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# PRACTICAL IMPLEMENTATION GUIDE: RESILIENT URBAN ENERGY SYSTEMS

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*Authors:*
*Alina Mures[1], Bard Rama[1] Carsten Rothballer[1], Inés Casamitjana Zaballa[1]*

*Reviewers:*
*Jefferson Vallejo R.[2], Tomo Anyoji[3]*

*Organizations:*
*1 - ICLEI – Local Governments for Sustainability, European Secretariat;*
*2 - EPMAPS, Agua de Quito, Alcadia Metropolitana Quito;*
*3 – Zero Carbon and GREEN×EXPO Promotion Bureau, City of Yokohama*

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# 1 INTRODUCTION

The World Meteorological Organisation (WMO) reported that 2024 was the hottest year ever recorded (World Meteorological Organization, 2025), affected by severe weather events everywhere across the globe: from deadly floods, heavy rainfalls and storms to increased heat waves and droughts. For instance, in October 2024, Valencia, Spain, was hit by intense rainfall that led to the flooding of several areas of the city, resulting in the loss of many lives, the disruption of essential services such as the supply of energy and drinking water, as well as damages to different types of infrastructure and properties (Medrano and Wilson, 2024). In fact, the Spanish floods severely affected the energy infrastructure; in particular, several high-voltage towers collapsed, leaving some 30,000 households and 155,000 people without electricity, exacerbating the challenges faced by residents and emergency responders (Bernal, 2024).

On April 28, 2025, Spain and Portugal experienced one of the worst European power outages in decades affecting millions of people and businesses, disrupting transport systems, communication networks, and internet connectivity. The blackout occurred after the loss of 15 GW of electricity generation within 5 seconds (Naishadham S., Wilson J., 2025). While the causes of the incident are still being investigated by the European Network of Transmission System Operators for Electricity(ENTSO-E) with results expected to be published in October 2025 (ENTSO-E, 2025), preliminary analysis presented by the Spanish Government suggests that some of the causes of the blackout were likely caused by inadequate voltage control, ineffective corrective actions, and improper disconnections of power generation plants (Spanish Council of Ministers, 2025).

**The consequences of power disruption extend well beyond infrastructure failures, affecting economic productivity, the delivery of essential services, and the wellbeing of citizens.** The same has been seen in Ireland, where the widespread loss of power, caused by Storm Éowyn in January 2025, left 768,000 Irish homes, farms, and businesses without electricity (European Commission, 2025). Such events underscore the urgency of strengthening energy resilience in urban areas and stress the **need for robust planning, investment in grid adaptation, and early-response mechanisms** to protect communities and ensure continuity of critical services.

**Cities are complex systems where different components - energy networks, food distribution networks, transport, and natural habitat - are interrelated and dynamic** (ICLEI - Local Governments for Sustainability, 2018). The shocks and stresses experienced by cities in one area have cascading effects on other areas. An example is the increased volatility of freshwater availability due to climate change which can affect energy supply and demand, influencing the energy transition overall (IEA, 2020). In 2024, Ecuador imposed nationwide blackouts to protect its power grid after drought severely reduced hydroelectric generation. The outages left households without power, forced businesses and factories to cut operations, and led to billions in economic losses (Noriega, 2024). Similarly, in France, scarce water flows and rising river temperatures, experienced recently, have prompted the temporary outage of nuclear power plants, due to the limited possibility of discharging residual heat from the plants into the water (European Commission, 2025).

ICLEI's Development Pathways, consisting of low-emission, nature-based, circular, resilient, and equitable development (Figure 1), offer cities a comprehensive framework "*to design climate action solutions in a holistic and integrated way, realizing a diversity of co-benefits, and creating change across their entire urban system*" (Arikan, Carreño, Van Staden, 2020, p. 5). Likewise, the Global Methodology for Infrastructure Resilience (CDRI) supports and builds the capacity of cities to enhance the resilience of urban infrastructure systems and adaptation investments. Its approaches are targeted towards enabling cross-cutting policies, facilitating cooperation and coordination among different sectors and stakeholders, and assisting in integrating disaster risk reduction and climate change adaptation into infrastructure planning and management (UNDRR and CDRI, 2023).

**The UTMC guide is intended for cities and local governments worldwide,** offering approaches that can support planning and implementation while being replicated across different contexts. Building on major urban initiatives, this document aims to expand on opportunities for strengthening urban energy systems resilience in an integrated and holistic approach towards climate neutrality. Harnessing the interconnectedness of urban systems is an opportunity for cities to capitalise on co-benefits



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and complementarities and promote synergies that contribute to the Nationally Determined Contributions (NDCs) submitted under the Paris Agreement, the UN Sustainable Development Goals and address environmental, health and social dimensions.

This resource provides an outlook of the main threats posed to urban energy systems, the means for strengthening the resilience of energy systems, and potential action strategy for cities. This non-technical document provides actionable recommendations for cities to enhance energy resilience as they transition towards climate neutrality. It builds upon existing resources and initiatives, incorporating the practical experiences of cities interviewed for this research, and concludes with guidance for creating more resilient urban environments. Readers are encouraged to explore the additional research sources cited within the guide.

# 2 UNDERSTANDING RESILIENCE IN URBAN ENERGY SYSTEMS

Driven by increasing urbanization, cities consume approximately 75% of the world's energy and contribute 70% of global greenhouse gas emissions, a trend the International Energy Agency (IEA) anticipates will intensify by 2050 (Zhang et al., 2024). Local governments are making significant investments to curb their environmental impact by mitigating CO2 emissions from sectors ranging from transportation and construction to food production and water management; nevertheless, the energy dependence of each of these sectors is a key consideration. Consequently, the very mitigation strategies that cities implement could inadvertently lead to a surge in electricity demand and a greater reliance on energy infrastructures already undergoing a complex transition away from fossil fuels towards renewable energy sources (Javanroodi et al., 2023; Kammen and Sunter, 2016). In this context, transitioning to **sustainable urban energy systems** entails not only transitioning to 100% renewable energy production, disinvesting from fossil fuels, and decarbonising electricity and energy carriers, but pursuing the electrification of mobility, heating, and cooling systems, as well as shifting towards net-zero materials and supply chains (Lwasa et al. 2022 in IPCC, 2022; ICLEI, 2024). Equally important in the transition are measures that reduce overall energy demand through digitalisation, modal shifts, and behavioural changes that minimise losses, inefficiencies, and intensity. Together, these actions strengthen the resilience and sustainability of urban energy systems, and ensure that energy is affordable, reliable, and safe, bringing significant benefits to the local communities in terms of improved well-being and livelihood (ICLEI, 2024).

