respond to price signals and incentives to reduce or shift their energy demand to another time can serve both their own interests, and those of the grid.

Local generation near cities reduces the need to import energy from fossil fuels elsewhere

Photo by @bangyuwang via Unsplash

4. "Guterres: Cities Are Where the Climate Battle Will Largely Be Won or Lost", UNFCCC. https://unfccc.int/news/guterres-cities-are-where-the-climate-battle-will-largely-be-won-or-lost (accessed Jul. 18, 2022) | 5. "Generating Power", United Nations. https://www.un.org/en/climatechange/climate-solutions/cities-pollution (accessed Jul. 18, 2022) | 6. "Around 2.5 billion more people will be living in cities by 2050, projects new UN report", United Nations. https://www.un.org/development/desa/en/news/population/2018-world-urbanization-prospects.html (accessed Jul. 18, 2022)

The flexibility of energy usage, enabling the balancing of supply and demand, is critical to becoming more reliant on variable forms of generation and transitioning to net zero. This is reinforced by the increasing electrification of sectors such as heating and transport, and the corresponding impact on the grid, which presents additional challenges for the future energy system.

Cities have limited electricity network capacity. We found that in an 'unmanaged future system' scenario, with lots of people using low carbon technologies such as electric vehicles and heat pumps, **electricity demand in a city during a peak hour could become triple the size of a typical hour today.** Grids and national energy regulators will seek to work with mayors and city leaders to help solve what they have started to call a 'congestion problem'.

Flexibility will be critical to managing these scenarios -and as it localises, the governance of the energy system will shift accordingly. Seizing the opportunity requires mayors to use the levers at their disposal, from land use strategy and planning permission to investment, procurement, digital skills training and datastores.

Yet how can cities ensure they're taking the highest impact, near-term steps to prepare themselves for what lies on the horizon? We analysed **17 cities globally** and categorised them into **five different city typologies** to understand the different scale and nature of the challenge and to propose solutions for their respective energy transitions.

North Amsterdam, one of the first districts to study its electricity congestion problem

Photo by @rxcroes via Unsplash

CLEAN ENERGY CITIES

Typologies of cities and their pathways to future energy systems

Indicators

To create detailed recommendations outlining the steps that cities need to take to transition to decarbonised energy systems, we sourced open data commonly available from 17 cities around the world, from developed and developing countries to global conurbations and smaller cities. These datasets were collected across numerous indicators, each of which belonged to one of four categories:

- **Demographic:** the overall size and density of a place
- **Decarbonisation:** how much electricity is generated from renewables, and how much of the city's heating and transport systems are electrified
- **Urban flexibility:** how much potential there is for local renewable generation and storage in and near the city, and how spatially segregated energy demand profiles of different land uses in a city are from each other
- **Consumer flexibility:** how the city benefits from digitalisation and electricity market reform to promote energy demand behaviours

Typologies

Data gathered from these cities yielded five different classifications, outlined below. These five different typologies enable cities to learn from one another and share innovations and progress.

- **Connected:** Large population concentrated in urban agglomerations, proximity of commercial and non-commercial uses, limited space for variable renewable energy and distributed energy resources, high levels of electric vehicle penetration, digitalisation and CO_2 targets already in place and advanced
- **Free-market:** Large population in isolated horizontally mixed cities, available variable renewable energy and space around the city, low levels of electric vehicle penetration, but high scores in digitalisation and innovation in electricity markets
- **Scalable:** Spread-out city with high population growth estimates, high variable renewable energy and plenty of land available around the city, moderate electric vehicle penetration and retail innovation but advanced wholesale market evolution
- **Distributed:** Spread-out city with large scale VRE in the surroundings, increasing EV adoption but moderate digital skills, innovative retail tariffs to maximise local RES consumption
- **Available:** Dense but smaller cities with abundant resources and land available, plenty of commercial floorspace in comparison to size, average electric vehicle penetration and digital skill, with the greatest innovation in retail tariffs

From indicators to typologies

		Connected	Free-market	Scalable	Distributed	Available
Population	Demographics					
Land use	Urban flexibility					
Local VRE, DER	Decarbonisation					
EV penetration	Urban flexibility					
Digitalisation	Consumer flexibility					
Market innovation	Consumer flexibility					

Smallest — Highest

Urban and consumer flexibility: managing electricity peaks in decarbonised cities

(i) Consumer flexibility

In a more flexible, decentralised electricity system, consumers in cities can benefit even more from the opportunities that local generation and storage offer. Our research with Cramton Associates looked at households with EVs,[7] local generation and on-premises batteries indicates that these consumers are willing to be flexible with their energy demand if there are financial incentives in place. We found that every one percent price increase encouraged customers on a dynamic plan, where the price changes every half an hour to mirror wholesale prices, to reduce their consumption by 0.26 percent. In a peak hour when the price increased by 230%, consumption by households with both local generation and storage reduced by up to 60%.

CNZ made conclusions from this work to test scenarios to illustrate the future energy system. We assumed in our scenarios that consumers are willing to:

- reduce peak hour electricity consumption by up to 60%
- use vehicle charging less often in peak hours, up to 60%
- use heating and air conditioning less often in peak hours, up to 30%

To showcase the impact that this could have across differing urban environments, we took a city in a developed economy (Paris) with a temperate climate and generation dominated by nuclear power, and a city in a developing economy (Buenos Aires) with a subtropical climate and generation dominated by fossil fuels. In our two examples, **25-30% of heating and cooling demand and 55-60% of EV charging demand** in a peak hour shifts to other hours of the day, slowing electricity growth for a peak hour in Paris down from a **140-190% increase** to a **110-140% increase**, and for a peak hour in Buenos Aires from a **130-300% increase** to a **114-230% increase**.

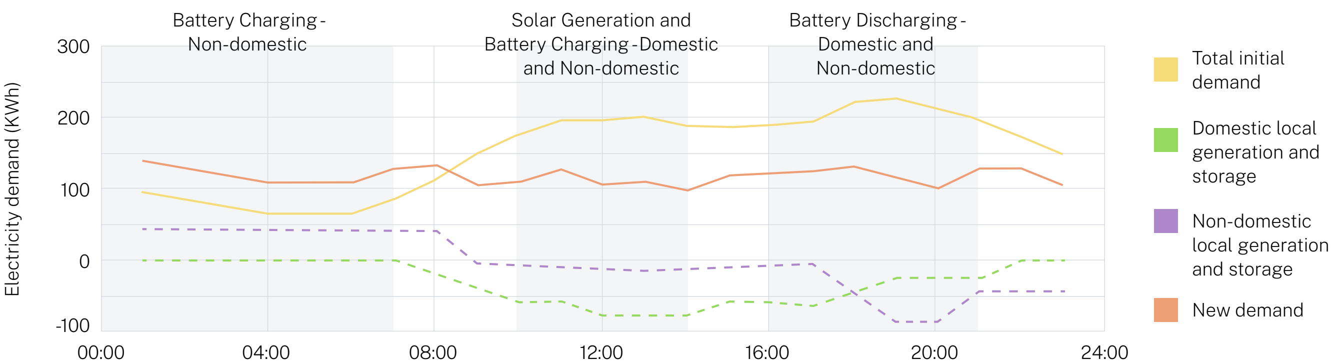
(ii) Urban flexibility

To make the energy transition real for city leaders, we tested future scenarios on an urban block of 200 residential and 25 commercial units. This helps us understand the functioning of urban environments, and how they can support flexibility as the energy transition rolls forward.

Using electricity demand profiles that cover heating, lighting, cooling, and appliances in the domestic and non-domestic sectors, we determined that the power demand of the block nearly triples from around 75-100 kW in the early morning to around 200-225 kW during the afternoon and evening. We tested two scenarios: one where only residents changed their behaviour to use less electricity in the afternoon and evening, and one where both residents and businesses changed their behaviour. **In the first scenario, an evening peak of electricity demand was retained, but in the second scenario, no more demand peak hours remained.**

The conclusions of our tests on an ideal urban block have important implications for policies regarding land use mix, transport planning, and low voltage (LV) network design. For example, we find a desirable ratio **of around 2:1 domestic to non-domestic floorspace in a city block or urban district that supports a constant, 24/7 import of electricity**, made possible by local generation and storage.

Demand Profiles in Paris - 2030

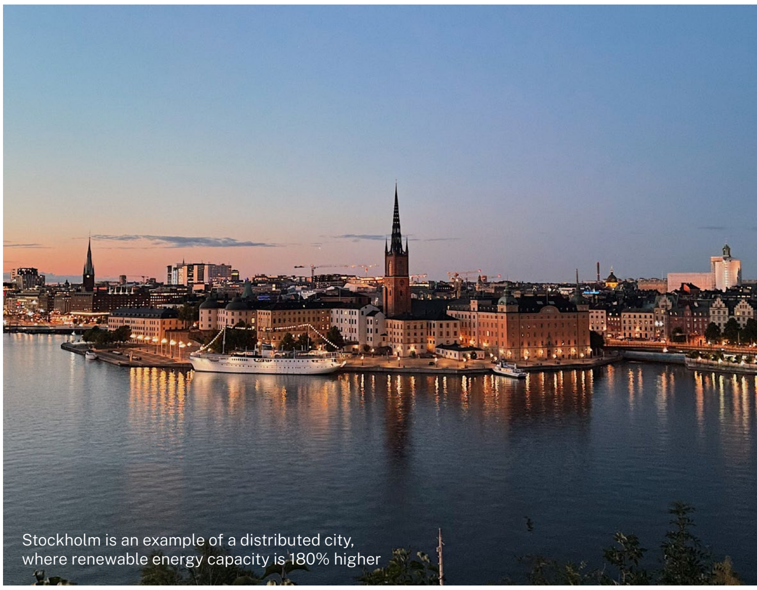


7. "Spotlighting the critical role of households in unlocking smart, flexible energy systems", CNZ. https://www.centrefornetzero.org/res/spotlighting-the-critical-role-of-households-in-unlocking-smart-flexible-energy-systems/ (accessed Jul. 18, 2022)

(ii) Urban flexibility

All cities should include policies for decarbonisation, urban flexibility, and consumer flexibility in their climate action plans, but cities should prioritise particular actions based on their typology. For example, high density cities should promote numerous, small-scale solar panels on building rooftops; others would benefit from increased battery storage or generation from large wind farms nearby and available grid capacity. Financing decarbonisation should focus on bottom-up collaborative purchasing for the most decentralised systems in distributed and available cities, whilst more institutional investment is required elsewhere. In some cities where consumers are central to the transition, the widespread adoption of innovative energy tariffs and smart products that automate consumption should be a core area of focus, delivering household flexibility at scale.

This report is a detailed resource for city leaders looking to combat the climate crisis and drive forward their respective local energy transitions. It provides key recommendations for each type of city and categorises them both in terms of their impact (on urban flexibility; on decarbonisation; on consumer flexibility) and urgency, mapping out a pathway that cities can adopt to make greener, fairer and more affordable energy systems a near-term reality.



Stockholm is an example of a distributed city, where renewable energy capacity is 180% higher

Photo by @oscnord via Unsplash

IMMEDIATE ACTIONS - 2025

Urban Flexibility | Decarbonisation | Consumer Flexibility

	Urban flexibility				Decarbonisation	Consumer flexibility	
	Source of flexibility	**Data platforms**	**Planning policies and standards**	**LCT community assets**	**Investment**	**Retail market reform**	**Consumer engagement**
Connected	Allow EVs with residential parking permits access to non-domestic chargepoints	Build data platforms for strategic infrastructure planning		Prefer smaller VRE modules and batteries as community assets	Start economic development programmes that fund energy innovators		Set up an information hub for consumer flexibility
Free-market	Procure EVs and chargepoints for public sector fleet and properties	Build district data platforms in areas of current high grid congestion		Prefer smaller VRE modules as community assets	Use economic development programmes to fund energy innovators		Make a grid stress management alert system
Scalable	Procure EVs and chargepoints for public sector fleet	Build growth area data platforms	Develop LCT policies for major public sector projects	Prefer medium-sized VRE modules and batteries as community assets	Procure storage in areas of grid congestion	Develop policies for public sector time of use tariffs	Create resident community energy boards
Distributed			Mandate local generation and storage for new build developments		Create programmes that support rooftop solar supply chain	Move public buildings supplied by renewable energy onto dynamic tariffs	Support smart heating/cooling and charging supplied by excess local renewable generation
Available	Set a goal for storage capacity per resident			Prefer larger-sized VRE modules and batteries as community assets	Support financing of storage for private owners	Place public sector properties on dynamic tariffs	Support rollout of domestic smart heating/cooling and charging paired with nearby storage

FUTURE ACTIONS - 2040

Urban Flexibility | Decarbonisation | Consumer Flexibility

	Urban flexibility				Decarbonisation	Consumer flexibility	
	Source of flexibility	**Data platforms**	**Planning policies and standards**	**LCT community assets**	**Investment**	**Retail market reform**	**Consumer engagement**
Connected	Designate EV/ smart charging district Coordinated EV charging hours	Include smart meter data in city datastore	Include rooftop solar in every non-domestic planning agreement	Require LCTs part of retrofit of entire social housing estate	Pension funds directly invest in future energy systems	Make all public sector chargepoints only open to EVs on intelligent tariffs	Create tax rebates for EVs that are flexible in the right locations in the city
Free-market	Procure EVs and chargepoints across public sector fleet	Designate a special data zone for innovation in energy technologies	Require all public buildings to have LCTs on site Develop community retrofit programmes	Designate solar districts in areas of grid congestion	Create local tax rebates for investments in renewable generation and storage	Create tax rebates for access to private chargepoints for those on intelligent 'roaming' tariffs	Create tax rebates for automating smart charging, heating and/or cooling
Scalable	Designate EV-only parking at public buildings	Build growth zone datastores	Require LCTs for all new builds, public and private Develop community retrofit programmes	Procure VRE modules and batteries for all public buildings	Invest in and create products of renewable generation and storage assets	Move all public sector properties onto a time of use tariff Create tax rebates for access to smart chargepoints	Support programmes for investment in community energy
Distributed	Designate an EV-only inner urban core	Build data platforms for strategic planning of generation and storage	Require local generation in masterplans	Procure LCTs at every medium voltage (MV) substation	Designate rooftop solar investment areas	Require all public sector properties have local generation and public chargepoints	Implement a joint venture for energy sharing for economically disadvantaged neighbourhoods
Available	Install strategic large-scale storage for every MV substation	Build data platforms for strategic planning of storage	Require local storage in masterplans	Procure on-premises batteries for all public sector buildings	Designate storage investment areas Sell green bonds to the markets	Tax rebates for local generation and storage on a dynamic tariff EV chargepoints on intelligent tariffs	Tax rebates for businesses that invest in storage that charge from renewables Create tax rebates for joining an intelligent tariff

THE OPPORTUNITY FOR CITIES

Cities have both a strong imperative and an unparalleled opportunity to lead the creation of the future energy system as it decentralises, decarbonises and digitalises.[8] The rapid expansion of electricity supply will soon fuel heating and transport.

If the current electricity network (see 'phase two' on the next page) endures, electricity grids and national governments will increasingly turn to local authorities to help them tackle an 'electricity congestion' crisis.[9] Attempting to 'build a way out of the problem' would be inefficient and expensive, with costs likely to be passed onto consumers as part of energy bills or general taxation. Instead, local decision makers can make use of a complementary set of measures to avoid this scenario, focusing in particular on energy flexibility.

As global centres of growth and production, cities will be first to embrace **digitalisation** and **decentralisation** to use energy flexibly and fairly. The future energy system will be decentralised, driven by low-cost local variable renewable energy (VRE) generation and local storage in buildings and in the batteries within electric vehicles. Digitalisation will provide the data to automate use when the grid is less carbon intensive using smart heating, smart EV charging and storage.

These transformations will shift the governance of the energy system from a national to local level. In order to embed such changes, local authorities can play an important part in bringing together residents and businesses to encourage their active participation in the future energy system and ensure that everyone can benefit from the opportunities it presents.

In this work we examine the levers available to cities, from urban planning, investment and procurement to digital skills training and datastores. We consider existing levers and propose some new ones, designed for both high impact and practical application.

Centre for Net Zero is part of Octopus Energy, servicing 25 million customers across 14 markets, with access to tens of billions of customer data points

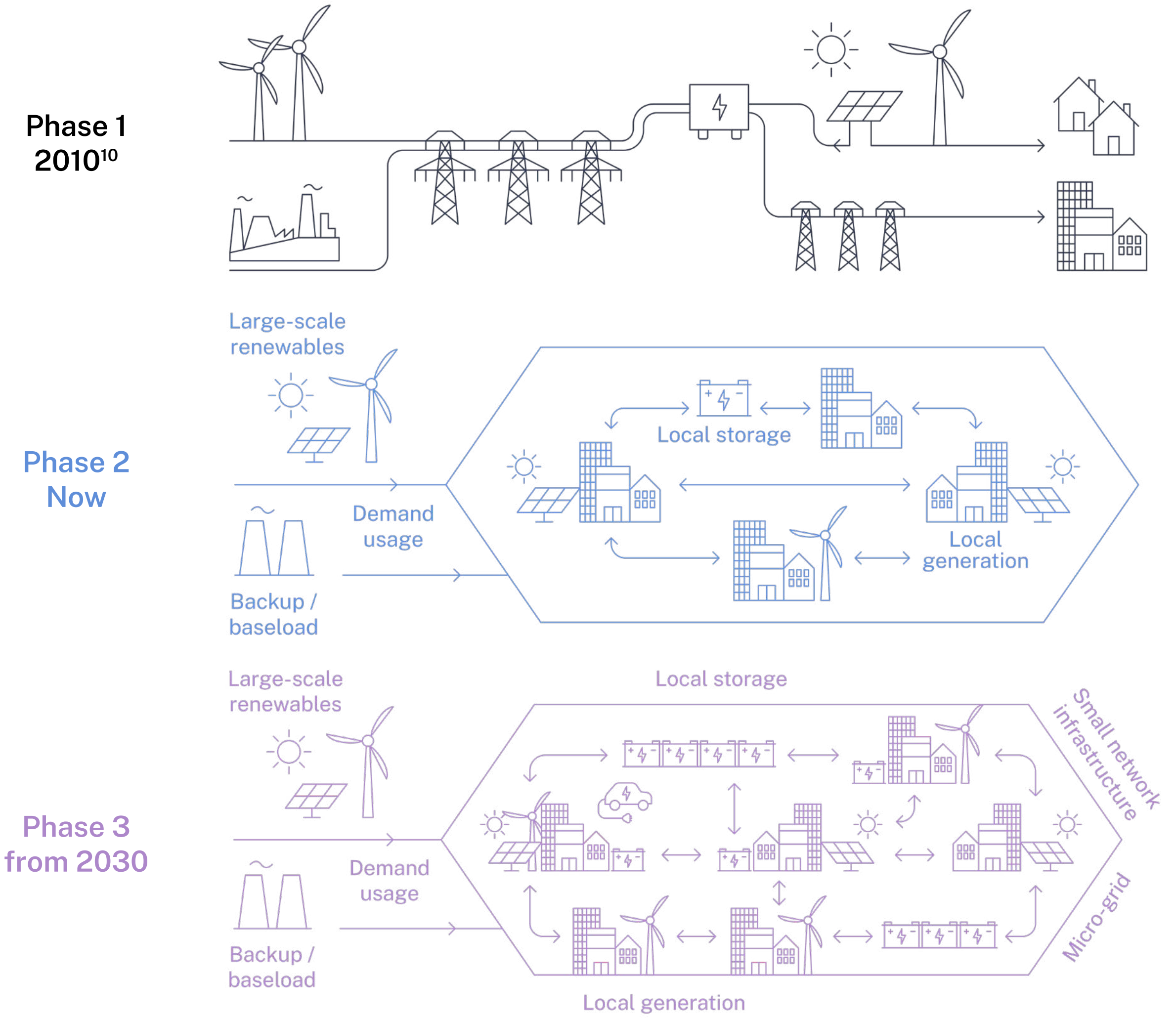
8. "Urban energy and the climate emergency: achieving decarbonisation through decarbonisation and digitalisation", Coalition for Urban Transitions. https://urbantransitions.global/wp-content/uploads/2020/03/Urban_Energy_and_the_Climate_Emergency_web_FINAL.pdf (accessed Jul. 18, 2022) | **9.** "Congestion in the electricity grid", Atelier. https://smartcity-atelier.eu/allgemein/blog-congestion-in-the-electricity-grid/ (accessed Jul. 18, 2022)

THE TRANSITIONING ELECTRICITY SYSTEM

In the recent past, the system was linear-running from generators to consumers. Power was predominantly traded by large incumbents on futures markets and energy was mainly generated from centralised sources such as large, fossil-fuel powered plants. Renewable generation was incentivised by governments with sites far away from cities -where the demand is concentrated-to sell into the grid. Some residential and commercial customers installed solar panels on their rooftops, selling back excess generation to a centralised grid.

