Smart Cities, Energy and Climate

Governing Cities for a Low-Carbon Future

Edited by

Oleg Golubchikov • Komali Yenneti

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Dedicated to our parents
Yuri Golubchikov and Nadezhda Dementyeva
Ramarao Yenneti and Jayalakshmi Yenneti

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Introduction: Cities in the Twin Net-Zero and Digital Transition

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1.1 The Rise of Smart Energy Cities

The future of cities is going to be *digital* and that future is also to be *low-carbon*. To use the language of modellers, there is a high confidence level that the future will be both digital and low-carbon: there are simply too many symptoms pointing us in that direction. But how can we make sense of these two dimensions of the urban future, digital and low-carbon? To what extent are they co-constitutive of one another? For example, how will the cities of the future harness digital innovations to optimise energy consumption, reduce greenhouse gases (GHGs) and achieve overall sustainability? Are those futures already shaping the cities of today? If so, what do these experiences of today tell us about the future, as much as they do about the current trends? These are some of the concerns as well as inspirations underlying this volume.

The global consensus about the need to limit global warming to 1.5 °C and global pressures for climate mitigation have far-reaching implications for cities. Accounting for GHG emissions inside and outside urban areas, the urban share of combined global CO_2 and CH_4 emissions was estimated 67–72% in 2020 (IPCC 2022). These emissions are certainly unevenly distributed across the world, with cities in high- and upper-middle-income countries contributing as much as an estimated 86% of global urban CO_2 emissions in 2015 (Mukim and Roberts 2023). However, as urbanisation is more rapid in the rest of the world, the share of cities in lower-income countries also increases. This means that cities around the world, as a 'global collective', and irrespective of their location, are seen as a key target for climate mitigation and 'deep decarbonisation' to achieve zero or near net-zero emissions (Seto et al. 2021).

Since the 'climate change problem is principally an energy problem' (MacKay 2009, p. 16) – the acknowledgement that it is fossil fuels that make the greatest contribution to GHG emission – actions addressing *energy* (reducing energy demand, switching energy provision to low-carbon supply and improving energy efficiency) are what climate governance at the

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urban level seeks to prioritise. Indeed, many socio-technical systems that contribute to GHG emissions, such as electricity systems, heating and transport, get 'densified' at the scale of the city, overlaying and interplaying with one another. Consequently, the whole variety of urban sectors and urban practices are implicated in the push for low-carbon transition: energy infrastructure, the built environment, the construction sector, industries, business and public services, transport and mobility, natural environments, waste and water management, food and other consumption practices, people's lifestyle and behavioural patterns, urban design and urban planning (Bulkeley et al. 2010; Golubchikov 2011; IPCC 2022; Seto et al. 2021).

The increasing digitalisation of society and the advent of 'smart city' add a new dimension to the urban climate agenda – the promise of leveraging digital innovation for accelerated energy transitions and decarbonisation. While there are no universal definitions for 'smart cities', the common denominator is the use of Information and Communications Technology (ICT) and automation for the improvements of urban processes, services and infrastructure (UNECE and ITU 2016). Wireless connectivity, the Internet of Things (IoT), big data and robotics have all been part of this trend, with artificial intelligence (AI) also becoming increasingly prominent at the urban scale (Cugurullo et al. 2023; Golubchikov and Thornbush 2020, 2022). Smart city has consequently gained wide currency in international practice with the promise of integration, efficiency, sustainability and people-centricity (Thornbush and Golubchikov 2020).

Smart buildings, smart water management, intelligent transport systems and smart waste management systems are a few developments that tap into digitally-enabled technologies in order to contribute to the promise of urban-scale decarbonisation. In parallel developments, energy systems are also becoming 'smart' and transitioning to net-zero and distributed/decentralised/micro-generation systems. Smart urban energy systems become an integral part of urban climate governance, offering solutions that not only optimise energy usage but also promote resilience and adaptability in the face of changing environmental and social dynamics. Smart energy systems can operate on a cross-system level, including the management of electricity via smart grids across different urban systems, or be integrated into particular urban systems, for example, buildings, with the deployment of smart energy meters, smart thermostats, battery storage, smart hot water tanks and electric vehicle charges, to name a few technologies. The relationships between providers of energy and users of energy also change; for example, enabled by smart energy systems the built environment becomes the infrastructure for energy generation and storage.