Yet, the pursuit of sustainable energy transitions alone is not sufficient. Given the interdependencies between urban infrastructures, and cities' exposure to climate risk, **the ability of energy systems to withstand, adapt, and recover from disruptions becomes critical.** In this context, the concepts of **resilience** and **adaptation** are pivotal in understanding how urban systems can respond, react, and avoid stresses and shocks. While closely related and complementary, they hold distinct meanings in urban planning and climate policy (Mehryar, 2022), and together they provide the conceptual foundation for strengthening urban energy systems against future uncertainties.

According to the Intergovernmental Panel on Climate Change (IPCC), adaptation refers to "*the process of adjusting to actual or expected climate hazards and its effects*" (IPCC, 2022). It involves implementing changes to reduce vulnerability to climate impacts or to seize potential opportunities for ensuring cities remain liveable, functional, and prosperous for their residents (European Environment Agency, n.d.). Adaptation strategies might include building flood defences, creating drought-resistant crops, or changing building codes to withstand extreme weather events.

Resilience, on the other hand, takes a more comprehensive approach and it is explained further in the section below.

## 2.1 Defining Urban Resilience


ICLEI - Local Governments for Sustainability defines resilience as "***the ability of cities to anticipate, prevent, absorb, and recover from hazards while maintaining essential functions, structures, and identity as well as adapting and thriving in the face of continual change***" (ICLEI, 2019). Resilience extends beyond adapting to climate-related hazards. It involves addressing other interconnected challenges, including economic crises, socio-political conflicts, and natural disasters.

**Resilience strengthens urban systems holistically** by integrating solutions related to urbanisation, sustainability, socio-economic development, and climate change. While adaptation primarily addresses the need to respond to climate-related impacts, resilience encompasses a broader set of strategies – ranging from policy design, infrastructure development, service provision, planning processes to education and communication initiatives – which ensures the long-term stability, functionality, and adaptability of urban environments.

Resilience entails the identification and assessment of hazards, the capacity of reducing exposure and vulnerability to hazards, minimizing exposure and vulnerability, strengthening resistance, enhancing adaptability, and improving preparedness for emergencies (ICLEI, 2019). This approach helps cities not only cope with climate impacts but also reduce emissions and develop in a sustainable way.


Figure 1 ICLEI's Five Development Pathways

**ICLEI's Development Pathways** offers a clear framework for climate neutral cities, focusing on five interconnected strategies: zero-emission, nature-based, circular, resilient, and equitable development. **Resilience**, in this context, goes beyond recovery from individual shocks, **it implies addressing diverse types of hazards** (including those related to climate change, natural hazards, and human activities) **and strengthening vital systems across sectors. This approach ultimately reduces the strain on both people and the environment whilst guiding cities towards climate neutrality** (Arikan, Carreño, Van Staden, 2020).



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## 2.2 Urban Energy Systems and Threats

The prosperity and quality of life in urban areas are significantly influenced by the energy system's ability to meet the energy demands of households, businesses, transportation, healthcare, water management, and food systems. These demands stem from the need for lighting, heating, and cooling for residential and commercial buildings, as well as for fuel for transportation and industrial activities.

While mitigation strategies are relevant to reducing GHG emissions within the energy sector, adopting a resilient lens is also needed to ensure the transition towards climate neutrality through solutions that are climate-proof, equitable and inclusive and that can allow cities to overcome and anticipate damages induced by different types of threats.

Urban energy systems face a wide array of hazards that extend far beyond climate change and extreme weather events. These can be related to the adoption of innovative technologies, geopolitical conflicts, cyberattacks, and other disruptions that can significantly impact the ability of energy systems to supply power reliably. Such disruptions not only affect residential and commercial buildings but also jeopardise critical city infrastructure and services, including healthcare facilities, police stations, transportation networks, wastewater treatment plants, financial institutions, and telecommunications systems (World Bank, 2011).

### BOX 1: WHAT ARE THE ENERGY SYSTEMS?

The energy systems encompass the overall process of extracting, producing, converting, delivering, and consuming energy. They refer both to the physical infrastructure - such as power plants, transmission lines, and distribution networks - and to societal dynamics, like energy use patterns and regulations. The energy systems enable essential activities, including transportation, heating, cooling, lighting, cooking, and industrial production. They can be centralised, relying on large-scale power plants and extensive grids, or decentralised, with energy generation and distribution occurring at a local level. They are designed to meet society's energy demand in a stable, efficient, and sustainable manner. (Clarke et al., 2022; Basu et al., 2019).

**The consequences of these disruptions are multifaceted: they can lead to physical damages that disrupt daily life and harm public health, as well as economic repercussions, such as rising energy prices, which create cascading effects on other dependent services.** In addition, vulnerable populations, including the unemployed, low-income individuals, and the elderly, are often disproportionately affected by these challenges. Table 1 provides a comprehensive overview of the potential risks associated with urban energy systems, while Chapter 3 highlights strategies to enhance resilience and ensure the continuity of essential services in the face of diverse threats while engaging in clean energy transition.

*Table 1 List of Threats to Energy Systems*

| Climatic and Non-Climatic Threats[1] | Impacts on energy systems |
|---|---|
| **Poor maintenance of infrastructure**<br><br>Ref: U.S. Department of Energy, 2017 | Energy systems rely on physical infrastructure like power plants, grids, and pipelines. Ageing or poorly maintained infrastructure is more vulnerable to failures, leading to energy outages, inefficiencies, and higher costs. Climate change exacerbates this issue by increasing the frequency of extreme weather events, which can damage already fragile systems, increase the risk of blackout and maintenance costs, as well as reduce the reliability of energy supply. |
| **Extreme weather events and climate change**<br><br>Ref: Zhang et al., 2024<br>Clarke et al., 2022<br>Sharifi and Yamagata, 2016 | Climate change intensifies extreme weather events such as hurricanes, heatwaves, floods, and droughts. These events can damage the energy infrastructure, disrupt fuel supply chains, reduce the efficiency of energy generation, or impact the energy demand, increasing demand for cooling or heating, hence putting pressure on the electricity supply. Overall, such situations increase the vulnerability of energy systems and their repair costs and create potential long-term disruptions to energy supply.<br>Droughts and water scarcity can affect the energy supply due to, e.g. reduced availability of biomass and waterpower generation, water-based cooling processes for energy generation, interrupted river transport etc.<br>While, at the same time, more intensive water management related to pumping (over longer distances), water treatment needs (for desalinisation or due to flooding, etc.) and increased cooling demands can trigger higher energy demands. |
| **Other natural hazards**<br><br>Ref: Hallegatte, Rentschler, and Rozenberg, 2019 | Natural hazards like earthquakes, tsunamis, and volcanic eruptions can cause catastrophic damage to energy infrastructure. Unlike climate-related events, these hazards may not directly be caused by climate change but still pose significant risks to energy systems, leading to sudden and severe disruptions to the energy supply, and requiring costly and time-consuming recovery efforts. |
| **Geopolitical instability**<br><br>Ref : International Energy Agency, 2021 | Geopolitical tensions, conflicts, and disputes can disrupt the supply of energy resources, especially when these rely on fossil fuels (e.g., oil, gas, and critical minerals). Sanctions, embargoes, or political instability in energy-producing regions can lead to price volatility and supply shortages, leading to reduced energy security, higher energy prices, and potential supply chain disruptions. |

1 For the purpose of this table, the term "Threats" is used as an to encompass both Hazards (unintentional, often natural events like extreme weather) and Threats (intentional, systemic, or human-induced failures like cyberattacks and geopolitical instability).