In the current era, electricity system operators have gradually opened secondary and tertiary electricity markets to allow smaller and intermittent assets, such as wind, solar or batteries, to participate and stack revenues. The intermittency of renewable generation has led to market volatility and an increase of balancing costs. It requires new systems to control and optimise these assets, trying to avoid energy spills and maximise the amount of renewable energy in the system. Overall, the system continues to be largely supply-led and the demand-side remains passive.

In the coming era, consumer flexibility will occupy a more central role in energy policy. Electricity demand will increase rapidly due to the electrification of transport and heat in homes. Electric vehicles, heat pumps, batteries, and smart thermostats will all have a role in managing and balancing the electricity system. This dramatic change needs leaders to encourage residents, businesses, finance, developers and innovators to play a more active role in the energy system.



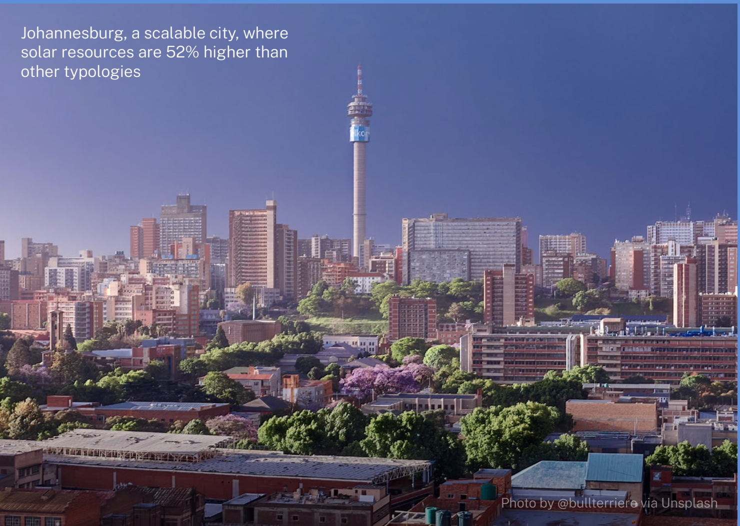
10. "Consumer engagement-a critical step on the road to net zero," Charlotte Johnson, Krakenflex. https://www.linkedin.com/pulse/consumer-engagement-critical-step-road-net-zero-charlotte-johnson/ (Accessed 4 November 2022)

BUILDING URBAN TYPOLOGIES

Every city is unique, but typologies can help to identify and highlight important characteristics found within cities from which we can draw conclusions and make relevant recommendations.

In this analysis, we took data from 17 cities from across the globe, chosen to represent a mixture of sizes, urban structures, rates of energy generation and consumption, and energy market structures. These typologies won't fit a city exactly, but are a starting point for cities to understand the solutions that could benefit them. Likewise, not all possible typologies are covered, but the ones we do cover help all cities understand the range of levers available for future clean energy systems.

For each city, we measured data relating to key future energy system metrics which we grouped into four broad categories: (1) Demographics, (2) Decarbonisation, (3) Urban Flexibility, and (4) Consumer Flexibility. Demographic trends measure the overall size and density of a city. Decarbonisation measures current investment in renewable electricity generation capacity in that country, and how much heating and transport is fueled by electricity. Urban flexibility is a measurement of decentralisation of a future energy system -how mixed energy profiles are throughout a city, and the potential for local generation and storage near the centre of the city. Consumer flexibility is a measurement of the digitalisation of a future energy system-from the extent of electricity tariff reform in the country to digital skills and the general public's perceived risk of climate change.



Johannesburg, a scalable city, where solar resources are 52% higher than other typologies

Photo by @bullterriere via Unsplash

THE METRICS

Demographics

Population: The total residential population of the city and of its metropolitan region

Land area: The land area of the city and of its metropolitan region

Commercial floorspace: The total amount of taxable commercial floorspace recorded by the city

Number of residential units: The number of dwellings in the city

Number of electricity meters: The number of electricity meters, both domestic and non-domestic, in the distribution network that covers the metropolitan region

Decarbonisation

Fuel for heating: The percentage of dwellings in the city that use electricity for heating

Renewable electricity generation: The percentage of electricity generated by renewable sources (solar, wind, hydro and biomass)

Variable renewable generation capacity: The capacity of variable renewable generation and storage (wind, solar, hydro, biomass and batteries) in the distribution network that covers the metropolitan region

City electricity demand: The annual total demand for electricity in the city as an average of the most recent pandemic and pre-pandemic year

Heating and/or cooling degree-days: Degree days are the difference between the daily temperature mean and a comfortable temperature (heated to 18°C and cooled to 21°C)

Urban Flexibility

Mix of land uses: The concentration of land uses in a 125 sq km area around the city centre, measured by the Herfindahl–Hirschman Index of market concentration

Potential land for local generation near city: The amount of green space and open space available for off-site generation within a 125 sq km area around the city centre

Solar roof generation potential: A scoring system devised by CNZ, combining the total land and building roofs available for generation in a 125 sq km area around the city centre with the days of high irradiance in the city

Wind generation potential: A scoring system devised by CNZ, combining the total land available for generation in a 125 sq km area around the city centre with the days of high wind in the city

Consumer Flexibility

EV ownership: The number of 100% EVs licensed in the city per capita

Startup environment: A scoring system devised by Crunchbase combining the quality and quantity of startups in a city

Take-up of digital services: The number of mobile internet connections per capita, uprated for urban areas

Attitudes towards climate change and 'green' issues: The percentage of people in a country that view climate change as an immediate risk

Population growth to 2035: The percentage growth of a city between 2020 and 2035

Innovation in electricity market: A scoring system devised by CNZ based upon the use of locational market pricing in the wholesale market and the use of real-time or other peak pricing tariffs in the retail market

Electricity grid open data: A scoring system devised by CNZ of the openness of the transmission network operator, electricity system operator, and the distribution network operator that covers the metropolitan region

Historical change in energy demand: The change in electricity demand in the country since 1980 to pre-pandemic levels in 2019

STANDARDISATION OF THE METRICS

It was important to ensure that all variables were measured on the same scale, otherwise variables with a greater range in their potential values may carry a disproportionate weight. The variables were standardised using the min-max normalisation or range standardisation technique, which produces output values in the range 0 to 1. Then for each variable, the range of values was rescaled, with the mean across all cities set to zero.

THE TYPOLOGIES

Data gathered from the 17 cities yielded five different typologies:

Connected

Large population concentrated in urban agglomerations, proximity of commercial and non-commercial uses, limited space for variable renewable energy and distributed energy resources, high levels of electric vehicle penetration, digitalisation and CO_2 targets already in place and advanced.

Free-market

Large population in isolated horizontally mixed cities, available variable renewable energy and space around the city, low levels of electric vehicle penetration, but high scores in digitalisation and innovation in electricity markets

Scalable

Spread-out city with high population growth estimates, high variable renewable energy and plenty of land available around the city, moderate electric vehicle penetration and retail innovation but advanced wholesale market evolution.

Distributed

Spread-out city with large scale VRE in the surroundings, increasing EV adoption but moderate digital skills, innovative retail tariffs to maximise local RES consumption.

Available

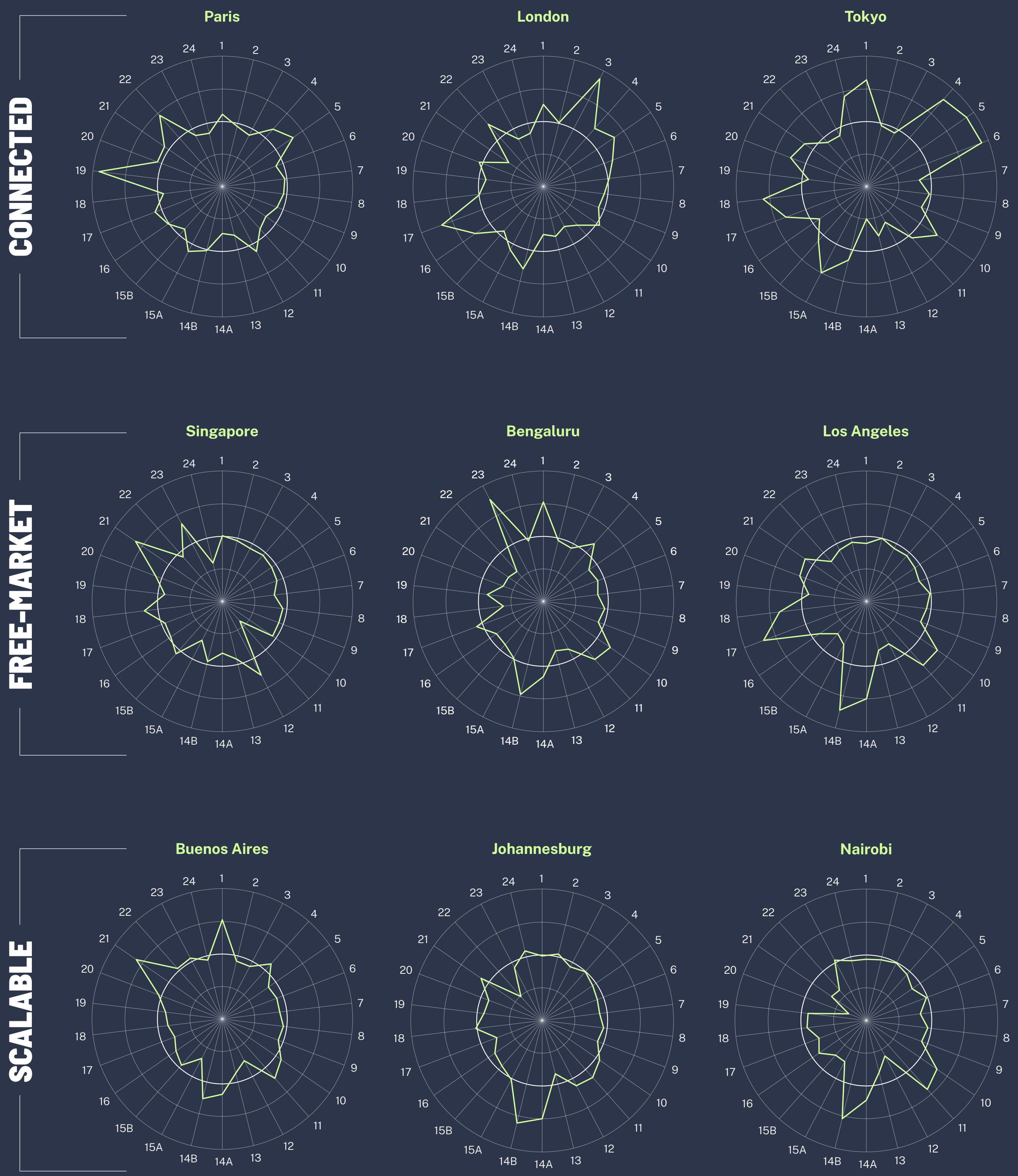
Dense but smaller cities with abundant resources and land available, plenty of commercial floorspace in comparison to size, average electric vehicle penetration and digital skill, with the greatest innovation in retail tariffs.

City data[11]

	Connected			Free-market			Scalable			Distributed				Available			
	Paris	London	Tokyo	Singapore	Bengaluru	Los Angeles	Buenos Aires	Johannesburg	Nairobi	Stockholm	Vancouver	Medellin	Amsterdam	Nantes	Valencia	Manchester	Sydney
Demographics	0.09	0.35	0.33	-0.11	-0.06	-0.05	-0.05	-0.08	-0.10	0.06	0.14	-0.10	-0.06	-0.12	-0.08	-0.10	-0.06
Decarbonisation	-0.12	-0.09	0.15	-0.07	0.02	-0.01	-0.08	-0.09	0.01	-0.08	-0.17	0.04	0.02	0.04	0.23	0.23	-0.03
Urban Flexibility	0.00	-0.12	-0.01	-0.06	0.14	0.17	0.10	0.24	0.15	-0.33	-0.13	-0.06	0.10	-0.24	0.12	-0.14	0.08
Consumer Flexibility	-0.01	-0.09	0.13	0.20	-0.09	-0.03	0.19	0.00	-0.23	-0.02	-0.02	0.00	-0.15	-0.01	0.11	-0.08	0.10

11. Standardised and normalised, see p.57 for methodology

ENERGY TRANSITION CITY PROFILES



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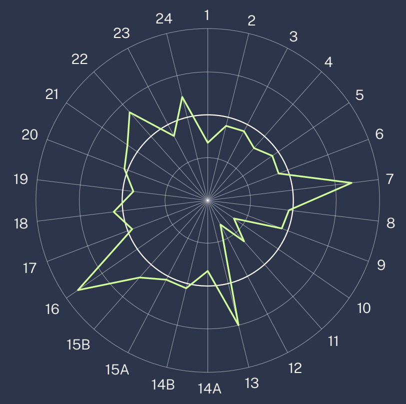

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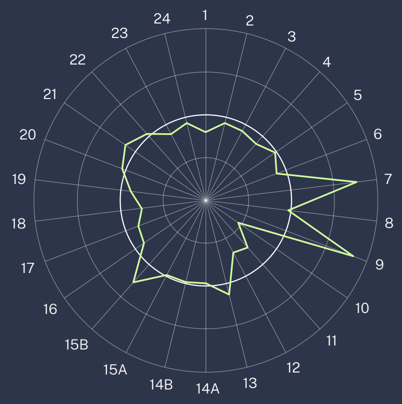

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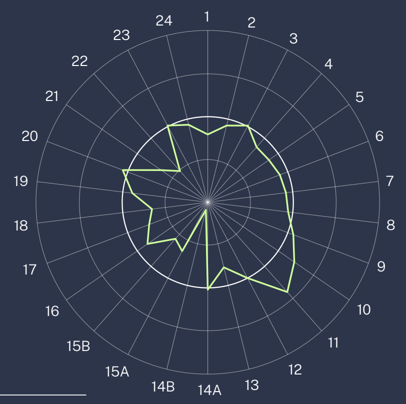

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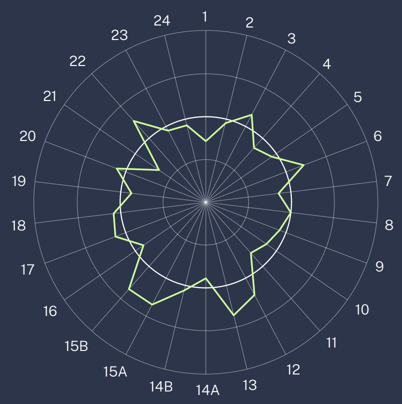
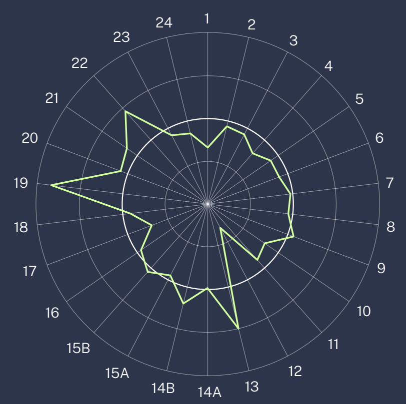


AVAILABLE

Nantes



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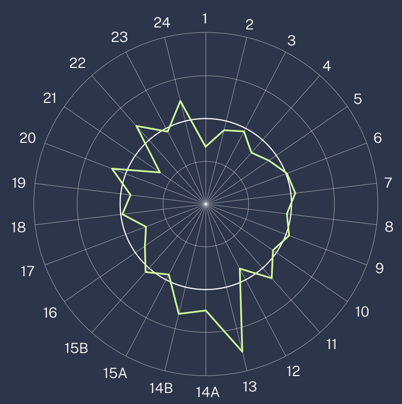

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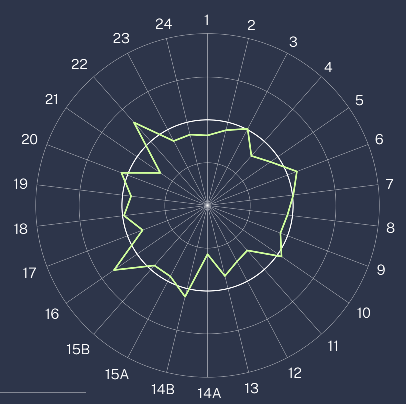
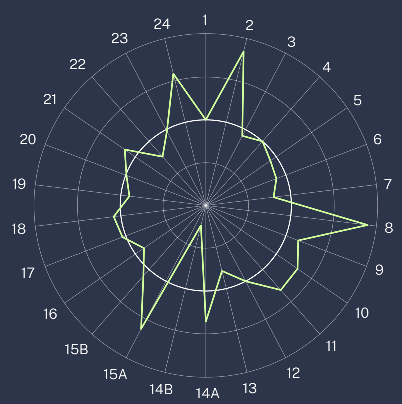


Sydney



Demographics

1. Population
2. Land area
3. Commercial floorspace
4. Number of residential units
5. Number of electricity meters

Decarbonisation

6. Fuel for heating / cooling end-uses
7. National Variable Renewable Electricity Generation
8. Regional Variable Renewable Electricity Generation
9. Regional connected variable renewable generation capacity
10. City electricity demand
11. Heating and/or cooling degree-days

Urban Flexibility

12. Mix of land uses
13. Potential land for local generation near city

14A. Solar roof generation potential

14B. Solar score

15A. Wind generation potential

15B. Wind Score

Consumer Flexibility

16. EV ownership
17. Startup environment
18. Take-up of digital services
19. Attitudes towards climate change and 'green' issues
20. Population growth to 2035
21. Innovation in electricity wholesale market
22. Electricity grid open data
23. Historical change in energy demand
24. Innovation in retail wholesale market

	Connected	Free-market	Scalable	Distributed	Available
Population					
Land use					
Local VRE, DER					
EV penetration					
Digitalisation					
Market innovation					

Smallest Highest

FLEXIBILITY SHIFTS PEAK DEMAND

Applying urban and consumer flexibility to city typologies

In a decarbonised energy system where heating, cooling and transport are all fuelled by electricity and not fossil fuels, there will be greater demand on the electricity grid. This increase in demand will arise from the adoption of low carbon technologies in those sectors, such as heat pumps and electric vehicles, many of which are reliable technologies that governments are currently encouraging consumers to adopt as part of their pursuit of net zero. Electricity system operators and network operators are interested in the potential for consumer flexibility to alleviate some of this additional demand.