What essentially combines these various trends and developments is the notion of *smart energy cities* (Thornbush and Golubchikov 2021). Smart energy cities can be seen as part of the evolution of the city-energy-sustainability nexus, also tapping into the opportunities that digital transition brings for managing energy demand, energy supply and energy flows within urban domains, where digitally-enhanced smart cities and energy transitions represent mutually supporting processes. Combining the developments in ICT-led smart cities and sustainable energy, the notion of the smart energy city has come close to represent a digitally-mediated variant of low-carbon cities. Smart energy city, in its different manifestations, is consequently one of the central elements emerging from the discussions in the present volume.

Many cities have already incorporated smart, climate and energy targets into their strategies and plans, with a growing 'club' of cities that declare their intent to become carbon-neutral, climate-neutral, climate-smart, or net-zero in the near future. The European Union's 100 climate-neutral and smart cities (European Union 2022) or India's climate-smart cities initiative (NIUA-C3 2020) are examples of even larger-scale commitments to net-zero cities and sustainable urban development. Other cities and regions around the world are also making strides towards achieving similar goals (Bulkeley and Stripple 2021; Mendes 2022).

The technology-centred visions for net-zero and digital transitions are not without their problems, however. The smart city concept in particular has been widely critiqued for its tendency to glorify technology, where citizens become subordinate to, rather than placed at the heart of, a sustainable city project and where the city's actual needs are often circumvented by the availability of technology (Luque-Ayala and Marvin 2020). As some lines of critique suggested (Yigitcanlar et al. 2019), policymakers often opt for 'Black Box' technology solutions promoted by technology companies, rather than producing long-term visions for the 'good city'. Relatedly, the issues around social justice – in particular, how costs and benefits are distributed and who is included in smart and low-carbon urban transitions – have become an important part of academic and policy conversations (Golubchikov 2020).

In response, the concept of 'smart city' has also morphed over time: from what some now call 'Smart City 1.0' (characterised by a top-down framework, with a focus on ICT infrastructure and deploying solutions promoted by technological companies) to 'Smart City 2.0' (a people-focused, users-friendly framework) and even to 'Smart City 3.0' (a framework for inclusive and participatory urban governance, even if still technology-enhanced) (Golubchikov 2020). The active involvement of stakeholders – including citizens – in the co-creation and implementation of smart city solutions is now claimed, in theory at least, to be the key to improving transparency and incentivising society towards more sustainable practices and behaviours. With regard to technologies, instead of their uncritical deployment, there is now a search for solutions that are tailored to specific needs of individual cities and communities.

This volume further explores how cities – in particular, their energy systems – are being re-shaped by smartisation and decarbonisation (as encapsulated in the notions of the twin net-zero and digital transition and smart energy cities) and with what consequences for wider society. The volume draws together insights and case studies from across a variety of disciplines – from smart energy grids to active and energy-efficient buildings, urban design, sustainable mobility and climate policies. Another objective is to foster an understanding of what these new trends mean for urban imaginaries, urban governance and, ultimately, for urban futures.

1.2 Thematical Threads and Issues

While the book comprehensively covers the role of the 'urban' in the twin net-zero and digital transition, it also generates a number of important common threads, which can be broadly grouped into three dimensions:

- Context-sensitive and contingent urban transitions;
- Complexities and uncertainties coming from the disruptive nature of transitions; and
- The imperative of people-centrality and justice.

These threads are reviewed in this section before the structure and individual chapters are introduced in the subsequent sections.

The very magnitude of the task of transition(s) requires long-term and persistent political, economic and institutional commitments, as well as innovative, creative and often 'alternative' ways of carrying out businesses, producing and consuming goods and services. However, what complicates the landscape is that underlying factors are not merely complex, but are variegated across different localities. There are, for example, wide variations between cities in terms of population densities, climate, inherited economic structures, existing building stock, infrastructure development and capacities of municipal authorities. Besides, cities are shaped by the different national systems of regulation. This means that the transition to a low- or post-carbon city is not linear and each city has its own pathway in this transition (Castán Broto 2019; Haupt et al. 2023; Rutherford and Coutard 2014). The tensions between geographically variegated contextual complexities, technical systems and existing regulations come to the attention of many chapters in this volume (e.g. Chapters 2, 3, 5, 11 and 14).