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| | |
|---|---|
| **Population growth and increased urbanisation rates**<br><br>Ref: Zhang et al. 2024<br>Javanroodi et al. 2023 | Rapid urbanisation and population growth drive higher energy demand for housing, transportation, and energy services such as heating and cooling. This puts pressure on energy systems to scale up production and distribution, risking increasing greenhouse gas emissions and meet demand unsustainably. |
| **Increased interdependence and interconnection across urban systems**<br><br>Ref: ARUP, 2019 | Urban systems (e.g., transportation, water, and energy) are highly interconnected and interdependent so that deficiencies in one sector can cascade into others. For example, the rise in electric vehicles (EVs) increases the demand for charging infrastructure and electricity, straining the grid. Widespread battery storage to decarbonize transport, substantially increases water requirements, since both electricity generation and battery manufacturing demand large water inputs.<br>Without a clear understanding of this entire system and the roles of the different actors involved, potential cascading failures might affect various parts and lead to depletion of natural resources and higher investment needs for infrastructure upgrades. |
| **Higher integration of renewable energy sources**<br><br>Ref: Clarke et al., 2022<br>Javanroodi et al., 2023. | Renewable energy sources like solar and wind are intermittent, meaning their output depends on weather conditions, thus affecting the electricity systems management. During extreme weather events, supply can drop sharply, while demand may spike (e.g., during heatwaves). This mismatch challenges grid stability: therefore, to ensure energy supply security, a digitalised and flexible integrated system is needed to ensure supply-demand balance. Some technologies that provide for grid flexibility are energy storage batteries, smart grids, and diversification of power sources to balance supply and demand when needed. |
| **Emerging disruptive technologies**<br><br>Ref: Greet and Barnes, 2017 | Emerging technologies such as advanced batteries, hydrogen fuel cells, and smart grids can transform energy systems. The rapid integration of AI and machine learning increases the dependence of energy systems on digital technologies. And while this helps to optimise energy management, their integration requires significant investment and adaptation of existing infrastructure, which can be disruptive in the short term. While these technologies may increase efficiency and sustainability, they need proper integration to ensure compatibility with legacy systems. |
| **Human error**<br><br>Ref: Jasiūnas et at. 2021 | Human mistakes in designing, operating, or maintaining energy systems can lead to failures. Examples include incorrect grid management, improper maintenance of power plants, or errors in disaster response planning. This may increase the risk of accidents, outages, and inefficiencies in energy systems. |
| **Physical and cyber security threats**<br><br>Ref: Unsal et al., 2021 | Energy systems are critical infrastructure and are vulnerable to physical attacks (e.g., sabotage of power plants) and cyberattacks (e.g., hacking of grid control systems). These threats can disrupt energy supply, increase the risk of large-scale outages, compromise public safety, and create economic losses. |
| Additional resources: For an exhaustive analysis of diverse threats to energy systems, the authors of this guide recommend referring to additional sources, such as: ARUP, 2019; Sharifi and Yamagata, 2016; World Bank, 2011 | |

## 2.3 Framing Resilience in Urban Energy Systems

Several studies have explored the concept of energy resilience through a systemic lens. Some analyses have been conducted on how this applies to the energy system as a whole. This guide adopts a broader perspective as it examines the concept in the urban context, where multiple actors and stakeholders are involved, and decision-making is not always in the hands of local governments (Sharifi and Yamagata, 2016).

While there is no agreed definition in academic world on resilient energy systems, in this guide we refer to **resilience in energy systems** as the ability of these systems to **effectively withstand, adapt to, and recover from various disturbances, including but not limited to climatic hazards, while maintaining the delivery of affordable and reliable energy services and protecting vulnerable populations from the cascading effects of energy disruptions.** A resilient energy system is characterised by its capacity to respond to disruptions, whether caused by extreme weather events, technological failures, or other external shocks and **to regain stability or equilibrium quickly**. Such systems are designed to learn from past incidents, implement adaptive strategies, and provide alternative solutions to meet energy demands even under altered or adverse conditions (Javanroodi et al., 2023; Chaudry et al., 2011).

Resilient energy systems should also be designed sustainably, integrating clean energy transition with the capacity to withstand and adapt to multiple disruptions. ICLEI's hierarchical framework - combining energy sufficiency, efficiency, integration, renewables and digitalisation - provides the elements to support cities' transition to sustainable energy systems, while enhancing their resilience (see Figure 2).