Past research by CNZ has shown that consumers do shift their demand in response to price signals by up to 60%-known as 'price elasticity' to economists.[12] Work with Cramton Associates showed that owners of distributed energy resources on real-time tariffs (batteries, electric vehicles, solar panels) turned down their demand in an expensive peak time period by up to around 60% for owners of all of these assets and 40% for those with only an EV or a solar panel.[13] These real-time tariffs mirror the wholesale market in the UK. This market dispatches electricity in general from the least costly, wind, solar, and nuclear, to the most costly, gas and coal.[14]

The CrowdFlex project by Octopus Energy and National Grid ESO showed that in a 'Big Dirty Turn Down' event, around a 60% electricity use reduction over a set 'dirty' time period was recorded for EV households, and around a 40% reduction for non-EV households. 'Turn Up' events resulted in an increase of around 600% in EV owning households and around 130% in non-EV households for electricity use in a 'clean' time period.[15] Those having an energy contract with real-time pricing maintained a 23% long-term reduction.

An uncomfortable lesson learned was that the load shifting in these cohorts occurred in places that did not especially need these consumer behaviours. Previous CNZ research found that in the UK, owners of EVs, solar panels, and batteries lived in bigger houses and in more rural and suburban locations than the national average.[16,17] In these places, there is typically no demand for excess local generation from these houses to meet, during the daytime. Nearby houses are more likely to be unoccupied and heating demand is low. There are typically few or no nearby offices or factories with demand in the day to use any of this excess generation. If the urban form of the place had these receivers (consumers) as well as generators of electricity, we predict that the potential shifts could be even greater.

Shifting of demand away from peak periods today

CNZ analysis shows that if decarbonisation of heat and transport occurs in an unconstrained way, then peak demand can easily triple by 2030. We tested this in two different types of cities, using different scenarios of uptake of EVs and heat pumps in Paris and Buenos Aires. Typical electricity power demand in a peak hour in Paris is around 70-100 kW depending on the season; in Buenos Aires 40-50 kW per 100,000 inhabitants. In both cases, peak demand will triple in the winter and double in the summer compared to current levels. If this is handled in the same way it is today with top-down managed generation, then economic development will be slowed by the necessary grid reinforcement works, with residents and buisnesses bearing the cost through energy bills or general taxation.

12. "Spotlighting the critical role of households in unlocking smart, flexible energy systems", CNZ. https://www.centrefornetzero.org/res/spotlighting-the-critical-role-of-households-in-unlocking-smart-flexible-energy-systems/ (accessed Jul. 18, 2022) | **13.** E. Bobbio, S. Brandkamp, S. Chan, P. CUramton, D. Malec, and L. Yu, 'Price Responsive Demand in Great Britain's Electricity Market' (2021). URL: https://www.cramton.umd.edu/papers2020-2024/price-responsive-demand-in-great-britain.pdf | **14.** "What is the merit order curve in the power system?" Next. https://www.next-kraftwerke.be/en/knowledge-hub/merit-order-curve/ (accessed Jul. 18, 2022) | **15.** "CrowdFlez-Phase 1 report" NGESO. https://www.nationalgrideso.com/document/230236/download (accessed Jul. 18, 2022) | **16.** "Mind the Gap: the costs of moving from gas boilers to heat pumps". CNZ. https://medium.com/centre-for-net-zero/mind-the-gap-587c127c671e (accessed Jul. 18, 2022) | **17.** "Centre for Net Zero's UK home decarbonisation index (HDI)", CNZ. https://medium.com/centre-for-net-zero/centre-for-net-zeros-uk-home-decarbonisation-index-hdi-81d37209c362 (accessed Jul. 18, 2022)

CNZ CONSUMER FLEXIBILITY ANALYSIS

CNZ considered indicators across finance and motivation as a proxy for measurement of 'elasticity' of consumers in digitalised, decentralised future energy systems. Pricing incentives for consumers to reduce demand at peak hours can be measured by the reform of the electricity market. Consumers' motivation to be 'elastic' in their demand across peak and off-peak hours can be measured by their digital skills and perceived risk of climate change.

The first indicator measures the reform of the wholesale electricity market. The more locational marginal pricing (LMP) is in the wholesale market, the more incentivised electricity retailers are to offer real-time pricing to consumers.[18] Cities scored higher the more fine-grained the level of pricing. For example, real-time pricing at the substation (LV/MV) level scored higher than real-time pricing at grid supply points or regional nodes. Cities scored lowest when they did not have LMP or when the prices varied by regional zone without any critical peak or real-time element to the wholesale price. Usually national rules apply to the cities within the country, hence we analyse how the market operates in the country to infer the score at a city level.

The second indicator measures the reform of the electricity retail market.[19] The more real-time or peak-time pricing uptake in the retail market, the more price elasticity of consumers to shift demand away from peak periods, especially those who have access to local generation and storage. Cities scored higher with take up of tariffs that used real-time pricing that tracks the wholesale market or daily variable peak pricing, and lower with seasonal critical peak pricing. Cities scored lowest when retail market take up was highest for static time-of-use tariffs or flat-rate tariffs.

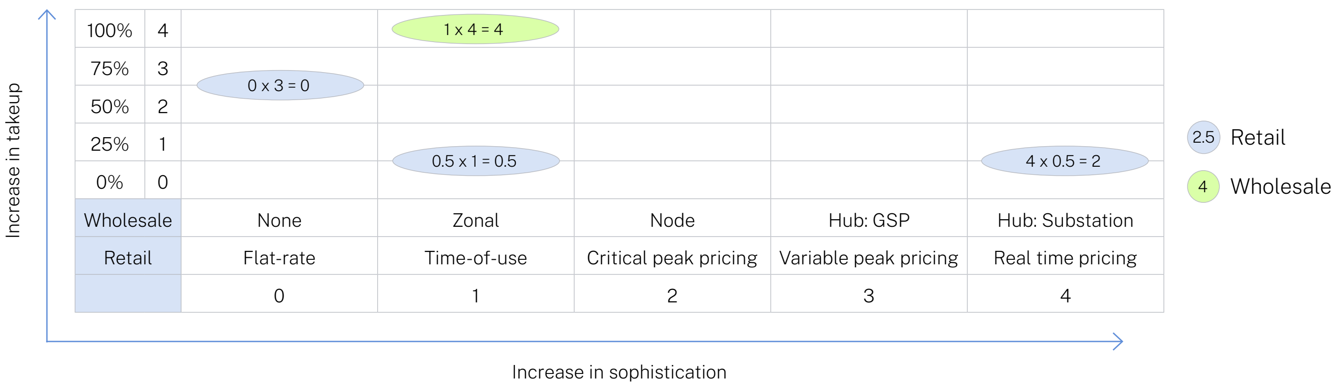
These two indicators were parameterised for ease of understanding by leaders, residents, and businesses. CNZ scored each city by adoption rate of innovative retail tariffs, and wholesale pricing models. With these scores, it is easier to compare cities that have different levels of adoption across the wholesale and retail market.

Wholesale	Retail[20]	Adoption (%)	CNZ Score
None	Flat-rate	0	0
Zonal	Time-of-use tariff	0-25	1
Nodal	Critical peak pricing	25-50	2
Hub: grid supply point	Variable peak pricing	50-75	3
Hub: substation	Real time pricing	75-100	4

There are other indicators in this category that directly measure the amount of flexibility that the city can offer. The percentage of electric vehicles in the vehicle fleet is a direct measure of the amount of storage capacity that could be used through the provision of smart charging.

Consumers who are motivated to use electricity at a lower carbon intensity and have the digital skills to use automation to take advantage of smart charging or smart heating are more likely to use real-time pricing to shift away from peak periods.[21] Awareness scores are higher when more of the population sees climate change as a serious threat to their country.[22] The more mobile internet connections there were per capita in the country, the higher the digital skills scores, taking account of more prevalence of internet usage in urban areas in the Global South.[23] The presence of start-ups can be seen as a proxy for the level of innovation in the city. The greater this score is, the higher the chance that more innovative solutions will be adopted in the city, favouring the implementation of flexibility.

As an example, the table below shows the score for France:



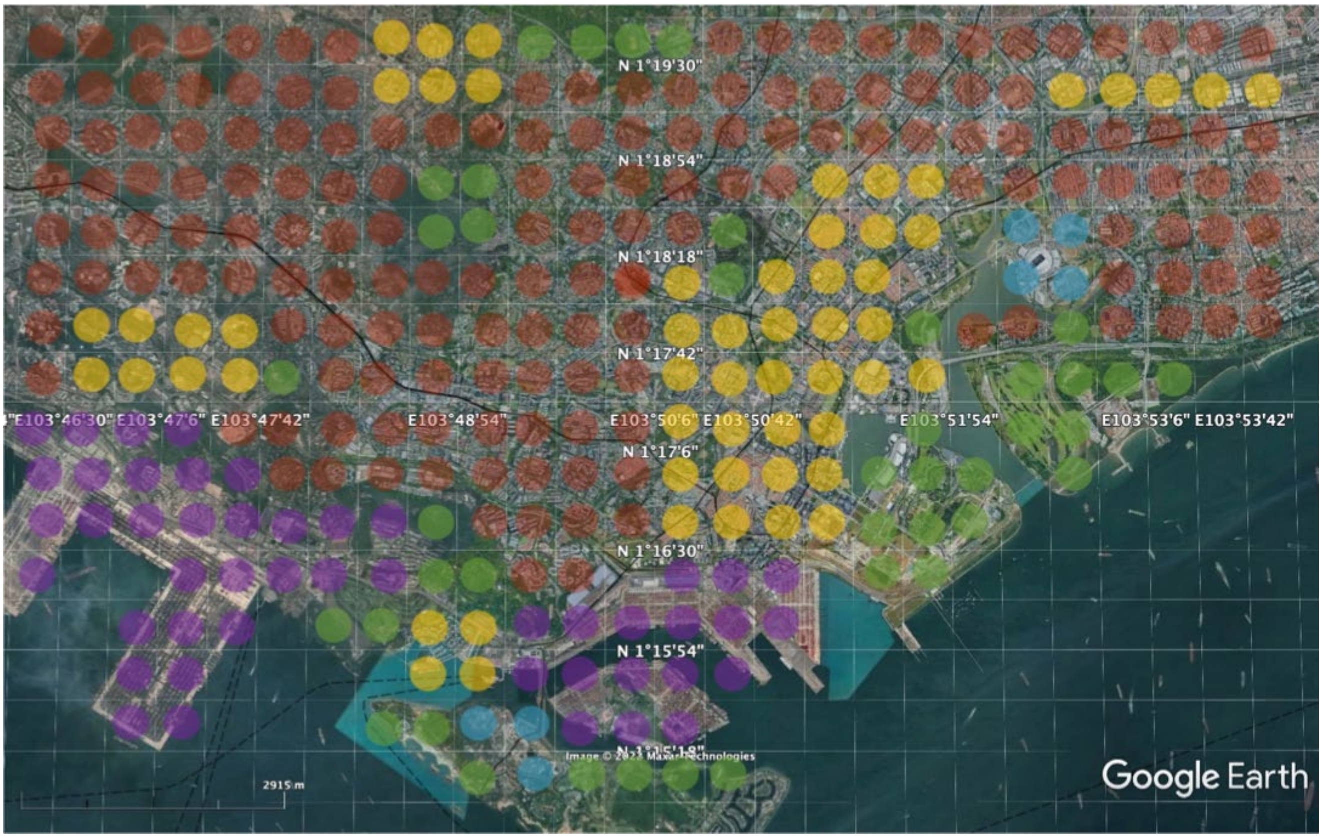
18. "Mapping of selected markets with Nodal pricing or similar systems Australia, New Zealand and North American power markets", NVE. https://publikasjoner.nve.no/report/2011/report2011_02.pdf (accessed Jul. 18, 2022) | **19.** "Innovation landscape for a renewable-powered future: solutions to integrate variable renewables", IRENA. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovation_Landscape_2019_report.pdf (accessed Jul. 18, 2022) | **20.** Time-of-use tariff: This typically applies to usage over large time blocks of several hours, where the price for each time block is determined in advance and remains constant. Real time pricing: Prices are determined close to realtime consumption of electricity and are based on wholesale electricity prices. Critical peak pricing: A rate in which electricity prices increase substantially for a few days in a year. Variable peak pricing: A hybrid of static and dynamic pricing, where the different periods for pricing are defined in advance, but the price established for the on-peak period varies by market conditions | **21.** "Empowering electricity consumers to lower their carbon footprint", IEA. https://www.iea.org/commentaries/empowering-electricity-consumers-to-lower-their-carbon-footprint (accessed Jul. 18, 2022) | **22.** "The Lloyd's Register Foundation World Risk Poll", Lloyd's Register Foundation. https://wrp.lrfoundation.org.uk/explore-the-poll/the-majority-of-people-around-the-world-are-concerned-about-climate-change/ (accessed Jul. 18, 2022) | **23.** "ITU-D ICT Statistics", International Telecommunication Union. https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx (accessed Jul. 18, 2022)

CNZ URBAN FLEXIBILITY ANALYSIS

Urban flexibility is a measurement of how mixed energy profiles are throughout a city, and the potential for local generation and storage near the centre of the city. We expect urban flexibility to play a leading role in reducing peak demand in cities in the future - the effect of having a local recipient of electricity from local generation and storage will increase in importance in the near-term energy transition. This includes the 'floating distributed' energy resources of electric vehicle batteries. A CNZ partnership with the Alan Turing Institute shows the benefit of a progressive LV flexibility market to enable load shifting minimises the requirement for grid network reinforcements.[24]

The first indicator is a measure of concentration of land uses in a 125 sq km area around a city centre, using the Herfindahl–Hirschman Index (HHI) of market concentration to estimate the mix of electricity demand profiles (domestic / non-domestic) in a typical district in that city. Below, we can see an example for Singapore.

The second indicator is a measurement of the potential for local variable renewable energy generation and storage for a city. We measured the number of days in the city where the wind is blowing and the sun is shining enough to incentivise investment in solar panels and onshore wind in the city's metropolitan area.



Map showing predominant land uses in Singapore city centre (residential (red), commercial (yellow), industrial (purple), institutional (blue), parkland (green))

24. "Partnership announcement: CNZ x The Alan Turing Institute", CNZ. https://www.centrefornetzero.org/partnership-announcement-cnz-x-the-alan-turing-institute/ (accessed Jul. 18, 2022)

FORECASTING SHIFTS FROM PEAK TO OFF-PEAK PERIODS

With the help of the indicators we have built, we developed forecasts for each city typology to show how to move away from demand peaks. This redistributes energy consumption to reduce the amount of carbon-intensive periods throughout the day, creating zero, or even positive energy periods. Earlier in this paper, we forecast what an unconstrained energy transition might look like for cities by 2030-potentially a tripling of peak electricity demand.

We estimate the flexibility of electricity demand for each of our five typologies in peak hours. We started with the average of the normalised indicators for urban and consumer flexibility for each of the typologies. Based on the difference between the indicators, we assigned how much the share of flexibility comes from either urban or consumer flexibility. We estimated low, medium and high uncertainty to understand the range of flexibility. Based on our analysis of the strengths of each typology, we estimated the top end of flexibility for each type of place, and split it across urban and consumer flexibility.

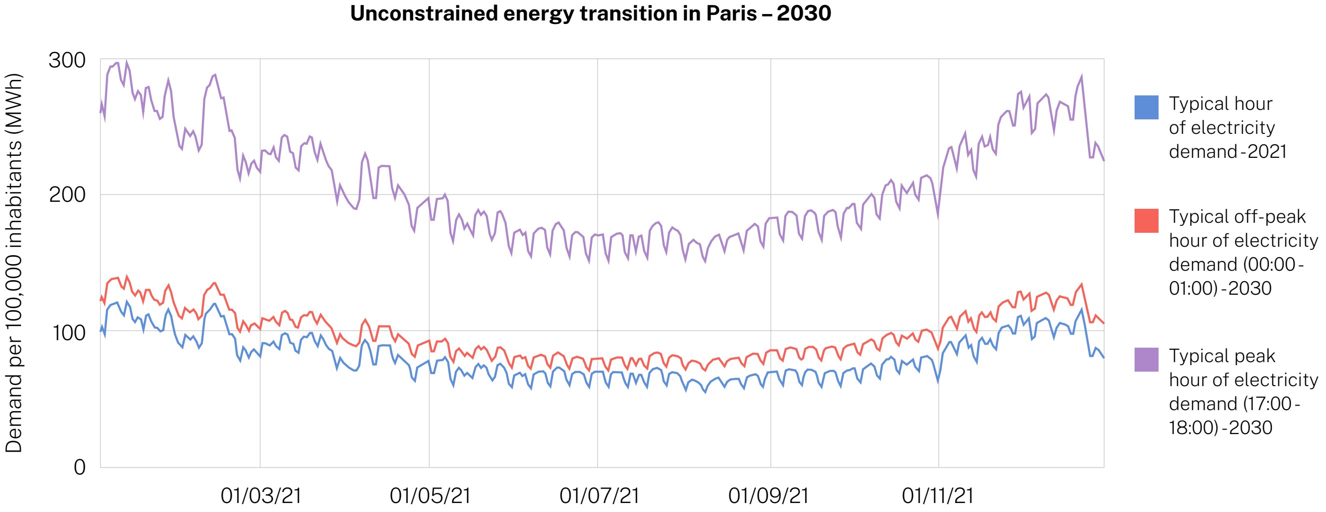
The results are presented in the table below:

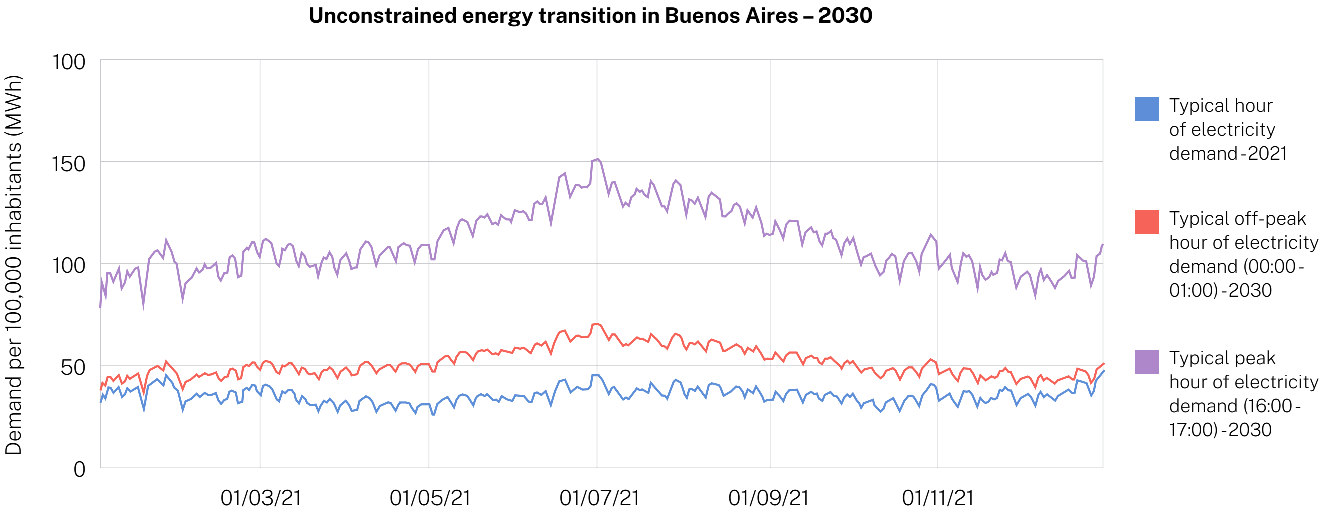
Typology	CNZ Urban Flex average	CNZ Consumer Flex average	Difference	Urban Flex Share	Consumer Flex Share	Uncertainty	Urban Flex Shift - top end	Consumer Flex Shift - top end
Connected	-0.04	0.05	-0.09	40%	60%	Low	20%	30%
Free-market	0.08	0.03	0.05	60%	40%	High	15%	10%
Scalable	0.17	-0.05	0.22	80%	20%	High	20%	5%
Distributed	-0.11	-0.05	-0.06	40%	60%	Medium	15%	22%
Available	.05	0.03	0.02	50%	50%	Medium	25%	25%

For each typology, we derived ranges for energy shifts away from peak demand due to urban and consumer flexibility, using the values above for top end flexibility and uncertainty with knowledge CNZ gained from our previous research on ownership of low carbon technologies. We found that consumers who owned EVs generally shifted their demand the most in both the CNZ/Cramton and the OE/NGESO Crowdflex projects. Other households that did not have an EV but had solar panels and/or home batteries shifted around half the energy from peak hours of those with EVs. From these results, the shift of heating and cooling demand would be half of the 'top end' EV demand in all of our typologies. These results can be seen in the table opposite:

Typology	Urban Flexibility		Consumer Flexibility	
	Range Heating / Cooling Shift	Range EV charging shift	Range Heating / Cooling Shift	Range EV Charging Shift
Connected	7-10%	15-20%	10-15%	25-30%
Free-market	0-10%	2-15%	0-5%	2-10%
Scalable	0-10%	5-20%	0-2%	0-5%
Distributed	2-7%	10-15%	5-10%	15-22%
Available	5-10%	15-25%	5-10%	15-25%

In our initial research, we took Paris, a Connected city and Buenos Aires, a Scalable city. In Paris the scale of the challenge is mostly down to the electrification of heat and transport in the city. In a scenario where gas heating and petrol cars are 90% phased out by 2030, this leads to a **140-190% increase in electricity demand during a peak hour,** depending on the season -more than doubling in a peak hour, and nearly trebling in winter. In Buenos Aires, a scenario where gas heating and petrol cars are 70% phased out by 2030 would lead to a **130-300% increase in electricity demand during a peak hour.**



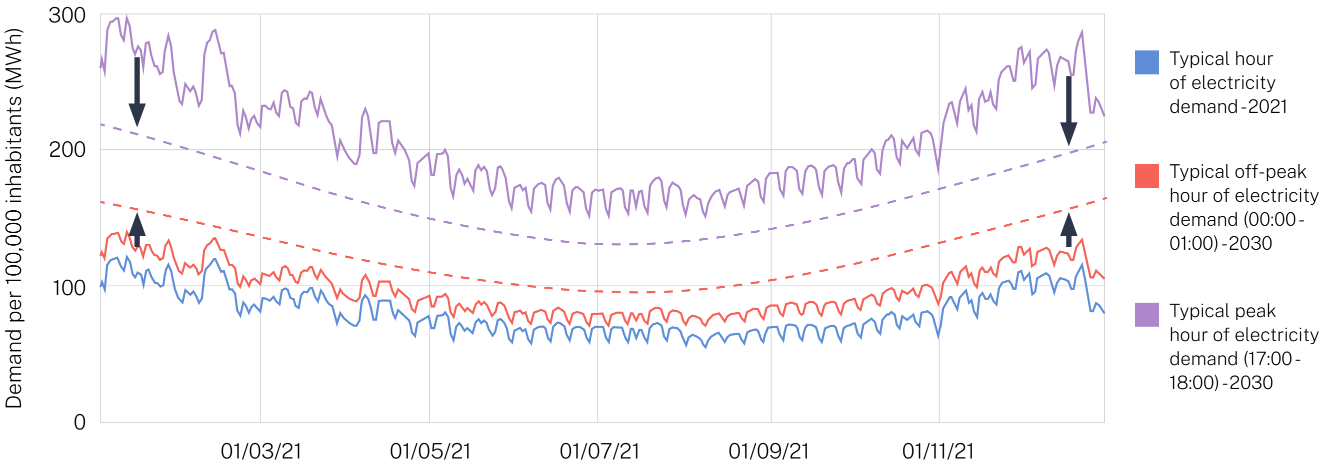


Consumers can shift much of their demand from the electricity system at peak times with only passive use of generation and storage. This means that there is no exporting of electricity to the grid, and buildings only use their own generated or stored energy. In Paris, we found that in a scenario where 80% of vehicles are EVs by 2030 and take up of small-scale solar with battery storage in buildings reaches 10% of buildings,[25] **20% of heating and cooling peak demand could be shifted to other hours of the day and 40% of EV charging demand** could be shifted this way. In **Buenos Aires, peak demand could be shifted by 10% and 20% respectively** where takeup of EVs is much lower.

Consumers can go much further if there is active use of generation and storage, where excess generation and stored electricity is used by others. In the same scenario where 80% of vehicles are EVs by 2030 and take up of small-scale solar with battery storage in buildings reaches 10% of buildings in Paris,[26] **another 10% of heating and cooling peak demand could be shifted to other hours of the day and 20% of EV charging demand** could similarly be shifted. In a city where there is more land available for generation and storage like **Buenos Aires, another 15% and 30% peak demand could be shifted.**

In our two examples, **25-30% of heating and cooling demand and 55-60% of EV charging demand** in a peak hour shifts to other hours of the day, slowing electricity growth for a peak hour in Paris down from a **140-190% increase** to a **110-140% increase,** and for a peak hour in Buenos Aires from a **130-300% increase** to a **114-230% increase.**

Flexibility used in the energy transition in a Connected city (Paris) – 2030



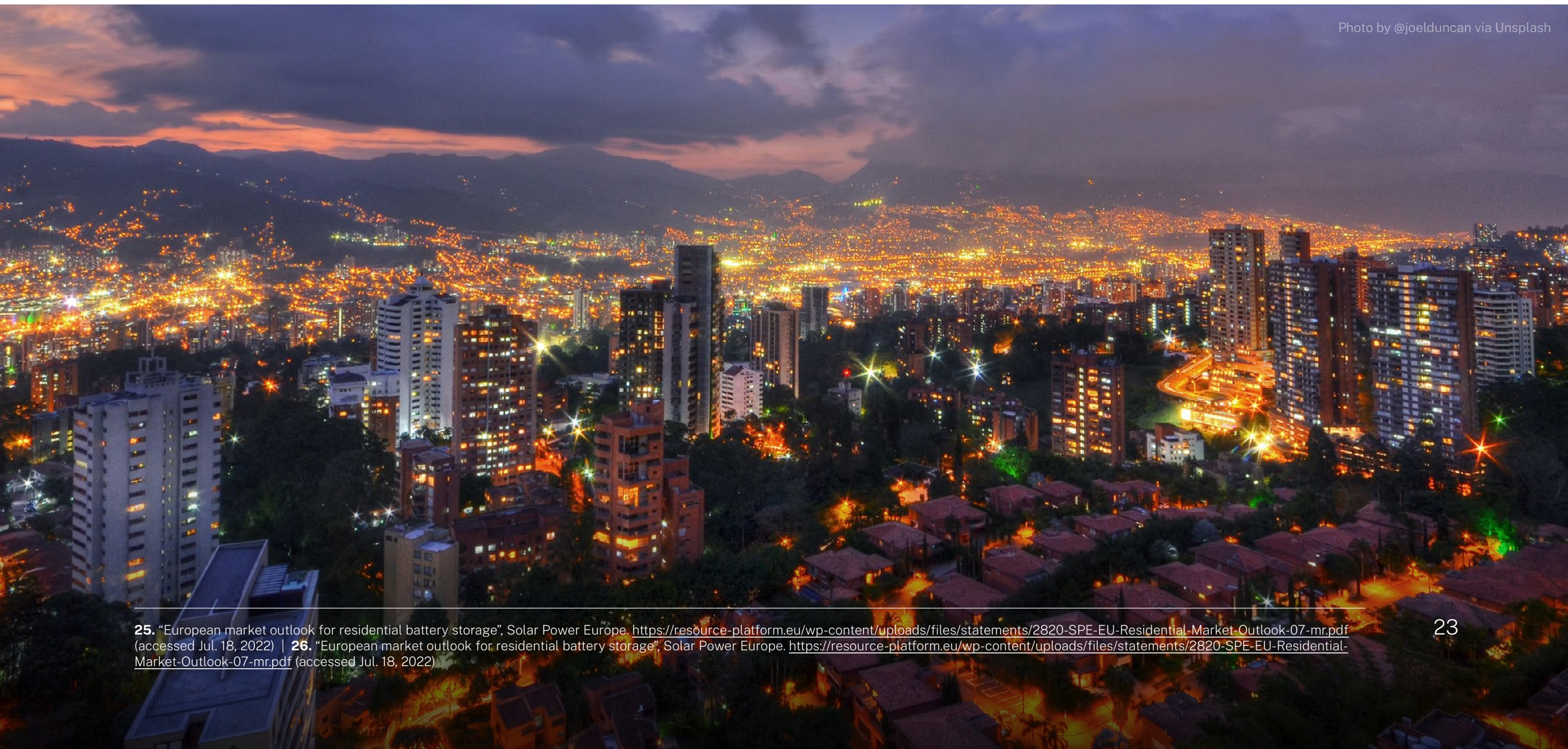


Photo by @joelduncan via Unsplash

25. "European market outlook for residential battery storage", Solar Power Europe. https://resource-platform.eu/wp-content/uploads/files/statements/2820-SPE-EU-Residential-Market-Outlook-07-mr.pdf (accessed Jul. 18, 2022) | **26.** "European market outlook for residential battery storage", Solar Power Europe. https://resource-platform.eu/wp-content/uploads/files/statements/2820-SPE-EU-Residential-Market-Outlook-07-mr.pdf (accessed Jul. 18, 2022)

MAKING IT REAL FOR AN URBAN BLOCK

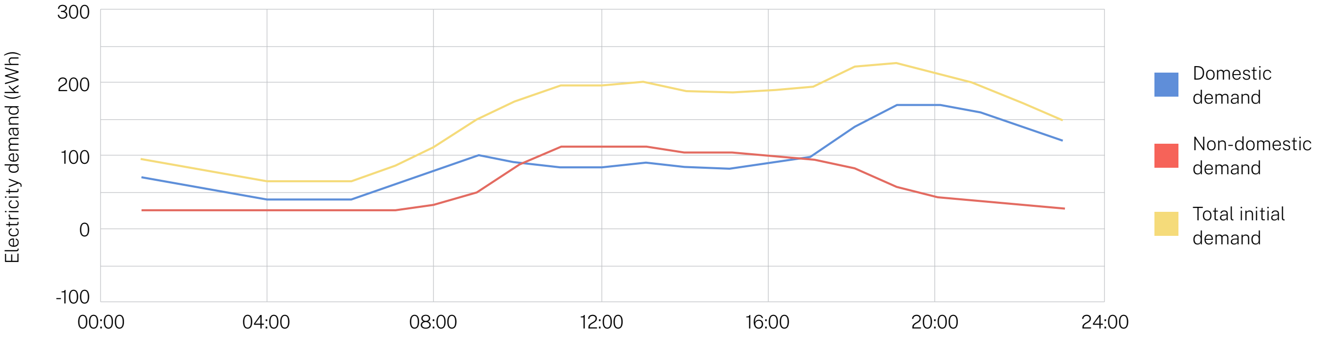
Imagining how an ideal urban block functions in the near future can make the transition real for city leaders, citizens and other stakeholders. It can be hard to think of land use, import and export tariffs, and dispatch of renewable electricity generation across an entire city and align that with the lived experience of residents and businesses.

It can be difficult for consumers and businesses to imagine a collective role in the capacity and frequency of the grid, instead of individual import and export to and from the electricity grid. This is why we have chosen to show how an urban block within a Connected city typology where consumers are participating fully in a flexible energy transition could operate.

We made the following assumptions about the block:

- 200 residential units (flats), all estimated to have an average floor area of 80 square metres, plus circulation space per flat of 20 square metres = 20,000 square metres
- 25 commercial units (offices) Assume seating for an average 20 employees, 20 sq m needed per employee for seating, meeting, and circulation space = 10,000 square metres
- 30% of domestic premises have access to either the battery of an EV or a home battery rated at 7 kW and a solar PV panel rated at 1 kW
- Scenario 2: All non-domestic premises have access to the equivalent of 10 EV or small, home-sized batteries rated at 7 kW and 10 solar PV panels rated at 1 kW
- From the irradiance of the city block and the roof angles of the buildings, the maximum utilisation of 1kW of the solar PV panels was set at 60% (noon, summer)

For this city block, the consumption today would look as plotted in the graph below:



Using electricity demand profiles that cover heating, lights, cooling and appliances in the domestic and non-domestic sectors, we determined that the power demand of the block nearly triples from around 75-100 kW in the early morning to around 200-225 kW during the afternoon and evening.

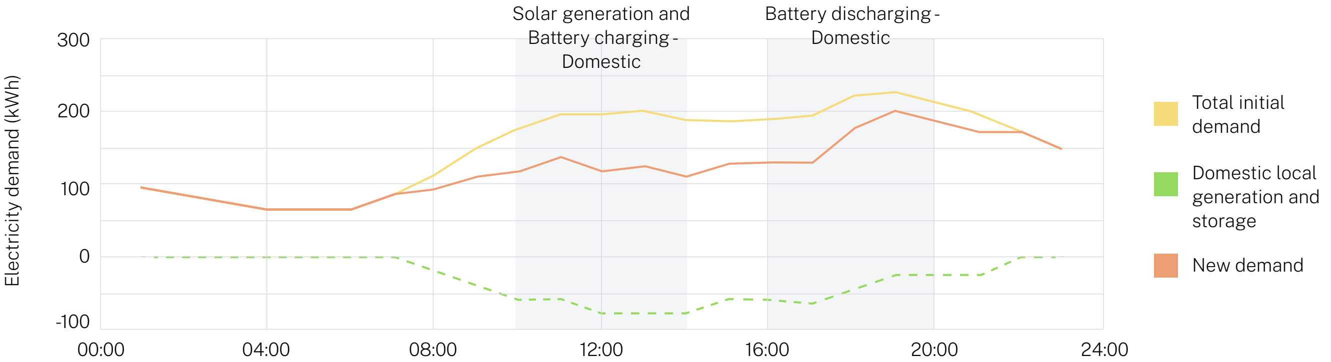
We tested two scenarios: one where only residents changed their behaviour to use less electricity in the afternoon and evening and one where both residents and businesses changed their behaviour.

Scenario 1: Domestic-only generation and storage

Cities often limit their policies for local generation and storage to the domestic sector only. The reasons for this range from land ownership of public housing, planning powers for new development, and fuel poverty. We then tested this scenario with the assumptions above for takeup of local generation and storage, including an assumption that many of the batteries in this scenario were likely to be EV batteries.

In this scenario, total demand from the grid from the urban block during the afternoon reduced to 100-125 kW, but rebounded back up to 200 kW by the evening. Demand was decreased by solar PVs in the daytime, but not enough power from batteries was available in the evening to bring demand below 200 kW. This was still double off-peak demand.

Our conclusion is that domestic-only policies will not bring the peak down sufficiently, and that non-domestic buildings and EVs need to be included. The load profile under these assumptions is plotted in the graph below:



Scenario 2: Domestic and non-domestic generation and storage

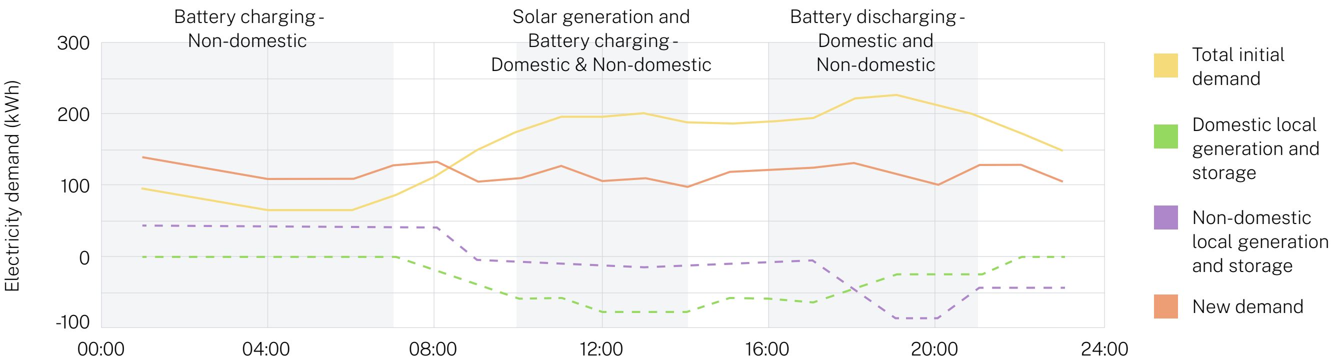
This scenario was tested with both non-domestic and domestic distributed energy resources in play -including an assumed number of EVs and batteries associated with the businesses inside the buildings and in the surrounding streets and car parks.

In this scenario, total demand from the grid from the urban block during the afternoon reduced to 100-150 kW, and stayed at 100-150 kW by the evening as both domestic and non-domestic batteries were discharging. All of these batteries (EV and home) were charged in off-peak hours from the grid, increasing demand to 100 -150 MW. In effect, using both the domestic and non-domestic sectors in local generation and storage achieves a 'constant, 24/7 import' of electricity from the grid for this urban block.

Finally, we end up with a flattened demand curve, as shown in the Figure below.

Delivering a clean energy urban block will affect cities' planning and transport policies. Our early analysis suggests a desirable ratio of around 2:1 domestic to non-domestic floorspace in a city block or urban district to support a **constant, 24/7 import of electricity** made possible by local generation and storage. In connected places, reserving street and car parking space for EVs with smart chargers can provide that storage alongside investment by landowners in on-premises batteries. More work is needed to measure the effectiveness of EVs as a 'floating energy resource,' where domestic EV owners charge and/or discharge on commercial streets and car parks or commercial EV owners charge and/or discharge on residential streets and car parks.

24/7 constant import of electricity to an urban block



RECOMMENDATIONS TO CITIES

Our analysis shows that cities are well placed to deliver and benefit from decarbonised energy systems, from improving the security of a cheap, green energy to fuelling job creation and creating digitally proficient workforces.

For each of our typologies, we've provided a range of high-impact, evidence-driven actions for the near-term (by 2025) and for the future (by 2040) that city leaders, local stakeholders, private sector innovators and investors can use for their city as they collectively seek to decarbonise city energy systems and deliver greener urban environments.

Leaders can prioritise immediate and future actions based on the makeup of their city now and in the future. This section breaks these actions down across the three categories of **urban flexibility, decarbonisation and consumer flexibility** for each of our typologies, identifying interventions that should be pursued by 2025 and 2040 respectively. Cities can use our 2025 recommendations with funding, powers, and partnerships they already have in place. A city can use our 2040 recommendations to take steps to increase their funding, powers, and partnerships for their future energy system.