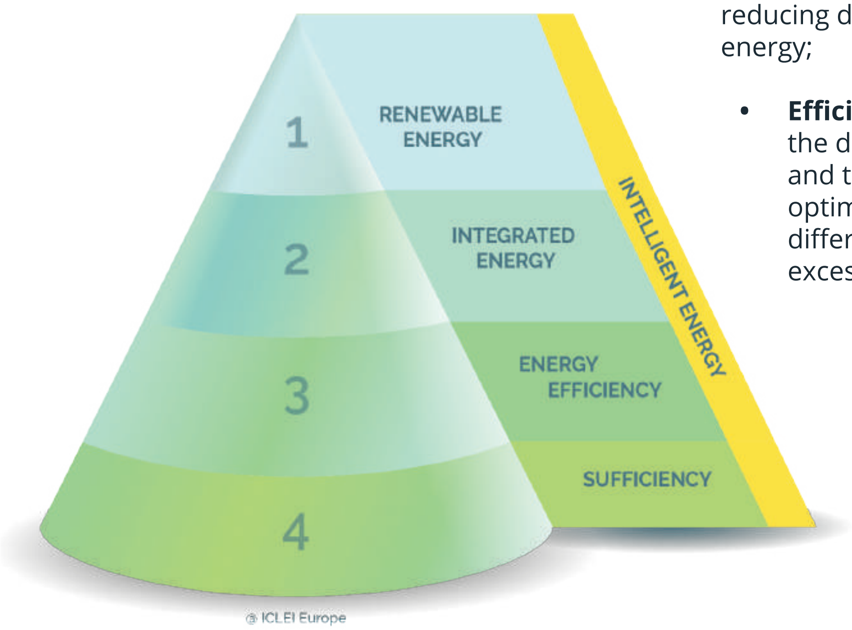


Figure 2 Sustainable Energy Systems Hierarchy, ICLEI Europe

- **Sufficiency** reduces the overall energy demand, altering consumption patterns, lifestyles and behaviour, hence reducing dependency on global supply chains and imported energy;
- **Efficiency** implies enhancing the energy use on both the demand and supply sides, improving infrastructure and technology performance (e.g., heat pumps), optimising the distribution and use of energy across different systems, and utilising surplus energy, such as excess heat, to reduce losses, and reduce costs;
- **Integration** strengthens urban systems by promoting sector coupling, interoperability, and closed resource loops, making them less vulnerable to cascading failures;
- **Renewable energy** entails the decarbonization and diversification energy supply, reducing exposure to fossil fuel volatility and geopolitical risks, and increasing affordability;

Finally, **integrating machine-learning and artificial intelligence** across all the above-mentioned areas, enhances reliability and adaptability across all dimensions, enabling faster recovery and adaptive responses to unforeseen disruptions.



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### 2.3.1 Characteristics of Resilient Energy Systems

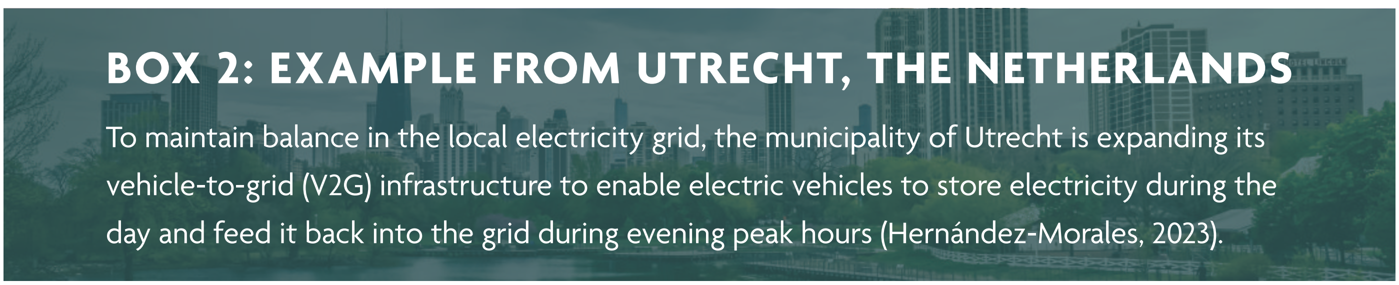
Resilient urban energy systems are critical to ensuring the continuous supply of power, particularly in the face of increasing climate-related and anthropogenic challenges. These systems need to be adaptable, diverse, and robust, while ensuring energy equity for all city dwellers. Below are key characteristics that define resilient urban energy systems.

#### *Redundancy and diversity*

Redundancy and backup systems provide crucial layers of defence against system failures. Energy storage solutions, such as batteries, are increasingly vital in providing immediate backup power and stabilizing the grid during fluctuations (IEA, 2020; ARUP, 2019).

A fundamental aspect of a resilient energy system is the diversity of energy sources. Relying on a mix of generation technologies, encompassing both different types of renewables and currently still conventional options, reduces vulnerability to disruptions affecting a single fuel source or technology (IEA, 2023).

Battery.
Credit: Artinun Prekmoung, on dreamstime-256337079



## BOX 2: EXAMPLE FROM UTRECHT, THE NETHERLANDS

To maintain balance in the local electricity grid, the municipality of Utrecht is expanding its vehicle-to-grid (V2G) infrastructure to enable electric vehicles to store electricity during the day and feed it back into the grid during evening peak hours (Hernández-Morales, 2023).

#### *Decentralization and distributed generation*

Decentralized systems enhance local control, reduce transmission losses, and improve energy access in remote or underserved areas. They also create a distributed grid that is more resistant to large-scale outages. The shift towards decentralization and distributed generation (DERs), including rooftop solar, microgrids, and combined heat and power (CHP), empowers local control and diminishes the cascading effects of widespread grid failures. Other characteristics include rapid deployment with significantly less on-site construction than large, centralized plants, operating independently upon installation, unaffected by the status or failure of others (Ackermann et al., 2001). Microgrids, in particular, offer the capability to isolate themselves from the main grid during disturbances, ensuring uninterrupted power supply to critical local loads.

#### *Flexibility and adaptability*

Resilient urban energy systems must be flexible and adaptable. This involves designing systems that can respond to varying loads, technological advancements, policy changes, and climate conditions. The ability to adjust energy production and consumption patterns in response to changing conditions is facilitated by smart grid technologies and demand-side management strategies (Gellings, 2009; Farhangi, 2010; ARUP, 2019).

## BOX 3: CITY OF CASCAIS, PORTUGAL

Several European countries have been experiencing a series of heatwaves in recent years. In Cascais and Lisbon, for instance, several electric buses were disabled due to overheating. To ensure continued transport services, the decarbonization strategy for Cascais' transit system is centered on the adoption of electric buses, as well as on hydrogen fuel cell buses, the latter being less sensitive to high ambient temperatures than battery-electric systems. While electric mini-buses (~8m) have been introduced on smaller lines, standard-size hydrogen buses (~12m) operate on main routes, ensuring uninterrupted transit service during extreme heat (Santos, Marques and Galvão, 2023).

The inclusion of smart grids, digital monitoring tools, and demand-response technologies facilitates this adaptability. These systems allow for the continuous optimization of energy usage, even as cities grow and face shifting challenges. Achieving such a level of resilience requires national and local decision-makers, along with utility companies, to facilitate the deployment of these technologies while enhancing the necessary capabilities and system's functionalities to support future power systems. Urban planning needs to be closely coordinated with energy system planning to ensure that infrastructure development and energy strategies are closely aligned for efficient and robust energy systems (IEA, 2024)

## BOX 4: EXAMPLE FROM ADJUNTAS, PUERTO RICO

In the municipality of Adjuntas, Puerto Rico, many residents lived nearly a year without electricity following Hurricane Maria, in 2017. Following the event, residents implemented a community-owned solar microgrid project in the city, consisting of 700 solar panels paired with a 187-kW battery storage system. This microgrid allowed 14 local businesses to generate their own power, enabling them to operate independently from the main electrical grid for approximately 10 days during outages (IEA, 2024).