The cities that informed the typologies:

Connected
Paris, London, Tokyo

Free-market
Singapore, Bengaluru, Los Angeles

Scalable
Buenos Aires, Johannesburg, Nairobi

Distributed
Stockholm, Vancouver, Medellin, Amsterdam

Available
Nantes, Valencia, Manchester, Sydney

Photo by @jamie_davies via Unsplash

WHO CAN HELP CITIES TAKE ACTION

Immediate, 2025 → Future, 2040

Actor	Source of Flexibility	Data platforms	Planning policies and standards	LCT community assets	Investment	Retail market reform	Consumer engagement
City Halls	Access to funding Procurement for public buildings	Opening up data in public ownership Building secure and trusted platforms	Directing powers - new build Convening retrofit	Procurement for public land Convenor of landowners with open space and rooftop space	Gathering demand from consumers to purchase VER modules Investing in economic development programmes, pension and investment funds in clean energy	Procurement of energy as a owner of buildings and streets	Incentives for automation and use of flexibility
Networks of cities	Documenting what works -connecting leaders to peers	Documenting and promoting data standards and quality	Documenting direct powers that work -connecting leaders to peers	Documenting what works -connecting leaders to peers	Connecting global investment markets to funds	Documenting what works -connecting leaders to peers	Documenting what works -connecting leaders to peers
Energy and tech innovators / suppliers	Testing demonstrators (e.g. X2G); de-risking flexibility through tariffs Managing microgrid data platforms	Data standards, sharing agreements with DER owners, smart heating/ charging consumption	Testing with consumers in new build areas of the city (smart heating/ charging)	Designing software to help grids and LCT owners optimise assets	Creating investable packages of DERs	Designing tariffs for consumers and businesses; developing tools to demonstrate financial savings	Gathering data on behaviours and use of automation in smart charging, heating, and cooling
Consumer activators	Recruiting participants to participate in peer-to-peer trading or crowd-sourced investment	Recruiting consumers to give access to data	Campaigning to get consumers to buy-in to low-cost operational energy	Connecting landowners with installers and gov subsidies	Gathering demand from consumers to purchase VER modules	Directing consumers to tariffs that save money and the planet	Directing consumers to use of flexibility to save them money
Place experts	Designing places with compatible land uses	Open sourcing tools for data-driven city design	Designing masterplans to maximise energy flexibility	Evaluating solar and wind potential of buildings; evaluating space available for storage	Evaluating solar and wind potential of undeveloped land and buildings	N/A	N/A
Electricity system operators	Promoting smaller DERs through connection charging policies	Access to open data for grid supply points frequency management and capacity market	Promoting smaller DERs through connection charging policies	Promoting smaller DERs through connection charging policies	Promoting smaller DERs through connection charging policies	Introducing locational marginal pricing	Creating engagement programmes with consumers to use energy to save money and the planet
National regulators	Providing funding to city governments for flexibility demonstrators	Mandating energy data standards and quality; data sharing regulations	National planning policies and general permitted development policies	General permitted development policies	Regulation of PPAs and collective investment in renewable projects	Redesigning pricing regulations to incentivise use of cheap and clean variable renewable energy	Funding tax rebates and investment by city governments

IMMEDIATE ACTIONS - 2025

Urban Flexibility | Decarbonisation | Consumer Flexibility

	Urban flexibility				Decarbonisation	Consumer flexibility	
	Source of flexibility	**Data platforms**	**Planning policies and standards**	**LCT community assets**	**Investment**	**Retail market reform**	**Consumer engagement**
Connected	Allowing EVs with residential parking permits access to non-domestic chargepoints	Building data platforms for strategic infrastructure planning		Prefering smaller VRE modules and batteries as community assets	Starting economic development programmes that fund energy innovators		Setting up an information hub for consumer flexibility
Free-market	Procuring EVs and chargepoints for public sector fleet and properties	Building district data platforms in areas of current high grid congestion		Prefering smaller VRE modules as community assets	Using economic development programmes to fund energy innovators		Making a grid stress management alert system
Scalable	Procuring EVs and chargepoints for public sector fleet	Building growth area data platforms	Developing LCT policies for major public sector projects	Prefering medium-sized VRE modules and batteries as community assets	Procuring storage in areas of grid congestion	Developing policies for public sector time of use tariffs	Creating resident community energy boards
Distributed			Mandating local generation and storage for new build developments		Creating programmes that support rooftop solar supply chain	Moving public buildings supplied by renewable energy onto dynamic tariffs	Supporting smart heating/cooling and charging in domestic sector supplied by excess local renewable generation
Available	Setting a goal for storage capacity per resident			Prefering larger-sized VRE modules and batteries as community assets	Supporting financing of storage for private owners	Placing public sector properties on dynamic tariffs	Supporting rollout of domestic smart heating/cooling and charging paired with nearby storage

FUTURE ACTIONS - 2040

Urban Flexibility · Decarbonisation · Consumer Flexibility

	Urban flexibility				Decarbonisation	Consumer flexibility	
	Source of flexibility	**Data platforms**	**Planning policies and standards**	**LCT community assets**	**Investment**	**Retail market reform**	**Consumer engagement**
Connected	Designating EV/ smart charging district Coordinating EV charging hours	Including smart meter data in city datastore	Including rooftop solar in every non-domestic planning agreement	Requiring LCTs part of retrofit of entire social housing estate	Pension funds directly investing in future energy systems	Making all public sector chargepoints only open to EVs on intelligent tariffs	Creating tax rebates for EVs that are flexible in the right locations in the city
Free-market	Procuring EVs and chargepoints across public sector fleet	Designating a special data zone for innovation in energy technologies	Requiring all public buildings to have LCTs on site Developing community retrofit programmes	Designating solar districts in areas of grid congestion	Creating local tax rebates for investments in renewable generation and storage	Creating tax rebates for access to private chargepoints for those on intelligent 'roaming' tariffs	Creating tax rebates for automating smart charging, heating and/or cooling
Scalable	Designating EV-only parking at public buildings	Building growth zone datastores	Requiring LCTs for all new builds, public and private Developing community retrofit programmes	Procuring VRE modules and batteries for all public buildings	Investing in and create products of renewable generation and storage assets	Moving all public sector properties onto a time of use tariff Creating tax rebates for access to smart chargepoints	Supporting programmes for investment in community energy
Distributed	Designating an EV-only inner urban core	Building data platforms for strategic planning of generation and storage	Requiring local generation in masterplans	Procuring LCTs at every MV substation	Designating rooftop solar investment areas	Requiring all public sector properties have local generation and public chargepoints	Implementing a joint venture for energy sharing for economically disadvantaged neighbourhoods
Available	Installing strategic large-scale storage for every MV substation	Building data platforms for strategic planning of storage	Requiring local storage in masterplans	Procuring on-premises batteries for all public sector buildings	Designating storage investment areas Selling green bonds to the markets	Providing tax rebates for local generation and storage on a dynamic tariff Installing EV chargepoints on intelligent tariffs	Providing tax rebates for businesses that invest in storage that charge from renewables Creating tax rebates for joining an intelligent tariff plan

CONNECTED CITIES

Urban Flexibility

By 2025: Allow EVs with residential parking permits to park at non-domestic chargepoints and/or near non-domestic building battery storage.

Connected cities will benefit from leveraging their ownership of streets and spaces to set visitor parking permit rules and charges. During the daytime when local renewable energy is more plentiful, EVs can charge batteries when parked at commercial premises using their residential parking permits. This would prevent networks from curtailing local renewable generation in the daytime. These cities have the third-highest level of EV ownership, with policies in these cities' climate action plans set to accelerate ownership further, growing the opportunity to leverage EV batteries for storage.

- **By 2040:** Designate EV-only smart charging districts in areas of grid congestion - parking permits on-street and in major car parks will only be renewed with a smart chargepoint.
- **By 2040:** Only allow EVs to park in places and at hours that would benefit grids the most in real-time (for example, commercial districts in the day / residential districts at night).

By 2025: Create data platforms for strategic infrastructure planning in a new era of smart charging, cooling, and heating.

Cities have powers as holders of planning application data to inform where more buildings are being matched with upgrades of the grid and/or active management with smart charging, heating and cooling. Efficient data-sharing will be critical to enabling the transition to a more flexible system. All the cities informing this typology have initiatives to store, analyse and facilitate sharing of a city's energy and infrastructure data between trusted partners, from network operators to research institutions. These platforms are in their initial stages of deployment, such as the Data for London platform,[27] the I^2AM PARIS platform,[28] and the SMAP Energy platform in Tokyo.[29] This data is critical for ESOs and DSOs, who need it for both frequency management and the capacity market, and premises and chargepoint owners, who will need the data to participate in peer-to-peer trading or crowd-sourced alternative investment opportunities.

- **By 2040:** Increase data in the store to include aggregated smart meter data to monitor effectiveness of smart charging, cooling, and heating on grid health, saving the planet, and saving money.

By 2025: Accept smaller VRE modules and batteries as community assets in planning agreements.

Connected cities will benefit from using their urban planning powers to favour smaller VRE modules and batteries when they are making planning agreements with applicants in connected places. It is common for applicants to propose contributions towards grid reinforcement and other community assets. It is reasonable to see VRE, such as rooftop solar, as a cheaper and more sustainable asset for an application to contribute as part of the granting of planning permission. These policies will empower place experts (architects, urban planners, transport planners) to evaluate the potential and space available for generation and storage to advise cities on how much VRE is in the development pipeline in the near-to-medium term. As a result of their size, connected cities have many buildings where solar PV panels could be installed. Our analysis shows that they rank first out of the typologies for roof availability, with more than 3460 hectares available on average, 700 hectares more than distributed cities, for example.

- **By 2040:** Commit to chargepoints, local generation and storage as part of the retrofit of the city's social housing estate and rooftop solar in major car parks as a condition of the renewal of parking permits.
- **By 2040:** Require every non-residential building to include rooftop solar in area action plans and masterplans that govern major growth and regeneration areas of the city.

CASE STUDY

Together Housing Group - Solar Panels with Battery Storage Technology in retrofit properties

All 250 tenants that were provided with solar panels and batteries received an induction detailing how best to use the solar energy. The housing group provided regular updates on the tenants' use of renewable energy and advised residents on how to improve their usage in future. Tenants are already engaged with monitoring their energy use. A year's worth of data from the project showed a conservative average saving of 625kg CO_2e per property per year.

Together Housing also partnered with Octopus Energy and Utilita Energy to trial time-of-use tariffs, allowing tenants to make further energy savings by taking advantage of off-peak energy prices and battery storage.

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27. "Mayor announces plan for Data for London platform", UKAuthority. https://www.ukauthority.com/articles/mayor-announces-plan-for-data-for-london-platform/ (accessed Jul. 18, 2022) | **28.** "The Creation of an open–access data exchange platform", Paris Reinforce. https://paris-reinforce.eu/i2am-paris/platform (accessed Jul. 18, 2022) | **29.** "SMAP Energy Platform promotes renewable energy usage with smart-meter data and gamification", SMAP Energy. https://smapenergy.com/smap-energy-platform-promotes-renewable-energy-usage-with-smart-meter-data-and-gamification/ (accessed Jul. 18, 2022)

CONNECTED CITIES

Decarbonisation

By 2025: Start economic development programmes that fund energy innovators

Connected cities should fund programmes for energy innovators to help residents and businesses purchase and install VRE modules and DERs. The sheer number of small-scale DERs needed for the capacity market means that private sector innovation is the best path to a fast transition. These cities are located in countries witheconomic development funds targeted to cities and regions (for example, the European Regional Development Fund in the EU and the Shared Prosperity Fund in the UK) to create markets in the interests of the city and its residents. These cities have sizeable populations and a large business sector with the budgets and consumer base needed to invest in VRE, DERs, and energy efficiency. The cities analysed by CNZ show that those in this category tend to be the most populous, with an average of almost 10 million inhabitants per city, closely followed by Scalable and Free-market cities, with 7.5 million on average, and almost five times as many inhabitants compared to distributed and available cities.

- **By 2040:** Cities as manager of employee pension funds directly invest in innovators of digital products for future energy systems as part of public-private joint ventures.

CASE STUDY

C40 Invest/Divest Forum

London and New York have committed to using their pension funds to invest in renewable energy and divest from fossil fuels. The oil and gas sector already has a weak economic outlook. Divest/Invest is promoted by C40 Cities as an effective way for city pension funds to protect their assets in the long-term and take advantage of the shift towards a green economy.


Photo by @pemarroquinmtz via Unsplash

Consumer Flexibility

By 2025: Cities set up a information hub for consumer flexibility.

Connected cities' flexibility targets can benefit from information hubs for consumers to know where and when they can charge and discharge their EV/batteries. Engaged, digitally proficient populations who can engage in and benefit from flexibility will be crucial in densely populated areas. Connected cities have the highest population density of all the typologies, and high levels of EV ownership. High scores in green attitudes in these cities indicate a greater propensity for behavioural change and use of automation, from smart heating and cooling to smart charging.

- **By 2040:** All chargepoints owned by the city are 'smart' and are only available to EVs that are on an intelligent charging tariff. 'Roaming' charges for EVs become the default payment system. All city properties move to smart heating and cooling.
- **By 2040:** Cities give discounts on council/property taxes and business rates to consumers that choose to charge/discharge their EVs and the smart charger owners in third-party locations that offer flexibility to the grid.

CONNECTED CITIES

By 2025	By 2040	Benefit	Supporting data	
Urban Flexibility				
EVs with residential parking permits access to non-domestic chargepoints	**EV/smart charging district designations** **Create coordinated EV charging hours**	High	Third highest EV ownership, 22% lower than the average	Lowest amount of undeveloped land near the city, 58 times lower than the average. However, quite mixed cities (second lowest HHI) and greatest commercial floorspace available, almost three times more than average
Data platforms for strategic infrastructure planning	**Include smart meter data in city datastore**	Very high	Highest start-up environment, 108% greater than the average and highest take up of digital services, 37% higher than the average	Most open data available about energy and cities - 22% more than average
VRE modules and batteries as community assets	**LCTs part of retrofit of entire social housing estate** **Every non-domestic planning agreement to include rooftop solar**	Very high	Highest population density, 85% more population than the average of the other cities. Quite mixed cities (second lowest HHI)	Lowest amount of undeveloped land near the city, 55 times lower than the average. Greatest roof available for solar uses (13% higher than the average)
Decarbonisation				
Economic development to fund programmes for energy innovators	**Pension funds directly invest in future energy systems**	Moderate	Economy of scale as largest cities, their population is 85% larger than the average	Highest start-up environment, 37% greater than the average and highest take up of digital services, 22% higher than the average
Consumer flexibility				
Cities set up a information hub for consumer flexibility	**All public sector chargepoints only open to EVs on intelligent tariffs** **Tax rebates for EVs that are flexible in the right locations in the city**	High	Highest population density, 85% more population than the average of the other cities and relatively high levels of climate change perception, 4% higher than average	Third highest EV ownership, 22% lower than the average

FREE-MARKET CITIES

Urban Flexibility

By 2025: Procure EVs and chargepoints for the public sector fleet and parking permits for privately-owned EVs.

Free-market cities will benefit from procuring EVs and chargepoints for any new additions and replacements to and for its public sector fleet and allow EVs with residential parking permits to use non-domestic chargepoints without a city parking charge. Free-market cities have high levels of EV penetration, comprising more than 1% of the vehicle fleet, only outnumbered by Distributed cities. However, it is important to foster the introduction of more EVs both in the domestic and non-domestic sectors, to further leverage the combined consumption and generation of electricity in these sectors.

- **By 2040:** Procure EVs and chargepoints to replace entire public sector fleet.
- **By 2040:** All public buildings in the city to have chargepoints and either local generation or storage.
- **By 2040:** Entire streets and blocks undertake a mandatory retrofit to include local generation and storage together if a majority of leaseholders/landowners vote for it.

By 2025: Create district data platforms to manage high grid congestion (e.g. intensification areas).

Free-market cities benefit from district data platforms in areas of current high grid congestion to monitor and promote smart charging, cooling, and heating (including aggregated smart meter data). Distribution network operators will need more active management of DERs in the short-to-medium term. This is more likely in Free-market cities, where strategic planning encourages more areas of intensification and regeneration. The cities that informed this typology had abundant solar resource, which is consistently available for 8 months of the year on average, by using available rooftop space -which averages more than 3000 hectares.[30]

- **By 2040:** Create a 'special data zone' (like a freeport) where suppliers and grid operators waive any fees or derivative profit-sharing with innovators across smart charging, cooling, and heating.

By 2025: Accept smaller VRE modules as community assets in planning agreements.

Free-market cities benefit most from local planning regulations that favour smaller VRE modules (e.g. rooftop solar and onshore wind). Free-market cities have the most mixed land use. They have lowest HHI values on average, at around 3900, between 400 and 1000 points lower than the other categories. These cities are horizontally-mixed, meaning that the commercial or residential blocks are concentrated in different parts of the city, increasing the complexity of energy flows. Smaller, more numerous modules deploy flexibility better in areas of cities dominated by adjoining land uses (e.g. residential, commercial).

- **By 2040:** Designate solar districts in areas of grid congestion (only approving planning permission for improvements with solar subject to affordability; provide business and/or council tax discounts for properties that install solar).

CASE STUDY

The California Solar Mandate

The new solar mandate in California (1st Jan 2023) uses the building efficiency standards for solar photovoltaic (PV) system and solar ready requirements. The solar mandate requirements are based on the floor area of the home and the climate zone, and the solar panel systems must be sized to provide for the full annual energy usage of the home. The requirements for solar power and battery storage will be for new commercial structures and high-rise residential projects. New low-rise homes must be wired in ways that ease and even encourage conversion of natural-gas heating and appliances to electric sources.

30. In our analysis, we have considered solar irradiance greater than 150 kWh/m²/month to be the criteria that defines abundance of the resource in the city.

FREE-MARKET CITIES

Decarbonisation

By 2025: Use powers for economic development to fund energy innovators.

Free-market cities benefit from promoting funding for energy innovators that focus on digital solutions for smaller-scale local generation and storage. This typology has the second-highest startup environment, digitalisation of services, and takeup of EVs out of the typologies. The benefit of this approach is that investment will diffuse into smaller and medium sized DERs that provide a greater net benefit to grid stability than single-site, large-scale storage currently favoured by investors.[31]

- **By 2040:** Cities give council/property tax discounts and business rate rebates to residents' associations that make their own investments in renewable generation and storage.

CASE STUDY

California Flex Alert

A Flex Alert is issued in the summer when extremely hot weather drives up electricity use, making the available power supply scarce. This usually happens in the evening hours when solar generation is decreasing and consumers are returning home and switching on air conditioners, lights, and appliances. The California Public Utilities Commission created a new incentive, the Emergency Load Reduction program, that compensates consumers who reduce their electricity use when a Flex Alert is in effect.

Photo by @kylry via Unsplash

Consumer Flexibility

By 2025: Work with electricity system operators to create a grid stress management alert system.

Free-market cities benefit from communication systems during times of acute grid stress that residents and businesses can use to manually and/or automate their use of heating, cooling, and charging. Cities like Singapore and Los Angeles already present some of the highest levels of internet connections per capita in our analysis, resulting in a high score for this typology. However, this typology is also derived from cities like Bangalore with one of the lowest scores (55 compared to 200 in Los Angeles). It is therefore important to ensure that the digital infrastructure is sufficiently mature before focusing efforts on improving the tech skills and flex potential of citizens.

- **By 2040:** Cities provide a business rate discount to premises that make their smart chargepoints available to EVs on an intelligent tariff and allow 'roaming' charges for EVs as default over paying the commercial premises owner directly.
- **By 2040:** Cities give council/property or business rate discounts to residents and businesses that are willing to automate turn down / turn up heating and cooling and use intelligent charging; cities can offer to be a coordinator of 'intelligent' energy for suppliers.

31. Greater Manchester Low Carbon Challenge Group, July 2022

FREE-MARKET CITIES

By 2025	By 2040	Benefit	Supporting data	
Urban Flexibility				
EVs and chargepoints for public sector fleet and properties **Parking permit incentives for EV uptake**	**EVs and chargepoints to replace public sector fleet** **All public buildings have LCTs on site** **Community retrofit programmes**	High	Most mixed cities, 12% higher than average	High levels of EV penetration, 20% lower than average
District data platforms in areas of current high grid congestion	**Special data zone for innovation in energy technologies**	Moderate	Second highest expected population growth 2020-2035, 24% and population 37% higher than the average.	Highest levels of wholesale innovation, 42% above average, however, slow innovation in retail markets, scoring the lowest, 46% below the average
Smaller VRE modules as community assets	**Designate solar districts in areas of grid congestion**	High	Second highest solar roof potential, 26% above average, with plenty of roof available, 4% above average	Third lowest amount of available land near the city, 80% lower than average.
Decarbonisation				
Use powers for economic development to fund energy innovators	**Local tax rebates for investments in renewable generation and storage**	High	Second highest digitalisation scores, 10% higher than average	Slow innovation in retail markets, scoring the lowest, 46% below the average
Consumer Flexibility				
Grid stress management alert system	**Tax rebates for access to private chargepoints for those on intelligent 'roaming' tariffs** **Tax rebates for automating smart charging, heating and/or cooling**	High	Some of the highest levels of internet connections per capita in cities in this typology	Slow innovation in retail markets, scoring the lowest, 46% below the average

SCALABLE CITIES

Urban Flexibility

By 2025: Procure EVs across the public sector fleet.

Scalable cities benefit from procurement of EVs for any new or replacement vehicles in their public sector fleet and make them available for flexibility services to their energy networks at the earliest opportunity. This typology has low EV ownership rates: for example, cities that informed the typology include Johannesburg and Nairobi, who don't report any licensed EVs on their respective national registers. Promoting and incentivising the adoption of EVs will be critical to growing local battery capacity and supporting growing populations. This typology is found in cities with the highest in potential population growth to 2035, at 130% higher than average, which means that large amounts of flexibility will be needed to accommodate incoming demand. EV markets must be accelerated to support this.

- **By 2040:** Public buildings only allow EV parking and smart charging on-site (with compassionate and essential service delivery exemptions).

CASE STUDY

Seattle waste removal EV fleet

When the 10-year contract for waste haulers came up for renewal in 2018, Seattle's waste and water utility — Seattle Public Utilities — saw an opportunity to implement a major change in waste hauling services. Seattle's new waste fleet includes 200 new clean emissions vehicles powered by electricity, renewable natural gas, and renewable diesel. This includes two full size 100% electricity recycling trucks.

CASE STUDY

1) Part S (revised 2021) of the Building Regulations 2010, England

2) Electric Vehicles (Smart Charge Points) Regulations 2021, England

From June 2022, building regulations in England will require new homes and commercial buildings, as well as those undergoing major renovation, to install electric vehicle charge points. The regulations ensure charge points have smart functionality, allowing the charging of an electric vehicle when there is less demand on the grid, or when more renewable electricity is available.

By 2025: Require all public buildings to have LCTs on site

By 2025: Develop community retrofit programmes

Scalable cities benefit from to include chargepoints, local generation and storage as requirements in procurement policies for major retrofit and intensification projects on public land, subject to affordability. There is more land available in these places to pair chargepoints with renewable generation: these cities have an abundance of solar resource -scoring 52% higher than average.

- **By 2040:** All new builds in the city to have chargepoints and either local generation or storage. Entire streets and blocks undertake a mandatory retrofit together if a majority of leaseholders/owners vote for it.

By 2025: Growth area data platforms for smart energy systems.

Scalable cities benefit from growth area data platforms for scalable places to monitor and promote impact of smart charging, cooling, and heating (including aggregated smart meter data). These cities have the least amount of renewable energy per inhabitant -more data is needed to manage both the rapid increase of generation, grid capacity and number of buildings from population growth. They are the second-highest mixed typology, and there will be a high benefit from data sharing that monitors the performance of smart charging, heating, and cooling.

- **By 2040:** Develop 'growth zone' datastores where in exchange for reduced reinforcement costs, suppliers agree to share consumer smart heating, cooling, and charging data. For example, testing intelligent tariffs for EVs and heating/cooling in premises as part of planning approval for the growth area.

SCALABLE CITIES

By 2025: Accept medium-sized VRE modules and batteries in planning agreements.

Scalable cities benefit from medium-sized VRE modules, batteries as community assets in planning agreements, and prioritising locations for approval of planning applications of large-scale VRE and DERs. These locations are more likely to take advantage of abundant solar resource: for almost 10 months of the year, cities that informed this typology can expect more than 150 kWh/m^2 on average and 3000 hectares of available roof space. Additionally, even though wind resources are not as abundant in some of these cities, there is still land available in green and unused spaces where wind turbines and distributed energy assets like batteries could be installed.

- **By 2040:** Commit to all public buildings containing medium-sized solar generation and batteries.

CASE STUDY

Installation of Solar Rooftops in Greater Chennai's Corporate Buildings

Greater Chennai Corporation (GCC) and Chennai Smart City Limited have installed solar rooftops in GCC buildings. One of the measures for promoting solar rooftop systems is that all new government and local body buildings shall be installed with solar rooftops and existing government and local body buildings will be provided with solar rooftops as part of a phased installation. Under this policy, GCC will be implementing solar rooftops in all 1,378 GCC buildings under its ownership.

CASE STUDY

24/7 Carbon-Free Energy (CFE) assistance programme

WRI is working with four medium-sized US cities as buyers of energy and local market participants to explore pathways for procuring and matching CFE on an hourly basis to meet their demands. WRI is offering a series of educational webinars on 24/7 CFE for a broad array of market participants, corporate purchasers, utilities, federal agencies, carbon free suppliers, verifiers, data providers, and other stakeholders. These webinars feature content on purchasing approaches, case studies of successful deals, best practices, market instruments, and policies that support 24/7 CFE purchasing.

Decarbonisation

By 2025: Purchasing of storage in areas of grid congestion.

Scalable cities benefit from procuring storage in areas of grid congestion in scalable places, borrowing against the value of future trading of electricity as batteries charge and discharge. Public resources in these cities (usually found in the Global South and emerging countries) are often more limited than in other typologies.[32] Big tech corporations such as Google, Amazon, Meta, Apple, and Microsoft are trying to reduce their carbon footprint through the implementation of storage and promotion of renewable energy projects in areas of the world with great potential.[33,34,35,36,37] As the importance of these markets increases over time, the abundance of resources and the ability of these countries to attract private investment will make possible the deployment of trading for supply energy intensive industries, from manufacturing to data centres.

- **By 2040:** Cities as managers of pension funds invest in and create products of renewable generation and storage assets that other institutions can invest in from the private sector.

32. "A New Dawn: Argentina Taps Into Its Renewable Energy Potential", International Finance Corporation. https://www.ifc.org/wps/wcm/connect/news_ext_content/ifc_external_corporate_site/news+and+events/news/argentina-taps-into-its-renewable-energy-potential (accessed Jul. 18, 2022) | **33.** "Google in renewable energy investment plan to spur $1.5bn", Recharge. https://www.rechargenews.com/transition/google-in-renewable-energy-investment-plan-to-spur-1-5bn/2-1-689830 (accessed Jul. 18, 2022) | **34.** "Facebook meets 100% renewable energy goal with over 6 GW of wind, solar, 720 MW of storage", Utility Dive. https://www.utilitydive.com/news/facebook-meets-100-renewable-energy-goal-with-over-6-gw-of-wind-solar/598453/ (accessed Jul. 18, 2022) | **35**. "Amazon is making big global investments in renewable energy", Amazon. https://www.aboutamazon.com/news/sustainability/amazon-is-making-big-global-investments-in-renewable-energy (accessed Jul. 18, 2022) | **36.** "Achieving 100 percent renewable energy with 24/7 monitoring in Microsoft Sweden", Microsoft. https://tinyurl.com/mrhbuyyd (accessed Jul. 18, 2022) | **37.** "Apple powers ahead in new renewable energy solutions with over 110 suppliers", Apple. https://www.apple.com/uk/newsroom/2021/03/apple-powers-ahead-in-new-renewable-energy-solutions-with-over-110-suppliers/ (accessed Jul. 18, 2022)

SCALABLE CITIES

Consumer Flexibility

By 2025: Public sector commitment to buy energy on a time-of-use tariff.

Scalable cities will benefit from moving public sector properties where the city is responsible for the bill onto a time-of-use tariff. Real-time pricing will enable these cities to fully utilise their renewable generation and LCTs and benefit consumers. While these cities have a lot of local generation capacity in the form of solar and wind, with additional opportunities to facilitate energy storage and flexibility within the city, all of the cities informing this typology rank poorly in terms of innovation of retail tariffs. Buenos Aires and Nairobi uniquely have 'use-of-use' tariffs, whereby the cost of electricity increases in accordance with use.

- **By 2040:** All public sector properties build local generation to offer cheap or at cost time-of-use tariffs for their EV fleets and for commuter EVs when the sun shines and the wind blows.
- **By 2040:** Give business rate and/or parking charges discounts to commercial premises that procure EV fleets and allow any EV to use their smart chargepoints to charge or discharge.

By 2025: Introduce and empower resident community energy boards.

Scalable cities benefit from resident community energy boards to make collective decisions on flexibility with a devolved budget to use. These options include use of messaging systems, communal storage/chargers, and EV parking permits. Currently, programmes are needed to increase trust in time of use and intelligent tariffs. Takeup of retail innovations is low, with the second lowest score, 6% lower than average; takeup of EVs is the lowest of any typology. Cities that informed this typology already often have pricing based on affordability and collective decision-making. Johannesburgers have rates that vary based on the average household income for each city ward.

- **By 2040:** Support resident community energy boards to make deals with renewable energy investors to install communal VREs.

By 2025	By 2040	Benefit	Supporting data	
Urban Flexibility				
Procure EVs and chargepoints for public sector fleet	**EV-only parking at public buildings**	High	Third largest group of cities, 36% above average, with the highest growth prospects, 130% higher than average	Highest scores in the wholesale market innovation with the introduction of close to nodal prices
LCT policies for major public sector projects	**LCT for all new builds, public and private** **Community retrofit programmes**	High	Greatest abundance of solar resource of any typology, 52% higher than average	Second highest population growth projection through 2035, 130% higher than average
Growth area data platforms	**Growth zone datastores**	High	Least amount of renewable energy per inhabitant	Second-highest mixed typology
Decarbonisation				
Medium-sized VRE modules and batteries in planning agreements	**Medium-sized VRE modules and batteries in all public buildings**	High	Third largest group of cities, 36% above average. Second highest roof available for solar, 5% higher than average	Greatest abundance of solar resource, 52% higher than average, with second highest population growth projects through 2035, 130% higher than average
Consumer Flexibility				
Purchasing of storage in areas of grid congestion	**Invest in and create products of renewable generation and storage assets**	High	Second highest roof available for solar, 5% higher than average. Second lowest HHI level, 5% lower than average	Greatest abundance of solar resource, 52% higher than average, with second highest population growth projects through 2035, 130% higher than average
Policies for public sector time of use tariffs	**All public sector properties moved onto a time of use tariff** **Tax rebates for access to chargepoints**	Moderate	Greatest abundance of solar resource, 52% higher than average	Highest score of wholesale locational marginal pricing, 42% higher than average
Resident community boards	**Community energy deal-making**	High	Second lowest score in innovation in retail tariffs, 6% lower than average	Lowest EV penetration levels, practically 0

DISTRIBUTED CITIES

Urban Flexibility

By 2025: Local generation and storage included as community assets in all planning agreements.

Distributed cities benefit from local generation and storage as planning agreement requirements for major new build projects. Distributed cities have the highest levels of undeveloped land around the city, with more than 160 hectares on average, and significant levels of solar and wind resources, with plenty of space to increase the penetration of these technologies. In these cities, planning policies for local generation on new builds already yield benefits. Daytime electricity supply is dominated by local renewable generation. They have the lowest 'import' needs of any type of city. Cities that informed this typology like Amsterdam, Medellin, Vancouver and Stockholm present abundant natural hydro resources, making this category reach the highest renewable connected capacity regionally with more than 100 MW per 100,000 inhabitants on average.

- **By 2040:** Create an EV-only inner core around the most congested substations, and impose number plate restrictions if necessary to keep enough commuter EVs in place at their address to provide V2G services in morning / evening peaks.
- **By 2040:** Select areas that are undergoing grid stress where all urban development masterplans must require in all developments 1) local renewables and storage 2) smart thermostats and chargepoints and 3) 'compatible' land uses for urban flexibility.
- **By 2040:** Create data platforms for strategic infrastructure planning and local generation hubs in a new era of smart charging, cooling, and heating.
- **By 2040:** Use public property to purchase and install strategic solar/wind generation for every MV substation in the city (Approx 1 in 30k-50k residents).

CASE STUDY

Grid congestion investment in Amsterdam

In collaboration with TU Delft, AMS Institute designed local storage and generation solutions that allow safe grid integration of large new consumers without grid expansion. Last June, electric grid operator Liander announced that the power grid in Amsterdam reached its maximum capacity in two areas in the city – one of these being Buiksloterham-Zuid/Overhoeks. Liander indicated that this area is limited by the capacity of the MV electricity grid. As a result, until local generation and storage is put in place or the grid capacity expands, new large consumers (i.e. commercial or industrial energy consumers) cannot receive power from the grid.

Decarbonisation

By 2025: Support programmes for the rooftop solar supply chain.

Distributed cities benefit from putting in place support programmes for the rooftop solar supply chain, improving market conditions for providers to gain benefits of scale. Investment in VREs should yield return because land is relatively cheap - these cities have the highest levels of undeveloped land nearby, 100% higher than the global average average, and the amount of connected renewable generation capacity near cities that informed this typology is high (180% above average).

- **By 2040:** Cities use their planning powers to designate 'rooftop solar investment areas' for the city to include planning agreements with landowners for rooftop solar that serves the wider district.

CASE STUDY

US Federal solar battery tax credit

Batteries qualify for the 26% tax credit if a battery will be fully charged with solar energy, not from the grid. The tax credit covers 30% of the cost of a storage system, up to $5,000 for residential batteries and up to $150,000 for commercial batteries.

Consumer Flexibility

By 2025: Public sector commitment to buy energy on dynamic tariffs.

By 2025: Support smart heating/cooling and charging in domestic sector supplied by excess local renewable generation

Properties where energy is paid for by the city will reap the rewards of a move onto dynamic pricing tariffs, and a fast transition to smart heating and cooling. Cities in this typology should benefit from these policies because of the typical prevalence of DERs. Cities that informed this typology like Stockholm already do so: it sits in one of the four regions in which the Swedish electricity market is divided. Vancouver pays one of the lowest electricity bills in Canada, due to the abundance of hydro resources in British Columbia and the presence of their own electricity distribution company. However, cities like Medellin are subject to national electricity pricing, even though most of the energy for the country is sourced in Antioquia, where Medellin is located.

- **By 2040:** All public sector properties build local generation to offer cheap energy available to EVs that are on an intelligent charging tariff. Allow 'roaming' charges for EVs as default over a bespoke payment system.
- **By 2040:** Cities create a joint venture between local businesses with storage and nearby economically-disadvantaged neighbourhoods to give them access to cheaper or free electricity for smart heating and charging.

DISTRIBUTED CITIES

By 2025	By 2040	Benefit	Supporting data	
Urban Flexibility				
Local generation and storage for new build developments	**EV-only core** **Local energy required in masterplans** **Strategy data platforms** **Public sector-owned LCTs at every substation**	High	Lowest levels of population, 65% lower than average, but second highest expected growth, 12% lower than the average	Highest levels of undeveloped land near the city, 180% higher than average
Decarbonisation				
Support programmes for the rooftop solar supply chain	**Rooftop solar investment areas**	Moderate	Lowest levels of take up of digital services, 13% below average	Highest levels of regional connected capacity, 180% higher than the average
Consumer Flexibility				
Public sector buildings on dynamic tariffs **Smart heating/cooling and charging with renewable generation**	**All public sector properties have local generation and public chargepoints on site** **Joint venture for energy sharing for economically disadvantaged neighbourhoods**	Moderate	Highest levels of regional connected capacity, 180% higher than the average	High scores in innovation in retails tariffs, just above the average

AVAILABLE CITIES

Urban Flexibility

By 2025: Set a goal for storage capacity on publicly-owned properties.

Available cities benefit from setting a MW/person battery capacity target for public buildings by 2025, to maximise the utilisation of the local generation available now. Cities that informed this typology have the highest renewable generation per 100,000 inhabitants, 260% higher than the average. They have the most innovative electricity retail tariffs and are planning for higher renewable capacity and flexibility.

- **By 2040:** Use public property to purchase and install strategic large-scale storage for every MV substation in the city (Approx 1 in 30k-50k residents).
- **By 2040:** All public sector buildings have an on-premises battery of an agreed MW per square metre by 2040; all enter an energy trading scheme for nearby buildings that sign up to smart heating/cooling and charging.

By 2025: Accept larger-sized VRE modules and batteries as community assets in planning agreements.

Available cities benefit from larger-sized VRE modules and batteries as community assets in planning agreements that take advantage of nearby land, solar and wind availability. There are high levels of wind and solar available found in cities that informed this typology: seven months of the year have high solar irradiance and more than 90 days of the year experience wind speeds of higher than 5 m/s on average, and more land available for the deployment of these technologies.

- **By 2040:** Select areas that are undergoing grid stress where all urban development masterplans must require in all developments 1) local storage with smart thermostats or EV smart charging and 2) have compatible land uses for urban flexibility.
- **By 2040:** Create data platforms for strategic infrastructure planning and monitor success of on-premises storage in a new era of smart charging, cooling, and heating.

AVAILABLE CITIES

Decarbonisation

By 2025: Support purchasing of on-premises storage by private owners.

Available cities would benefit from supporting building owners in purchasing storage in available places by negotiating with the market on their behalf to gain benefits of scale. Improved borrowing conditions will also improve uptake of DERs in commercial buildings in residential areas and vice-versa. Due to the size of these cities, the available commercial floorspace is not comparable to large metropolitan areas like London, Paris or Singapore. We see battery storage as one of the best options for building flexibility in these cities.

- **By 2040:** Use planning powers to designate 'storage investment areas' for the city to include planning agreements with landowners for collective storage that serves the wider district.
- **By 2040:** Raise capital for projects creates a green bond for storage projects in the city.

CASE STUDY

Auckland Green Bonds

Auckland Council has obtained certification for the Green Bonds from the Climate Bonds Initiative. The certification means that the Green Bonds meet the criteria set out in the Climate Bonds Standard. All Council's investments are intended to generate long-term, positive environmental, social and/or economic outcomes for the region. Auckland Council has successfully raised $200 million from its Green Bond share issue in 2018, with the funds raised set to be used to fund electric trains and associated infrastructure.

Consumer Flexibility

By 2025: Commit public sector buildings and all chargepoint users to use dynamic tariffs.

By 2025: Support rollout of domestic smart heating/cooling and charging paired with nearby storage

Available cities benefit from moving public sector properties onto dynamic pricing tariffs when up for renewal, and from encouraging take-up of smart heating/cooling and charging across the public and domestic sectors. These actions encourage the use of available variable renewable generation in the daytime. These places have a large amount of VRE generated in rural areas nearby and limited but growing DERs, including storage, in the city. The levels of renewable generation in these cities are expected to grow considerably in the short to mid-term. Cities that informed this typology like Sydney and Valencia have the highest innovation retail scores in our analysis (12 and 8 out of 16 respectively), since time-of-use tariffs and variable pricing have been encouraged at national levels in both Australia and Spain.