### *Robustness and reliability*

Robustness and reliability are key characteristics of any resilient energy system. Ensuring the robustness and hardening of energy infrastructure is critical for withstanding potential hazards. This involves designing and constructing physical assets, such as transmission lines and substations, to endure extreme weather events and other physical threats. Moreover, robust cybersecurity measures are indispensable for protecting energy systems from malicious cyberattacks (ASCE, 2021; Ten et al., 2010; IEA, 2019). Systems must be designed to withstand physical stress, such as extreme weather events, as well as cyberattacks and operational failures. This can involve hardening infrastructure against storms, floods, or heatwaves, and implementing robust cybersecurity measures to prevent system breaches. Ensuring the robustness and hardening of energy infrastructure is critical in the face of increasing climate-related hazards, as highlighted by the IPCC's assessment of escalating extreme weather events (IPCC, 2022).



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## *Real-time monitoring and control*

To build resilience, urban energy systems must be supported by robust monitoring, and control mechanisms. These include real-time monitoring systems, early warning tools, and data-driven forecasting models that allow cities to anticipate future energy demand and potential disruptions. Real-time monitoring and control systems are crucial for the early detection of potential issues and rapid response to disruptions, a capability increasingly important in the context of climate-related uncertainties and extreme events (IPCC, 2022).

By continuously collecting and analysing data, cities can adapt their strategies to improve system performance and ensure energy supply even during crises. Real-time monitoring and control systems are vital for maintaining system stability and enabling rapid response to disruptions. Advanced smart sensors (Farhangi, 2010), data analytics, and communication networks provide continuous insights into system performance, allowing for early detection of anomalies and swift intervention.

### BOX 5: EXAMPLE FROM PORTO ALEGRE, BRAZIL

Porto Alegre, Brazil.
Credit: Photo by Michele Ricucci, on iStock-22233297655

The municipality of Porto Alegre is integrating real-time monitoring into its urban infrastructure strategy with the aim to strengthen resilience against extreme heat and inner-city flooding.

Porto Alegre will implement a project to enhance the resilience of urban infrastructure to flooding, through nature-based solutions, data-driven tools and community-centred strategies. The initiative focuses on protecting critical infrastructure, such as schools, hospitals, and transport infrastructure while also empowering vulnerable communities. By protecting urban systems, reducing service interruptions and mitigating flood risks, the project is expected to save approximately $25 million.

Assessments of vulnerabilities and flood risks are made via geospatial databases, risk maps and advanced modelling which will inform the city’s master plan. The city will implement interventions such as pedestrian walkways and integrated public transport hubs, fostering both mobility services and urban resilience overall (CDRI, n.d).

### *Interconnectedness and integration*

Resilient energy systems must be highly interconnected and integrated with other urban systems, including water, waste, mobility, and food. This interconnectedness allows for the seamless flow of resources and energy between systems, enabling cities to address multiple challenges simultaneously. Integration and interoperability across different components of the energy system - covering both power systems (electricity generation, transmission, and distribution) and thermal systems (heating and cooling networks), including various fuel types, technologies and energy consumers, enhance overall resilience by allowing for greater flexibility and resource sharing during disruptions (IEA, 2019). Digitalisation plays a key role in enabling integration and interoperability. Data-driven approaches improve system integration and real-time decision-making: for instance, big data on transport, energy, water, and waste supports targeted interventions and optimized operations. In fact, smart grids - through instruments such as smart meters - improve the demand-supply side management of electricity, enhancing energy efficiency; but they also ease the integration of fluctuating renewable energy (OECD, 2019). The integrated approach not only boosts resilience but also enhances the efficiency of the urban system as a whole.

### *Governance*

Effective governance and planning are fundamental for building and maintaining resilient energy systems, requiring integrated approaches that consider long-term climate risks and uncertainties (IPCC, 2022). Clear policies, regulations aiming to build resilient energy systems, and improve disaster risk reduction capacity, as well as coordinated efforts among all levels of government and energy systems operators are essential.

National governments play a key enabling role by providing policies, legislation, technical support, and financial resources that empower local governments to reduce risk and build resilience (UNDRR, 2017). Local governments, in turn, have the local knowledge to adapt national goals to local circumstances, ensuring that policies reduce vulnerability and advance local priorities. They set climate and energy targets, establish zoning and permitting regulations, update city-level energy codes, and lead renovation programs (IEA, 2024). In addition, municipalities can directly collaborate with utility companies to develop renewable energy projects and implement energy efficiency programmes. Through local climate and energy plans, municipalities can influence utility strategies at the local level, as shown below in the example box 5, summarising the experience of Quito’s municipality. Given their vital role in energy production and distribution, utility companies are also key players, as these can enhance energy resilience through their investment decisions and operational choices. They can expand renewable energy capacity, upgrade transmission and distribution networks to integrate renewables, and actively manage distributed resources in collaboration with energy consumers who generate their own energy (IRENA, IEA and REN21, 2018).

Long-term planning that proactively considers future risks and uncertainties is also crucial for ensuring the enduring resilience of urban energy infrastructure (IPCC, 2014). Energy systems that are governed by inclusive, transparent processes are more likely to gain public support and succeed in the long term. Therefore, engaging citizens and local stakeholders in the planning, development, and management of energy systems is a necessary requirement to ensure that these systems are socially acceptable and aligned with local needs.



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# 3 ACTION STRATEGY FOR RESILIENT ENERGY SYSTEMS

Adaptation Strategies for European Cities.
Credit: Image by Alesund_Gorshkov13_dreamstime

Achieving resilient and sustainable energy systems demands local governments to adopt policies that support smart, inclusive, and sustainable energy solutions; promote renewable energy projects at the neighbourhood or district scale; and advance low-emission transportation measures to cut air pollution. Streamlined permitting processes, zoning, and updated public procurement regulations are channels of influence that can help accelerate distributed energy deployment and enable the growth of community-owned renewable energy initiatives (IEA, 2024).

Improvements to energy infrastructure, accelerated deployment of decentralised renewables and storage, as well as AI integration should be complemented by actions that maintain and restore urban ecosystems. Integrating green and blue solutions, such as green corridors, green roofs, or sustainable water management, can help reduce the impact of environmental hazards, such as floods or droughts, improve water storage, reduce urban heat, and enhance citizens' well-being. Nature-based solutions can help absorb CO2 emissions, while having multiple co-benefits, such as reduced energy demand for cooling, improved air quality, enhanced biodiversity, strengthening community resilience and quality of life, among others.