- **By 2040:** Give council/business rate rebates to properties that have local generation and/or storage and join a smart heating/cooling intelligent tariff plan. Only give planning permission for chargepoints that allow EVs to charge on an intelligent tariff.
- **By 2040:** Give business rate discounts to city-centre businesses that sign up to build local batteries for charging with plentiful daytime renewable energy supplies.
- **By 2040:** Create tax rebates for domestic consumers that use smart heating/cooling and/or charging with on intelligent tariffs

AVAILABLE CITIES

By 2025	By 2040	Benefit	Supporting data	
Urban Flexibility				
Set a goal for storage capacity per resident	**Install strategic large-scale storage for every MV substation** **All public sector buildings have an on-premises battery**	Moderate	Highest renewable energy generation per inhabitant 260% above average	Highest scores in retail tariffs, 31% above the average
Larger-sized VRE modules and batteries as community assets	**Local storage required in masterplans** **Data platforms**	High	Second smallest cities, 55% below average. Second highest levels of undeveloped land near the city, 95% above average	Highest renewable energy per inhabitant, 260% above average
Decarbonisation				
Support financing of storage for private owners	**Storage investment areas** **Green bonds**	Moderate	Relatively low commercial floor space available but high in comparison to city size	Highest renewable energy per inhabitant, 31% above average.
Consumer Flexibility				
Public sector properties on dynamic tariffs **Smart heating/ cooling and charging paired with renewables**	**Tax rebates for commercial and domestic consumers that use smart heating/ cooling and/or charging with intelligent tariffs** **New smart chargers only to take intelligent tariffs** **Tax rebates for city centre storage on private land**	Moderate	Highest renewable energy per inhabitant, 31% above average	Low EV penetration, just above average Low take up of digital services, just average

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APPENDIX A

Recommendations scoring and development

Source of Flexibility

Normalised and standardised typology score	Connected	Free-market	Scalable	Distributed	Available	
Land available	-0.03	-0.05	-0.05	0.11	-0.07	
Commercial floorspace	0.24	-0.09	-0.07	-0.02	-0.04	
Land use mix	0.02	0.20	0.08	-0.13	-0.08	
EV ownership	-0.04	-0.04	-0.19	0.19	-0.06	
Solar roof potential	-0.36	0.14	0.28	0.02	-0.08	
	Connected	**Free-market**	**Scalable**	**Distributed**	**Available**	**Assumptions**
Land available	Average	Average	Average	Very high	Low	Less land available = need to focus on battery storage for flexibility, generally
Commercial floorspace	Very high	Low	Low	Average	Average	More commercial floorspace = more on-premises batteries
Land use mix	Average	Very high	High	Very low	Low	Higher land use mix = more benefit from EV fleets
EV ownership	Average	Average	Very low	Very high	Low	More EV ownership = more benefit from V2G
Solar roof potential	Very low	Very high	Very high	Average	Low	More solar roof = more focus on smart charging in daytime use / less = more focus on smart charging in nighttime
Policy impact score	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	
Storage (general)	0.03	0.05	0.05	-0.11	0.07	
On-premises batteries	-0.06	0.02	0.11	0.00	-0.06	
EVs	0.11	0.01	-0.13	0.01	-0.02	
EV fleets	0.02	0.20	0.08	-0.13	-0.08	

Storage policy change needed (General)	**Average**	**Average**	**Average**	**Very Low**	**High**
EV (or On-premises)	Low	Average	Very high	Average	Low
Commuter EVs	Very high	Average	Very low	Average	Average
EV fleets	Average	Very high	High	Very low	Low
Recommendation score	0.23	0.27	0.36	0.26	0.23
Recommendation rating	Strong	**Strong**	**Very strong**	**Strong**	Strong
2025 Recommendations	Allow EVs with residential parking permits to park at non-domestic chargepoints and/or near non-domestic building battery storage	Procure EVs and chargepoints for public sector fleet and allow EVs with residential parking permits to use non-domestic chargepoints without a city parking charge	Procure EVs and chargepoints for public sector fleet	*No recommendation*	Use procurement powers to have x MW/person battery capacity in public buildings across public sector estate by 2025
2040 Recommendations	Only allow EVs to park in places and at hours that would benefit grids the most in real-time (commercial districts (centre/outskirts) / residential areas in city centres/outskirts)	Procure EVs and chargepoints for public sector fleet	Public buildings only allow EV parking and smart charging on-site (with compassionate and essential service delivery exemptions)	Create an EV-only inner core around the most congested substations	All public sector buildings have an on-premises battery of x MW/m^2 by 2040

If low, no recommendation

Planning policies and standards

Normalised and Standardised typology score	Connected	Free-market	Scalable	Distributed	Available	
Population	0.35	0.15	0.15	-0.21	-0.30	
Population growth	-0.14	0.05	0.27	-0.05	-0.11	
Land available	-0.03	-0.05	-0.05	0.11	-0.07	
Land use mix	0.02	0.20	0.08	-0.13	-0.08	
Retail innovation	0.03	-0.19	-0.02	0.12	-0.02	
In words...	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	**Assumptions**
Population	Very high	Very high	Very high	Very low	Very low	More population = more need for retrofit policies
Population growth	Very low	High	Very high	Average	Very low	More population growth = more need for planning
Land available	Average	Average	Average	Very high	Low	More land available = more focus on new builds
Land use mix	Average	Very high	High	Very low	Low	Lower mix -more focus on proximity policies
Retail innovation	Average	Very low	Average	Very high	Average	More innovation = more benefits of planning policies
Policy impact score	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	
Planning (general)	-0.05	-0.07	0.13	0.04	-0.06	
New Builds	-0.03	-0.05	-0.05	0.11	-0.07	
Retrofit	0.35	0.15	0.15	-0.21	-0.30	
Proximity	-0.02	-0.20	-0.08	0.13	0.08	

Planning policy change needed (general)	**Low**	**Low**	**Very high**	**Average**	**Low**
New Builds	Average	Average	Average	Very high	Low
Retrofit	Very high	Very high	Very high	Very low	Very low
Proximity	Average	Very low	Low	Very high	High
Recommendation score	0.45	0.46	0.40	0.49	0.51
Recommendation rating	**Very strong**	**Very strong**	**Very strong**	**Very strong**	**Very strong**
2025 Recommendations	No recommendation	No recommendation	Procurement policy commits to presumption for chargepoints, local generation and storage as requirements for major retrofit projects on city-owned land subject to affordability	Planning policy includes local generation and storage as planning gain requirements for major new build projects	No recommendation
2040 Recommendations	Commit to chargepoints, local generation and/or storage as part of retrofit of entire social housing estate by 2040	All public buildings in the city to have chargepoints and either local generation or storage. Entire streets and blocks undertake a mandatory retrofit together if a majority of leaseholders/ owners vote for it	All new builds in the city to have chargepoints and either local generation or storage. Entire streets and blocks undertake a mandatory retrofit together if a majority of leaseholders/ owners vote for it	Mayors must select areas that are undergoing grid stres where all urban development masterplans to require to obtain planning permission 1) have local renewables and storage 2) smart thermostats and chargepoints and 3) have 'compatible' land uses for urban flexibility	Mayors must select areas that are undergoing grid stres where all urban development masterplans must require to obtain planning permission 1) local storage with smart thermostats or EV smart charging and 2) have compatible land uses for urban flexibility

If low, no recommendation

Data

Normalised and Standardised typology score	Connected	Free-market	Scalable	Distributed	Available
Population growth	-0.14	0.05	0.27	-0.05	-0.11
Land available	-0.03	-0.05	-0.05	0.11	-0.07
Startup environment	0.37	0.25	-0.24	-0.06	-0.26
Generation per inhabitant	-0.09	-0.14	-0.15	0.24	-0.01
Solar roof potential	-0.36	0.14	0.28	0.02	-0.08
Open data store for the electricity grid in region (transmission and distribution)	0.22	-0.23	-0.3	-0.01	0.34
Retail innovation	0.03	-0.19	-0.02	0.12	-0.02

In words...	Connected	Free-market	Scalable	Distributed	Available	Assumptions
Population growth	Very low	High	Very high	Average	Very low	More population growth = higher benefit of data sharing, especially if LMP is implemented
Land available	Average	Average	Average	Very high	Low	More land available = more capacity can be put in, increasing data
Startup environment	Very high	Very high	Very low	Low	Very low	Better environment = more likely to produce new products and solutions based on consumer data
Generation per inhabitant	Low	Very low	Very low	Very high	Average	Higher generation per inhabitant = more benefit from data sharing, especially when access to local renewable generation goes beyond landowner
Solar roof potential	Very low	Very high	Very high	Average	Low	Higher land use mix = more benefit from data sharing, especially when access to local renewable generation goes beyond landowner
Open data store for the electricity grid in region (transmission and distribution)	Very high	Very low	Very low	Average	Very high	Higher open data store = more data available for use by innovators
Retail innovation	Average	Very low	Average	Very high	Average	Higher retail innovation = higher benefit from data sharing, especially if LMP is implemented

Policy impact score	Connected	Free-market	Scalable	Distributed	Available
Data (general)	0.12	0.15	0.02	-0.05	-0.18
More data needed	0.03	0.17	0.09	-0.18	0.02
Data innovation potential	0.37	0.25	-0.24	-0.06	-0.26
Microgrid data needed	-0.36	0.14	0.28	0.02	-0.08
Open data available	0.22	-0.23	-0.3	-0.01	0.34

Data policy change needed (general)	Very high	Very high	Average	Low	Very low
More data needed	Average	Very high	High	Very low	Average
Data innovation potential	Very high	Very high	Very low	Low	Very low
Microgrid data needed	Very low	Very high	Very high	Average	Low
Open data available	Very high	Very low	Very low	Average	Very high
Recommendation score	1.10	0.93	0.92	0.32	0.88
Recommendation rating	**Very strong**	**Very strong**	**Very strong**	**Strong**	**Very strong**
2025 Recommendations	Create data platforms for strategic infrastructure / transport planning in a new era of smart charging, cooling, and heating	Create district data platforms in areas of current high grid congestion to monitor and promote smart charging, cooling, and heating (including aggregated smart meter data)	Create growth area data platforms with infrastructure providers to monitor and promote impact of smart charging, cooling, and heating (including aggregated smart meter data)		No recommendation
2040 Recommendations	Increase data in the store to included aggregated smart charging and heating data through meter data to monitor effectiveness of smart charging, cooling, and heating on grid health, saving the planet, and saving money	Create a 'special data zone' (like a freeport) where suppliers and grid operators waive any fees or derivative profit-sharing with innovators across smart charging, cooling, and heating	Develop 'growth zone' datastores where in exchange for reduced reinforcement costs, suppliers agree to share consumer smart heating, cooling, and charging data, for example testing intelligent tariffs for EVs and heating/cooling in premises as part of planning approval for the growth area	Create data platforms for strategic infrastructure planning and local generation hubs in a new era of smart charging, cooling, and heating	Create data platforms to enable council/ business rate rebates to properties that have planning permission and built on-premises storage

If low, no recommendation

LCT community assets

Normalised and Standardised typology score	Connected	Free-market	Scalable	Distributed	Available	
Population	0.35	0.15	0.15	-0.21	-0.30	
Population growth	-0.14	0.05	0.27	-0.05	-0.11	
Land available	-0.03	-0.05	-0.05	0.11	-0.07	
Land use mix	0.02	0.20	0.08	-0.13	-0.08	
Solar roof potential	-0.36	0.14	0.28	0.02	-0.08	
Solar resource	-0.04	-0.04	-0.19	0.19	-0.06	
Regional connected capacity	-0.10	-0.10	-0.10	0.18	0.00	
In words...	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	**Assumptions**
Population	Very high	Very high	Very high	Very low	Very low	Higher population = smaller modules
Population growth	Very low	High	Very high	Average	Very low	Higher growth = more modules
Land available	Average	Average	Average	Very high	Low	Low land available = smaller modules
Land use mix	Average	Very high	High	Very low	Low	Lower land use mix = more modules needed
Solar roof potential	Very low	Very high	Very high	Average	Low	Less solar roof potential = more storage needed
Solar resource	Average	Average	Very low	Very high	Low	Less solar resource = more storage needed
Regional connected capacity	Very low	Low	Very low	Very high	Average	Less connected capacity = more VRE / DER needed
Policy impact score	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	
VRE / DERs needed (General)	0.10	0.10	0.10	-0.18	0.00	
Size	-0.16	-0.05	-0.05	0.05	0.18	
Number	-0.06	0.12	0.18	-0.09	-0.09	
Storage	0.20	-0.05	-0.04	-0.11	0.07	
Generation	-0.20	0.05	0.04	0.11	-0.07	

VRE / DERs policy change needed (General)	**Very high**	**High**	**Very high**	**Very low**	**Average**	**If low, no recommendation**
Size	Very low	Low	Average	Average	Very high	
Number of modules	Low	Very high	Very high	Low	Low	
Storage	Very high	Low	Average	Very low	High	
Generation	Very low	High	Average	Very high	Low	
Recommendation score	0.72	0.37	0.41	0.53	0.42	
Recommendation rating	**Super strong**	**Strong**	**Strong**	**Very strong**	**Very strong**	
2025 Recommendations	Accept smaller VRE modules and batteries as community assets in planning agreements	Accept smaller VRE modules as community assets in planning agreements	Accept medium-sized VRE modules and batteries as community assets in planning agreements	No recommendation	Accept larger-sized VRE modules and batteries as community assets in planning agreements	
2040 Recommendations	Require every non-residential building to include rooftop solar in all city growth area action plans / masterplans	Designate solar districts in areas of grid congestion (only planning permission for improvements with solar subject to affordability; business and/or council tax discounts for properties that install them)	Commit to all public buildings to have medium-sized solar generation and batteries	Use public property to purchase and install strategic solar/wind generation for every MV substation in the city (Approx 1 in 30k-50k residents)	Use public property to purchase and install strategic large-scale storage for every MV substation in the city (Approx 1 in 30k-50k residents)	

Investment

Normalised and Standardised typology score	Connected	Free-market	Scalable	Distributed	Available	
Land use mix	0.02	0.20	0.08	-0.13	-0.08	
Regional connected capacity	-0.10	-0.10	-0.10	0.18	0.00	
EV ownership	-0.04	-0.04	-0.19	0.19	-0.06	
Startup environment	0.37	0.25	-0.24	-0.06	-0.26	
Population	0.35	0.15	0.15	-0.21	-0.30	
Population growth	-0.14	0.05	0.27	-0.05	-0.11	
Solar roof potential	-0.36	0.14	0.28	0.02	-0.08	
Generation per inhabitant	-0.09	-0.14	-0.15	0.24	-0.01	
Digitalisation	0.17	0.05	-0.08	-0.06	-0.04	
In words...	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	**Assumptions**
Land use mix	Average	Very high	High	Very low	Low	More land use mix = better for local generation and storage
Regional connected capacity	Very low	Low	Very low	Very high	Average	High capacity = develop supply chain for generation and storage
EV ownership	Average	Average	Very low	Very high	Low	High ownership = opportunities for investment in smart charging hubs (products)
Startup environment	Very high	Very high	Very low	Low	Very low	High startup environment = more investable products
Population	Very high	Very high	Very high	Very low	Very low	High population = more economies of scale for investment
Population growth	Very low	High	Very high	Average	Very low	High growth = opportunities for investment will increase
Solar roof potential	Very low	Very high	Very high	Average	Low	High potential = higher return on investment
Generation per inhabitant	Low	Very low	Very low	Very high	Average	Low = higher potential for return on investment
Digitalisation	Very high	High	Low	Low	Average	High = higher return on products that depend on automation
Policy impact score	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	
Investment (general)	-0.06	0.12	0.18	-0.09	-0.09	
Return on investment	-0.23	0.00	0.06	0.13	-0.05	
Economies of scale	0.35	0.15	0.15	-0.21	-0.30	
Products	0.16	0.11	-0.21	0.07	-0.16	
Supply chain	-0.10	-0.10	-0.10	0.18	0.00	

Investment change needed (General)	Low	Very high	Very high	Low	Low
Return on investment	Very low	Average	High	Very high	Average
Economies of scale	Very high	Very high	Very high	Very low	Very low
Digital products	Very high	Very high	Very low	High	Very low
Supply chain	Very low	Low	Very low	Very high	Average
Recommendation score	0.80	0.38	0.60	0.50	0.60
Recommendation rating	**Super strong**	**Super strong**	**Super strong**	**Very strong**	**Very strong**
2025 Recommendations	Cities use their powers for economic development to fund programmes for energy innovators	Cities use their powers for economic development to fund energy innovators that focus on digital solutions for collective local generation and storage	Cities use their procurement powers to purchase storage in areas of grid congestion, borrowing against the value of future trading of electricity as batteries charge and discharge	Cities use their powers for economic development for support programmes for the rooftop solar supply chain	Cities support building owners in purchasing storage in available places by negotiating with the market on their behalf to gain benefits of scale
2040 Recommendations	Cities manage employee pension funds, directly investing in innovators of digital products for future energy systems as part of a public-private joint venture	Cities give council tax discounts and business rate rebates to residents' associations / collectives that make their own investments in renewable generation and storage	Cities manage pension funds, investing in and creating products of renewable generation and storage assets that other institutions can invest in from the private sector	Cities use their planning powers to designate 'rooftop solar investment areas' for the city to include planning agreements with landowners for rooftop solar that serves the wider district	Cities raise capital for projects creates a green bond for storage projects in the city Use planning powers to designate 'storage investment areas' for the city

If low, no recommendation

Retail market reform

Normalised and Standardised typology score	Connected	Free-market	Scalable	Distributed	Available	
Population growth	-0.14	0.05	0.27	-0.05	-0.11	
Land available	-0.03	-0.05	-0.05	0.11	-0.07	
Generation per inhabitant	-0.09	-0.14	-0.15	0.24	-0.01	
Digitalisation	0.17	0.05	-0.08	-0.06	-0.04	
Open data store for the electricity grid in region (transmission and distribution)	0.22	-0.23	-0.3	-0.01	0.34	
Retail innovation	0.03	-0.19	-0.02	0.12	-0.02	
In words...	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	**Assumptions**
Population growth	Very low	High	Very high	Average	Very low	More population growth = general pressure for ToU
Land available	Average	Average	Average	Very high	Low	More land available = more variable generation
Generation per inhabitant	Low	Very low	Very low	Very high	Average	More variable generation now
Digitalisation	Very high	High	Low	Low	Average	More dig = more customer buy-in, easier to implement
Open data store for the electricity grid in region (transmission and distribution)	Very high	Very low	Very low	Average	Very high	Higher open data store = easier to implement
Retail innovation	Average	Very low	Average	Very high	Average	More retail innovation now = more ToU in general
Policy impact score	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	
Retail (general)	-0.05	-0.07	0.13	0.04	-0.06	
Generation increase	-0.06	-0.09	-0.10	0.18	-0.04	
Implementation	0.20	-0.09	-0.19	-0.04	0.15	

Retail change needed (General)	**Low**	**Low**	**Very high**	**Average**	**Low**	**If low, no recommendation**
Generation increase	Low	Low	Low	Very high	Average	Use of generation for smart heating/ cooling/charging
Implementation feasibility	Very high	Low	Very low	Average	Very high	Implementation of intelligent pricing / 'roaming' for EV charging
Recommendation score	0.31	0.25	0.42	0.25	0.25	
Recommendation rating	**Strong**	**Strong**	**Very strong**	**Strong**	**Strong**	
2025 Recommendations	No recommendation	No recommendation	Move public sector properties where the city is responsible for the bill moved onto a time of use tariff	Move all public sector properties that the city is responsible for onto dynamic pricing tariffs, and all properties onto smart heating and cooling	Move public sector properties onto dynamic pricing tariffs when up for renewal	
2040 Recommendations	All chargepoints are 'smart' that are owned by the city, and are only available to EVs that are on an intelligent charging tariff. Allow 'roaming' charges for EVs as default over a bespoke payment system. All city properties moved to smart heating and cooling.	Cities give a business rate discount to premises that make their smart chargepoints available to EVs on an intelligent tariff and allow 'roaming' charges for EVs as default over paying the commercial premises owner directly.	All public sector properties build local generation to offer cheap or at cost time-of-use tariffs for their EV fleets and for commuter EVs when the sun shines/wind blows.	Cities use their planning powers to designate 'rooftop solar investment areas' for the city to include planning agreements with landowners for rooftop solar that serves the wider district	Give council/ business rate rebates to properties that have local generation and/or storage and join a smart heating/ cooling intelligent tariff plan. Only give planning permission for chargepoints that only allow EVs to charge on an intelligent tariff.	