## BOX 6: CITY OF MARSEILLE

Through the Cool Noon project, the city of Marseille is developing shaded, ventilated, and water-integrated "cool routes," supported by digital maps that direct residents and visitors to comfortable areas. In parallel, Marseille is also implementing a Tree Plan, according to which thousands of trees are planned across public spaces, schools, and community facilities. Together, these measures will lower reliance on electric cooling, reduce energy demand, and protect public health by mitigating heatwave risks (Covenant of Mayors, 2025.).

This five-steps action strategy, grounded in proven examples and global frameworks, provides a clear and comprehensive pathway for cities to enhance the resilience of their energy systems. By systematically assessing risks, setting clear goals, implementing robust measures, fostering collaboration, and continuously learning, cities can build energy systems that are not only more robust and adaptable to shocks but also support sustainable, equitable, and climate-neutral urban futures. In essence, the action strategy in Chapter 3 operationalizes the concepts and approaches discussed in Chapter 2, providing a practical framework for cities to enhance their energy resilience. Chapter 2 highlighted the increasing vulnerability of urban energy systems to a range of threats, including climate change, technological disruptions, and socioeconomic inequalities. It also emphasized several key characteristics of resilient energy systems, including redundancy and diversity, decentralization and distributed generation, flexibility and adaptability, robustness and reliability, real-time monitoring and control, interconnectedness and integration, and effective governance.

The action strategy outlined below is informed by ICLEI's Climate Action Approach (Figure 3) and guided by leading global frameworks and best practices integrated throughout the strategy. In line with ICLEI's Climate Action Approach, the action strategy provides a structured roadmap for cities to enhance energy resilience by systematically addressing these vulnerabilities and building upon these key characteristics (Figure 4). Step 1 and Step 2 provide guidance on assessing urban risks and vulnerabilities (Analyze); Step 3 and Step 4 provide guidance on designing and implementing measures that strengthen energy resilience while supporting the interconnectedness of energy systems with other urban systems, including water, waste, and transportation towards sustainable development goals (Act). Finally, Step 5 explains how cities can accelerate progress by building institutional coordination and aligning policies and regulations with resilience priorities. This includes cultivating partnerships across sectors, investing in local capacity, establishing dedicated offices to coordinate action, expanding these efforts and connecting them with national and international networks, campaigns, and initiatives (Accelerate).


Figure 3 ICLEI's Climate Action Approach



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## Phase 1 - ANALYZE

### 3.1 Step 1 – Comprehensive risk assessment

The foundation of any effective resilience strategy is a thorough understanding of the risks. This initial phase focuses on identifying the full spectrum of potential threats to a city's energy system.

- **Map multi-hazard risks** - Cities must conduct a city-wide assessment of climate hazards (floods, heatwaves, storms), cyber vulnerabilities, supply chain disruptions, and the condition of aging infrastructure and prepare a baseline synthesis report. Adopting an integrated risk framework, such as the one used by Seattle Public Utilities (SPU, 2019), which spans water, energy, and wastewater services, allows for a holistic understanding of interconnected risks. This process should be reflective, incorporating lessons learned from past events and considering future climate projections (IPCC, 2022; Arup, 2019).

- **Prioritize critical assets -** Cities should identify "hot spots" (e.g., key substations, data centers) and model potential cascading failure scenarios across interconnected systems. This prioritization enables focused investment in protecting the most vital components, ensuring the robustness and reliability of the system (ASCE, 2021; Ten et al., 2010). This inclusive approach is crucial for building trust and shared ownership of the resilience strategy (Arup, 2019).

- **Incorporate community insights** - Risk assessment should go beyond technical exercise. Engaging residents, utility companies, NGOs, and local businesses in participatory risk-mapping workshops, similar to the approach of Montréal's Resilience Bureau (Resilient Cities Network, 2018), ensures that social equity considerations are embedded from the outset and that the needs of vulnerable populations are adequately addressed. This inclusive approach is crucial for building trust and shared ownership of the resilience strategy.


Figure 4 Action Strategy

### 3.2 Step 2 – Goal-setting and integrated planning

With a clear understanding of the risks, cities can then define their resilience objectives and integrate them into broader planning processes.

- **Develop a cross-sector resilience plan** - Cities need to embed energy resilience into Sustainable Energy and Climate Action Plans, disaster risk strategies, and capital investment programs. Frameworks like the Resilient Cities Network (Resilient Cities Network, 2023) can guide plan formulation, ensuring a holistic and integrated approach. This integration should also account for the interconnectedness of energy systems with other urban systems, including water, waste, and transportation.

- **Articulate financing pathways** - Implementing resilience measures requires significant investment. Cities must proactively identify and secure funding through diverse mechanisms. This includes leveraging blended finance, green bonds, and public-private partnerships, drawing on resources such as the MCR2030's funding modules (UNDRR, 2024). Access to finance for climate and disaster-resilient infrastructure remains a major hurdle, particularly for cities in the Global South, where financial resources are limited, credit ratings are low, and technical expertise may be insufficient. Initiatives such as the Urban Transition Mission Center's Funding & Finance Helpdesk (F&F Helpdesk) and ICLEI's Transformative Actions Program (TAP) provide crucial support. TAP helps local and regional governments transform their sustainable development projects, including early-stage projects, into solid, investment-ready projects, helping to bridge the gap between planning and finance by improving project quality and bankability. By 2025, the TAP Portfolio features over 100 sustainable projects across the globe, 13 of which originate from UTM Cities – a testament of their growing leadership in urban sustainability. Similarly, the F&F Helpdesk assists cities in connecting them with Project Preparation Facilities (PPFs) that offer technical assistance, financial support, and capacity-building to prepare bankable projects. In addition, through its Funding Watch, the F&F Helpdesk helps UTM cities navigating available funding and financial opportunities worldwide. In 2024, the F&F Helpdesk supported the selection of urban projects submitted to the CDRI Urban Infrastructure Resilience Program, which provided financial support for feasibility studies and assessments. Strengthening urban energy systems was one of the key priorities for cities accessing the helpdesk.

## *Phase 2 - ACT*

### *3.3 Step 3 – Technical implementation*

This phase could be framed as the one that translates the plans and goals into concrete actions to enhance the physical and operational resilience of the energy system. The Arup framework's "Infrastructure and Ecosystems" dimension (Arup, 2019) and its seven qualities of resilient systems provide valuable guidance for selecting and implementing appropriate technical measures.