Consumer engagement

Normalised and Standardised typology score	Connected	Free-market	Scalable	Distributed	Available	
Population	0.35	0.15	0.15	-0.21	-0.30	
Digitalisation	0.17	0.05	-0.08	-0.06	-0.04	
Solar resources	-0.02	0.12	0.19	-0.15	-0.07	
Startup environment	0.37	0.25	-0.24	-0.06	-0.26	
Retail innovation	0.03	-0.19	-0.02	0.12	-0.02	
In words...	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	**Assumptions**
Population	Very high	Very high	Very high	Very low	Very low	More population = more engagement from consumers
Digitalisation	Very high	High	Low	Low	Average	Less digitalisation = more need for bridging the digital divide
Solar resources	Average	Very high	Very high	Very low	Low	High solar resources = more engagement from consumers
Startup environment	Very high	Very high	Very low	Low	Very low	High startup = more product potential and locally-oriented
Retail innovation	Average	Very low	Average	Very high	Average	Low retail innovation = more need for a public sector intervention in the market
Policy impact score	**Connected**	**Free-market**	**Scalable**	**Distributed**	**Available**	
Engagement (general)	0.16	0.14	0.17	-0.18	-0.18	
Bridging digital divide	-0.17	-0.05	0.08	0.06	0.04	
Products available	0.37	0.25	-0.24	-0.06	-0.26	
Public sector intervention	-0.03	0.19	0.02	-0.12	0.02	

Engagement change needed (General)	Very high	Very high	Very high	Very low	Very low
Bridging digital divide	Very low	Average	High	High	Average
New product potential	Very high	Very high	Very low	Low	Very low
Public sector intervention	Average	Very high	Average	Very low	Average
Recommendation score	0.73	0.63	0.51	0.42	0.52
Recommendation rating	**Super strong**	**Super strong**	**Very strong**	**Strong**	**Strong**
2025 Recommendations	Cities set up a information hub for consumers to know where/when they can charge/ discharge their EV/batteries to improve flexibility	Cities set up a messaging system during times of acute grid stress that residents and businesses can use to manually and/or automate their use of heating, cooling, and charging	Cities create resident community energy boards-options include use of messaging systems, communal storage/chargers, and EV parking permits	Cities support rollout of domestic smart heating/ cooling and pair charging with nearby generation	Cities support the rollout of domestic smart heating/ cooling and pair charging with nearby storage
2040 Recommendations	Cities give discounts on council/property taxes and business rates to consumers that choose to charge/ discharge their EVs at better locations for flexibility and the business premises that open up their smart chargers to allow this	Cities give council/property or business rate discounts to residents and businesses that are willing to automate turn down / turn up heating and cooling and use intelligent charging	Cities support resident community energy boards to make deals with renewable energy investors to install communal VREs	Cities create a joint venture between local businesses with storage and nearby economically-disadvantaged neighbourhoods to give them access to cheaper or free electricity for smart heating and charging	Cities give business rate discounts to city-centre businesses that sign up to build local batteries for charging with plentiful daytime renewable energy supplies Council/property tax discounts provided for residents that use intelligent tariffs for smart heating/ cooling and charging

If low, no recommendation

APPENDIX B

Standardisation and Normalisation

NORMALISATION

It was important to ensure that all variables were measured on the same scale, otherwise variables with a greater range in their potential values may carry a disproportionate weight in the classification.

Most variables are reported on a per-capita basis (for example, energy demand per capita).

Second, the variables were standardised using the min-max normalisation or range standardisation technique, which produces output values in the range 0 to 1.

$$x_{st} = \frac{x - min\,(x)}{max\,(x) - min\,(x)}$$

The range standardisation method compares each value of a variable, x, to the minimum value Xmin. This is then divided by the distance between the minimum value, Xmin, and the maximum value, Xmax, of the variable. After the data have been range standardised, each variable has a range of one with the maximum value being one and minimum value being zero.

STANDARDISED MEAN

For each variable, the range of values is rescaled, setting the mean of the standardised variables to zero.

$$x_{stmean} = x_{st} - mean\,(x_{st})$$

RADIAL PLOTS

On the radial plots, a red circle represents the standardised mean – zero in all cases. This circle around the radial is at a constant distance from the centre. Therefore, data points that appear on the outside of the circle represent statistics that have a higher value than the standardised mean, while data points that appear on the inside of the circle represent statistics that have a lower value than the standardised mean.

APPENDIX C

Data Sources

BASIC STATISTICS

City land area and population: Urban centre and urban clusters around the city. The city boundary sometimes could be used, but in most places the urban area is larger.

Region land area and population: Urban clusters and rural areas that are nearby to a city (for example, Ile-de-France for Paris).

Electricity as the fuel for heating / cooling end-uses: We aren't considering non-electric heating fuels in this analysis (natural gas, oil). We're likely going to need much more electricity for decarbonised heat and transport systems if this percentage is low.

Commercial Floorspace: The lettable floor space in the city (usually recorded to calculate business rates)

Residential units (dwellings): These are all the inhabitable residential buildings in the city

Number of electricity meters: These are all of the domestic meter points in the city

CURRENT GENERATION

Current national electricity generation by fuel, national
The dispatch of electricity at present (before the DNO to DSO transition) is done by transmission networks that call on different power generators. Typically, the cheapest energy is from renewable sources (wind, solar), followed by nuclear, followed by fossil fuels (natural gas, coal, oil). The national percentage of renewable fuel is a 'baseline' to judge the share of renewable energy for a city. In the indicators we use the annual average daily renewable generation (wind, solar, hydro and biomass) in 2019 (pre-pandemic) and 2021 (post-pandemic) per 100,000 inhabitants in the country.

Regional electricity renewable generation
Regions near a city are where renewable electricity generation can be fed to the city without encountering constraints in the grid from transferring electricity from region to region.

The metric we use to compare is the average regional renewable energy generation per 100,000 inhabitants in the region.

Regional electricity renewable generation capacity
Available capacity of renewable generation that is in the region that can be fed to the city without encountering constraints in the grid from transferring electricity from region to region.

The metric we use to compare is the average regional renewable energy capacity per 100,000 inhabitants.

DEMAND / CONSUMPTION BASELINE

Electricity demand (city)
The daily electricity consumption of the city for both domestic and non-domestic meters, scaled down from the region or nation as grid supply points that approximate the city are difficult to access. In this metric, again we use the annual average daily demand in 2021 per 100,000 inhabitants in the country/region.

The metric we use to compare is the average national renewable energy generation per 100,000 inhabitants.

Housing density (calculated)
The number of dwellings per hectare of the city

Commercial and industrial floorspace density (calculated)
The number of square meters per hectare of the city

Land use mix (Herfindahl–Hirschman Index of market concentration)
The concentration of land uses in a 125 sq km area of the city that surrounds the centre of the city (calculated as the sum of the square of percent of land covered by one land use). The city is divided into 500 x 500 (25 hectare) zones, and an analyst estimates the majority of ground floor floorspace of that zone based on satellite imagery and commercial mapping (Google Maps). The land uses are:

- Commercial / retail
- Residential
- Industrial
- Institutional / educational / leisure (excluding green space)
- Formal green spaces

Informal green spaces and agricultural land is not included in this calculation. For the selection of this measure, see Jiao et al 2021.

Issues for the future to resolve:

Modifiable areal unit problem. The index will produce different calculations for a 500 x 500 m district, a 1km x 1km district

Insensitivity to district-wide land use concentration: A district with 90% resi counts the same as one with 60% resi - they are both classified as residential

Permutation of districts: Two area's districts can have the same land use distributions, but different spatial arrangements - some which can be better at the co-location of energy storage assets

Undeveloped land near the city (hectares)
Informal green spaces and agricultural land not included in this calculation above.

Solar roof potential - direct normal radiation
The monthly sum of the solar radiation energy that hits one square meter of a plane always facing in the direction of the sun, measured in kWh/m^2, including only the radiation arriving directly from the disc of the sun. This information is sourced from the EU Photovoltaic Geographical Information System (PGIS) ERA5 database.

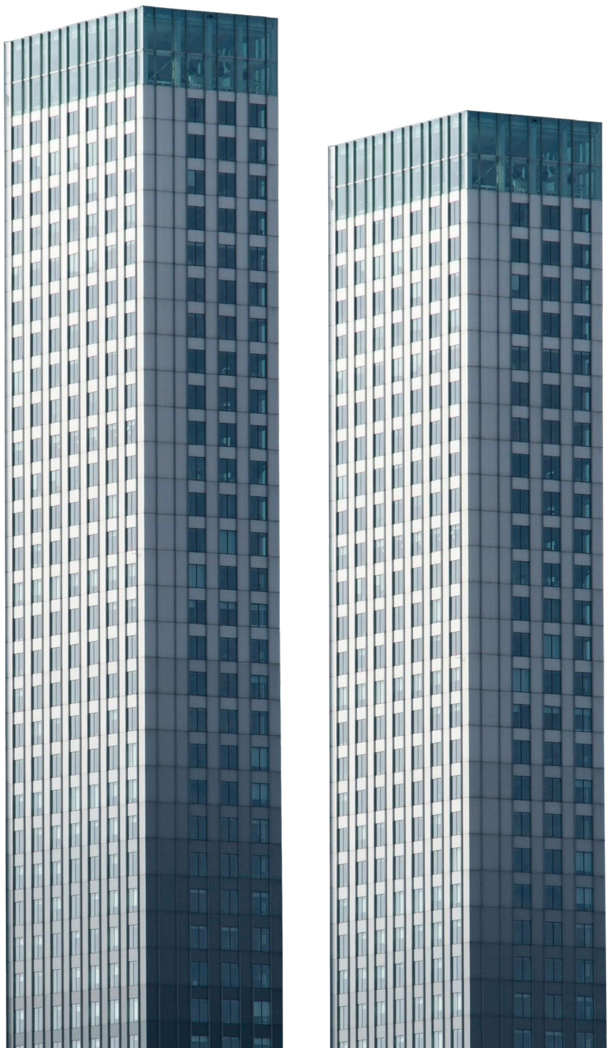
We use a scoring method to compare cities, by which we compare the average solar radiation throughout the year with the available roof available using the land estimates from the previous section land use mix. To do so we assume that only 30% of the total amount of residential, industrial, commercial and institutional roof available is suitable for solar technologies.

This metric combines the average number of months in the last 15 years (2005 to 2020) in which irradiance is greater or equal to 150 kWh/m^2 and the available roof space for solar as indicated above.

Wind speed potential - average speed
The daily wind speed at the airport closest to the city sourced from MeteoStat.

Similarly to what has been proposed for the roof potential, we score different cities by comparing the amount of land available for wind projects and the observed wind speed in the last 5 years. For this indicator we compare the average number of days in the year when the wind speed was greater than 5 m/s with 10% of the total available open space (green and unused land).

The metric of the indicator takes into account the total average number of days per year over the last 5 years with wind speeds higher than the 5 m/s threshold (3 m/s are necessary to start producing power).



DEMAND / CONSUMPTION POTENTIAL

Heating and cooling degree-days
A degree day is computed as the integral of a function of time that generally varies with temperature. The function is truncated to upper and lower limits that vary by organism, or to limits that are appropriate for climate control. The function can be estimated or measured by one of the following methods, in each case by reference to a chosen base temperature (we have chosen 18°C for heating and 21°C for cooling):

Frequent measurements and continuously integrating the temperature deficit or excess;

- Treating each day's temperature profile as a sine wave with amplitude equal to the day's temperature variation, measured from max and min, and totalling the daily results;
- As above, but calculating the daily difference between mean temperature and base temperature;
- As previous, but with modified formulae on days when the max and min straddle the base temperature.

A zero degree-day in energy monitoring and targeting is when either heating or cooling consumption is at a minimum, which is useful with power utility companies in predicting seasonal low points in energy demand.

The metric we use to score this indicator is the number of days where the heating/cooling degree days are higher than 10°C in the last 36 months as reported in DegreeDays for the airport closest to the city.

EV Ownership

Number of 100% electric vehicles that are reported as being licensed in the city per capita. This is usually collected by national statistical agencies using data from vehicle licensing agencies. Some countries licence 100% electric and plug-in hybrid vehicles differently; others combine them. We use a ratio of 100% electric: plug-in hybrid nationally to scale down this combined reporting. Most EVs are registered in cities on a per capita basis, and we uprate EV ownership accordingly. For the metric we represent the penetration of EVs in the city, i.e. the fraction of EVs in the vehicle fleet of the city.

Startup environment
We use the Startup Blink / Crunchbase Global Startup Ecosystem map, a crowdsourced community resource where entrepreneurs can add startups to the map for free. The map provides a visual database of a sample of the global startup ecosystem and is supported by our data partners, such as Crunchbase, SEMRush, and Meetup.

Take-up of digital services
We use the International Telecom Union statistics on the number of mobile internet contracts per 100 people nationally, uprated for urban areas based on a separate statistic of the use of the internet in urban and rural areas in developed and developing countries. The formula used simply ramps up the mobile phone subscriptions by the co-efficient between urban and total percentage of users in different geographies.

Attitudes towards green climate issues
We use the Lloyd's Register Foundation World Risk Poll survey of more than 1000 people per nation. We use the percent for each nation that responded very *serious* to the question "How much of a threat is Climate change to the people of this country in the next twenty years?"

Population growth to 2035
We use the population growth from 2020 to 2035 from the UN World Urbanization Prospects estimates (pre-Covid estimates).

GRID

Use of electricity wholesale locational market hub / zonal / nodal pricing
We developed a scoring method for use of wholesale locational markets based on a scan of the literature (for example, GB, Spain):

Percent of region under locational market pricing	Score		Type of locational market pricing	Score
100	4	x	Node: Substation level	4
75	3		Node: Grid Supply point level	3
50	2		Hub: Average of all of the nodes, with full constraint costs included	2
25	1		Zonal: Average of all the nodes, on the basis of simplified transmission constraints	1
0	0		Nothing	0

Open data store for the electricity grid
We developed a scoring method for the availability of open data for the electricity grid based on our experience cleaning and performing analysis on the data. The metric consists of a grade between 0 and 1, 0 being the worst grade and 1 the best.

Historical change in electricity demand (1980s - today)
This is the change in electricity demand since the change in the west from industrial to post-industrial economies, and the movement of energy-intensive industry to developing economies (such as the BRICS). This is an indication of the amount of headroom likely to be contained within cities (who were at the centre of energy-intensive industries)

Innovation in Retail Tariffs
We developed a scoring method of innovation in retail tariffs based on a scan of the literature (using the definitions in IRENA) summing all consumers by type of pricing scheme:

Percent takeup of pricing scheme	Score		Type of pricing	Score
100	4	x	Real time pricing	4
75	3		Variable peak pricing	3
50	2		Critical peak pricing	2
25	1		Static time-of-use	1
0	0		Flat-rate	0

In the tables below, we present first all the indicators included in this report along with all the data sources used in this analysis for each of the cities investigated.

Indicator	Description
1	Population
2	Land area (metropolitan region or greater combined authority)
3	Commercial floorspace
4	Number of residential units
5	Number of electricity meters
6	Fuel for heating / cooling end-uses
7	Electricity generation by fuel type (solar, wind, storage, backup generators...)
8	Regional electricity generation by fuel type (solar, wind, storage, backup generators...)
9	Regional connected renewable generation capacity
10	Electricity demand (city)
11	Heating and cooling end-use demand (long-term mean)
12	Land-use mixed status
13	Undeveloped land near the city
14	Solar roof potential
15	Wind speed potential
16	EV ownership
17	Startup environment
18	Take-up of digital services
19	Attitudes towards climate change and 'green' issues
20	Population growth to 2035
21	Use of electricity market hub/zonal/nodal pricing
22	Open data store for the electricity grid in region (transmission and distribution)
23	Historical change in energy demand
24	Innovation in Retail Tariffs

Indicator	Paris	London	Tokyo	Singapore	LA	Bengaluru	Buenos Aires	Johannesburg	Nairobi	Stockholm	Vancouver	Medellin	Amsterdam	Nantes	Manchester	Valencia	Sydney
1	PAR1	LON1	TYO1	SIN1	LAX1	BLR1	BUE1	JNB1	NBO1	STO1	YVR1	MDE1	AMS1	NTE1	MAN1	VLC1	SYD1
2	PAR2	LON2	TYO2	SIN2	LAX2	BLR2	BUE2	JNB2	NBO2	STO2	YVR2	MDE2	AMS2	NTE2	MAN2	VLC2	SYD2
3	PAR3	LON3	TYO3	SIN3	LAX3	BLR3	BUE3	JNB3	NBO3	STO3	YVR3	MDE3	AMS3	NTE3	MAN3	VLC3	SYD3
4	PAR4	LON4	TYO4	SIN4	LAX4	BLR4	BUE4	JNB4	NBO4	STO4	YVR4	MDE4	AMS4	NTE4	MAN4	VLC4	SYD4
5	PAR5	LON5	TYO5	SIN5	LAX5	BLR5	BUE5	JNB5	NBO5	STO5	YVR5	MDE5	AMS5	NTE5	MAN5	VLC5	SYD5
6	PAR6	LON6	TYO6	SIN6	LAX6	BLR6	BUE6	JNB6	NBO6	STO6	YVR6	MDE6	AMS6	NTE6	MAN6	VLC6	SYD6
7	PAR7	LON7	TYO7	SIN7	LAX7	BLR7	BUE7	JNB7	NBO7	STO7	YVR7	MDE7	AMS7	NTE7	MAN7	VLC7	SYD7
8	PAR8	LON8	TYO8	SIN8	LAX8	BLR8	BUE8	JNB8	NBO8	STO8	YVR8	MDE8	AMS8	NTE8	MAN8	VLC8	SYD8
9	PAR9	LON9	TYO9	SIN9	LAX9	BLR9	BUE9	JNB9	NBO9	STO9	YVR9	MDE9	AMS9	NTE9	MAN9	VLC9	SYD9
10	PAR10	LON10	TYO10	SIN10	LAX10	BLR10	BUE10	JNB10	NBO10	STO10	YVR10	MDE10	AMS10	NTE10	MAN10	VLC10	SYD10
11	Global reference used																
12	As indicated in this appendix, calculated by CNZ																
13	As indicated in this appendix, calculated by CNZ																
14	Global reference used																
15	Global reference used																
16	PAR16	LON16	TYO16	SIN16	LAX16	BLR16	BUE16	JNB16	NBO16	STO16	YVR16	MDE16	AMS16	NTE16	MAN16	VLC16	SYD16
17	Global reference used																
18	Global reference used																
19	Global reference used																
20	Global reference used																
21	PAR21	LON21	TYO21	SIN21	LAX21	BLR21	BUE21	JNB21	NBO21	STO21	YVR21	MDE21	AMS21	NTE21	MAN21	VLC21	SYD21
22	As indicated in this appendix, calculated by CNZ																
23	Global reference used																
24	PAR24	LON24	TYO24	SIN24	LAX24	BLR24	BUE24	JNB24	NBO24	STO24	YVR24	MDE24	AMS24	NTE24	MAN24	VLC24	SYD24

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He has a doctorate in energy and the built environment from the Bartlett School of Environment, Energy and Resources, University College London and is qualified as a chartered town planner from the Royal Town Planning Institute. In academia, he managed a £2m grant portfolio of technologies that support a digitalised, green economy for UK Research and Innovation.

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A mathematician and physicist by training, Daniel's interest lies in the intersection between energy, sustainability and human behaviour. He is responsible for supporting several research areas at Centre for Net Zero, spanning electric vehicles, heat pumps and cities. He also helps design real-world trials that the Centre runs on these research areas.

Previously, Daniel worked at Aurora Energy Research and Accenture, where he contributed directly to the delivery of power market forecasts for European countries, developed research about green hydrogen production and its viability, and helped develop cloud solutions for customer relationship management. Daniel has also published literature about the development of solar energy technologies and holds a master's degree in Sustainable Energy Futures at Imperial College London, graded with Distinction.

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