- **Diversify and decentralize supply -** To reduce single-point failures and enhance energy security, cities should deploy a balanced portfolio of energy sources, encompassing both renewable and conventional options (IEA, 2023), and establish microgrids for critical districts. This approach enhances the redundancy and diversity of the energy system. It also aligns with recommendations from **Pacific Northwest National Laboratory (PNNL)** on community resilience guidelines (PNNL, 2022). The development of decentralized and distributed generation, including rooftop solar, microgrids, and combined heat and power (Ackermann et al., 2001), as seen in the case of Minato Mirai 21 district, in Yokohama, can further empower local control and diminish the cascading effects of widespread grid failures.

- **Modernize and harden infrastructure -** Investing in smart grid technologies, such as automated fault detection networks, and physical hardening measures, like elevated substations and underground cabling, is crucial for improving reliability under extreme conditions. The use of smart systems in urban management enhances data collection and sharing, improving awareness of system interconnections and potential vulnerabilities. Data sharing from local utility companies increases transparency, facilitates knowledge sharing between different municipal departments, improving urban planning processes.

- **Scale storage and demand flexibility -** Balancing the variability of renewable energy sources and enhancing grid stability requires scaling up energy storage capacity and implementing demand-side management strategies. Cities should install utility-scale batteries, pumped hydro, and vehicle-to-grid systems, coupled with dynamic pricing and demand-response programs, following IEA guidance (IEA, 2021). The inclusion of smart grids, digital monitoring tools, and demand-response technologies facilitates flexibility and adaptability (Gellings, 2009; Farhangi, 2010).



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### 3.4 Step 4 – Monitoring, testing and learning

Resilience is not a static endpoint but an ongoing process of improvement. Several frameworks emphasize evaluation and adaptation, highlighting the importance of being reflective and learning from experience.

- **Deploy real-time dashboards** - To track progress and ensure accountability, cities should implement digital platforms to monitor key resilience metrics and publish them for transparency. Real-time monitoring and control systems are crucial for the early detection of potential issues and rapid response to disruptions (IPCC, 2022).

- **Conduct annual stress tests -** To evaluate system response to extreme events and identify potential weaknesses, cities should conduct annual stress tests, simulating scenarios such as cyberattacks, fuel embargoes, and climate extremes. Formulate strategies for ongoing resilience assessment and identification of system vulnerabilities, engaging relevant stakeholders in the process. Conduct regular stress testing, standardised where applicable, and routinely implement compliance testing as a standard practice. (UNDRR, 2022)

- **Institutionalize after-action reviews -** Learning from both successes and failures is crucial for continuous improvement. Cities should institutionalize post-event analyses and participate in peer-learning exchanges through networks (like ICLEI) to capture lessons learned and iteratively update their resilience strategies. Through these exchanges cities uncover (UCLG, 2025) key connections between their initiatives and wider resilience strategies, contributing to a shared understanding of practical solutions for more inclusive urban development.

## Phase 3 - ACCELERATE

### 3.5 Step 5 – Governance, policy and collaboration

Strong governance mechanisms are the backbone of a local energy resilience strategy. Creating an enabling environment is not a one-off task but an ongoing process that must accompany the strategy's implementation. Local governments play a critical role in ensuring institutional coordination, aligning policies, and fostering partnerships to embed resilience into every stage of planning and action.

- **Establish a dedicated resilience office** - To effectively coordinate stakeholders, track progress, and update plans, cities should consider forming a cross-departmental unit, modelled on Montréal's Bureau de la Résilience (Resilient Cities Network, 2018).

- **Align policies and regulations -** Existing policies and regulations may need to be updated to reflect resilience priorities. Cities should revise building codes, DER interconnection standards, and permitting processes to embed resilience criteria, guided by frameworks like the City Energy Resilience Framework (CERF) (Resilient Cities Network, 2023) and UNDRR best practices (UNDRR, 2023). Effective governance and planning are fundamental for building and maintaining resilient energy systems, requiring integrated approaches that consider long-term climate risks and uncertainties (IPCC, 2022).

- **Cultivate partnerships and capacity** - Building energy resilience requires collaboration across sectors. Cities should engage utility companies, technology providers, academia, and finance actors in long-term public-private partnerships. They should also invest in training programs and awareness campaigns to build technical skills and foster a culture of risk-informed decision-making, as emphasized by PNNL (PNNL, 2016).

- **Advocate globally** - Cities can promote their political commitments and  to resilience by participating in initiatives such as the Cities Race to Resilience campaign or Making Cities Resilient 2030. Further, Urban Transition Mission Center provides resources and a platform for collaboration for cities on the resilience of energy systems. Participation in such initiatives helps showcase best practices, gain recognition, and inspire action. Local governments can refine strategies, foster cross-boundary collaboration, and connect to global frameworks through advocacy and dialogue with key partners.

# 4 URBAN ENERGY SYSTEMS RESILIENCE ON THE GROUND: CITIES BEST PRACTICES

## BOX 7: BEST PRACTICE CASE - CITY OF QUITO, ECUADOR

Quito, Ecuador.

Credit: Photo by mehdy33300 on iStock-1151948509

Quito's municipal water utility company, EPMAPS, has developed an integrated approach to strengthen water-energy resilience by using its water pipe system to implement hydropower plants, so it can not only provide water supply, but also ensure self-sufficiency in power generation.

EPMAPS began installing hydropower plants in the 1990s - starting with the Recuperadora (14.7 MW) and later the Carmen plant (8.3 MW). Together, these facilities nowadays cover approximately 80% of its own electricity needs.

The developed mechanism enables the generation of energy through the installation of turbines in high-pressure zones within the water pipe system. This enables the production of electricity and ensures the uninterrupted flow of water. This approach has proven to be critical during grid disruption. During a major blackout in 2024, EPMAPS Papallacta Integrated System, which apport at least 45% of Quito's water demand, ensured energy supply to the National Transmission System and continued water pumping operations, preventing a citywide water shortage.



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EPMAPS is exploring diverse innovative solutions to enhance energy self-sufficiency, by leveraging its natural and built environment. Key initiatives include:

- Ongoing development of small-scale hydropower projects in high-pressure zones in existing water pipelines.
- Future plans to install solar PVs on office buildings and small facilities to support self-consumption and sell excess electricity to the city grid.
- Designing of projects aiming to install floating PV systems on water reservoir. This would reduce the evaporation and improve solar efficiency by 10–20% through water-based module cooling.

**Key stakeholders involved**

To achieve energy self-sufficiency, EPMAPS built on strong multi-level collaboration and stakeholders' engagement.

- As a water utility company, EPMAPS leads operations, and expands knowledge and expertise on hydropower and energy systems.
- Close collaboration with Empresa Eléctrica Quito ensured access to necessary permits and grid interconnection for energy projects, especially solar and small-scale hydropower.
- The Ministry of Environment and local municipal departments are involved to align solar energy projects with regulatory frameworks and gain the relevant authorisations.
- Partnerships with technical universities are also relevant. EPMAPS provide access to operational data for universities to elaborate hydroelectric systems models to improve project design and efficiency.
- Local communities are key partners, offering land access and participating in the co-management of rural microgrids and power system generation projects.

**EPMAPS Business model & financing**

EPMAPS has achieved energy self-sufficiency, reducing its electricity costs while generating revenue through surplus power production.

In fact, to further diversify its energy portfolio, EPMAPS implemented small hydropower plants and is developing new ones for commercial purposes to sell electricity and generate profits. This approach implies that when local electricity generation exceeds demand, excess power is sold to the national electricity market. While, during periods of higher electricity demand, EPMAPS maintains balance by combining electricity from distributed small-scale hydropower plants with purchases from the grid.

This flexible approach not only reduces local energy costs but also strengthens resilience by diversifying sources.

This example is drawn from discussions with representatives (Jefferson Vallejo R.) from EPMAPS, Agua de Quito, Alcadia Metropolitana Quito.

# BOX 8: BEST PRACTICE CASE – YOKOHAMA, JAPAN

Yokohama, Japan.
Credit: Photo by Victor Lu, cXmxKkyQMVk, on Unsplash

As Japan's largest city by population (3.7 million), Yokohama is a leading city toward net zero. The city is targeting to reduce greenhouse gas emissions by 50% by 2030 and reach net zero emissions by 2050, while transitioning to a circular economy.
Yokohama has limited local renewable energy production potential, estimated at 10% of the city electricity consumption by 2050, therefore, the municipality has implemented different innovative solutions to enhance energy systems resilience:

- Implementation of diverse energy mix;
- Circular energy, such as the use of methanization to convert waste into clean city gas
- Distributed solar energy, by installing panels on road, water surfaces, and public facilities for localised power;
- Smart financing (Public Private Partnerships (PPAs)) securing clean energy for public infrastructure with minimum upfront costs;
- Regional partnerships and collaboration with 17 municipalities for external renewable supply and shared benefits
- Holistic governance, empowering citizens, fostering innovation and strong leadership for adaptive energy. Its pillars are:
    - Citizen empowerment;
    - Business engagement;
    - Technological innovation;
    - City-led action.

**The case of Minato Mirai 21 district**

An example of the approach adopted is Yokohama's Minato Mirai 21 district - a central business area with over 140,000 workers - serves as a model of sustainable and resilient urban energy systems. Accounting for 10% of the business sector's electricity use in the city, the district is being transformed into a net-zero energy area through integrated solutions:

- **Distributed renewable energy:** Solar PV systems have been installed not only on buildings but also on roads and over water, expanding renewable energy generation in a densely built environment;
- **Multi-stakeholder partnerships**: The city collaborates with district heating providers and construction companies to develop high-performance, net-zero buildings, combining energy efficiency with low-carbon supply;
- **Partnership across municipalities:** Recognizing the limited local potential for renewable energy production, Yokohama has established partnership agreements with seventy municipalities to source renewable electricity generated in those areas through private companies. To ensure shared benefits, a portion of the electricity revenue is returned to the local communities where the power is produced.

This strategy not only helps decarbonize the district but also strengthens the resilience of its energy system by diversifying energy supply sources, decentralizing energy generation, and building strong inter-municipal collaboration.

This example is drawn from discussion with representatives (Tomo Anyoji) from Zero Carbon and GREEN×EXPO Promotion Bureau, City of Yokohama.



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# 5 RECOMMENDATIONS FOR CITIES

To enhance energy resilience, cities must embark on a transformative journey, **adopting a holistic and integrated approach** that recognizes the deep interconnectedness of energy systems with the very fabric of urban life. This means breaking down silos and fostering collaboration across city departments, ensuring that energy resilience is not an isolated goal, but rather a **central pillar of broader urban development strategies.**

A rigorous **risk assessment** that goes beyond simply identifying potential hazards is key for effective decision-making. Cities must delve deep to understand the vulnerabilities that threaten their energy systems, from the escalating impacts of climate change to the evolving landscape of technological disruptions, cyber threats, and socioeconomic inequalities. This requires a careful approach, **prioritizing critical assets**, and engaging diverse stakeholders, residents, businesses, and community organizations alike, to ensure that the **voices of the most vulnerable** are heard and their needs addressed.

In building resilience, cities must embrace the principles of **diversification and decentralization,** moving away from a reliance on centralized, monolithic energy systems towards more distributed and diversified models. This entails promoting a **variety of energy sources**, from the solar power and wind to the geothermal energy and fostering the development of local energy generation through rooftop solar, microgrids, and combined heat and power systems. Local governments can promote community-owned renewable energy initiatives through grants and direct investment, or through indirect means such as public procurement decisions (D'Herbemont and Roberts J., n.d) and adopt energy efficient standards for buildings which help maintain indoor space conditions (heating and cooling) during power outages (Lawson, 2018). By doing so, cities can not only reduce their vulnerability to disruptions but also empower communities and enhance local control over energy resources.

Cities should commit to **integrate energy systems planning with urban planning** to ensure that infrastructure development and energy strategies are sustainable and resilient, and secure investments in **robust and reliable infrastructure**, capable of withstanding the shocks and stresses of a changing world. In this regard, cities can use NbS, such as green roofs, urban forests, and similar, which help reducing urban heat, thereby lowering the cooling energy demand, but also providing other co-benefits. Cities must prioritize the protection of their energy systems and establish strong collaboration with utility companies to ensure the hardening of critical energy assets against extreme weather events and implementation of cybersecurity measures. Utility companies must embrace **the power of real-time monitoring and control**, easing the deployment of advanced technologies to track energy flows, and respond swiftly to disruptions, ensuring that the energy continues to flow even in the face of distress.

Cities must also cultivate a culture of **collaboration and partnership**, establishing alliances with utility companies, technology providers, research institutions, and other stakeholders. They must develop and enforce supportive policies and regulations, updating building codes, streamlining permitting processes, and incentivizing investments in resilience measures. Above all, they must prioritize energy equity, ensuring that the benefits of resilience are shared by all, particularly the most vulnerable, and that no one is left behind in the transition to a more resilient future.

Finally, the pursuit of energy resilience is a continuous journey of learning, adaptation, and improvement. Therefore, cities should establish robust mechanisms for monitoring progress, evaluating the effectiveness of their initiatives, and learning from both successes and failures. They must remain agile and adaptive, constantly updating their strategies to reflect changing conditions, emerging threats, and the evolving technology and innovation.



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