For technological providers and policymakers, it is the scalability and replicability of different solutions (institutional or technical) that matters (e.g. Chapters 5 and 13). However, translating 'solutions' from one context into another means their de-territorialisation from the whole system of institutional, social and cultural relationships into which these solutions were embedded and re-territorialisation them into the new contexts (this is alternatively conceptualised as disembedding and re-embedding in Chapter 5). This is often problematic and limits the replicability of 'good practices'. Furthermore, technological providers develop their solutions for a universal deployment to ensure that they are deployed 'at scale' and maximise returns on investments. Local context is important, but either for experimentation and testing solutions (upstream) or as one of the many local markets (downstream), with the aim to upscale and replicate solutions across the largest possible geographical area. However, even if built on generalised and replicable solutions, the deployment of smart urbanism involves re-negotiation of these solutions with social and organisational structures and local needs and interests, which are a product of localised processes (Chapter 18). If so, the local context becomes much more than a testbed or a market – but as the place-based arena of negotiation (and often contestations) between what is seen technical and what is seen social. This can (and should) be seen as a process of transforming 'non-political technologies' into being a political, socio-technical actor, where local contexts play the role of the mediator (Chapter 2).

Related to this thread are complexities that accomplish the twin net-zero and digital transition in cities. While the transition brings disruptive changes to many existing institutions and practices, this is happening against the multi-layered palimpsest of different systems that make existing cities, including infrastructural and institutional asynchronies (e.g. different urban-scale systems having their own legacies and operational rhythms) and asymmetries (e.g. tensions between different institutional logics and interests) (e.g. Chapter 3). This makes urban systems open to alternative pathways of development; but this also means uncertainties around urban futures, including room for unintended consequences of different actions.

Many previous notions also acquire new meanings. Even the seemingly very 'mundane' urban services such as street lighting experience deep transformations with the conversion into 'smart' street lighting (Chapter 21). Energy systems in smart cities also experience new types of vulnerabilities than in the 'analogous cities'; this requires new understanding as well as approaches to reduce the vulnerabilities (Chapter 15). Blockchain and distributed ledger technology can be used to improve the reliability of smart grids, as well as facilitate new energy governance regimes such as P2P energy transactions (Chapter 17). The complexity of managing urban systems also increases with the push towards coordination of energy performance at the scale of urban districts rather than solely individual buildings (Chapter 19). Cities also need more nuanced tools for decision-making for sustainable planning and development; for example, even more traditional tools such as scenario-building and modelling need to take into account the increased complexity of the relationships between different urban systems (Chapters 8 and 9). Big data is increasingly available for modelling, but there are new types of complexities such as translating users' data into decision-making (Chapter 20). Exchange of experiences between cities and other actors is important in navigating these complexities, although such exchange may also lead to the propagation of particular narratives (Chapter 16).

Many contributors to this volume are still concerned that the consensus about reducing GHG mission is not sufficiently coordinated with the principles of distributive justice and participatory democracy, while low carbon transition is not immune of its own socio-political struggles. The imposition of particular development strategies for cities often confronts equity, affordability and civic participation. There is a clear understanding that at the core of transitions must be people, citizens and communities and their actual needs (e.g. Chapter 4). This requires no less than 'humanising' relationships in smart cities (Chapter 6), foregrounding deliberative participation and human-centred principles (Chapter 7), as well as addressing placed-based and context-specific energy needs and vulnerabilities (e.g. Chapter 14). Evidence is abundant that without redistributive policies and also without engagement with procedural/participatory justice, low carbon transitions have uneven impacts on different communities and places, with vulnerable social groups and deprived areas being left behind the benefits of transition (Chapters 10 and 12; also see Yenneti et al. 2016; Golubchikov and O'Sullivan 2020; O'Sullivan et al. 2020).

Ideas around 'energy justice' and 'just transition' offer important critique for unpacking the underlying circumstances, focusing the attention on the social costs of climate transition and the imperative of ensuring that the transition towards a climate-neutral economy happens in a fair way (Bouzarovski et al. 2023; Sovacool et al. 2013). Partly for the same reason of ensuring just transition many cities, for example, insist on retaining municipal ownership of key utilities and infrastructure, including those which are energy related. As, for example, Chapters 5 and 18 demonstrate, publicly owned vertically integrated energy providers are not only more socially accountable, but also potentially more conducive of more seamless whole-system transformations. In any case, policies need to be people-smart, prioritising, for example, low-income groups or social housing (Golubchikov 2020; Golubchikov and Deda 2012).

These threads outlined above are common but by far not exhaustive of the whole range of issues raised in this volume. The book consists of 21 chapters, including 20 chapters that follow this introductory chapter. They are divided into three parts:

Part I: Imagining smart urban energy systems;
Part II: Urban design, planning and policies; and
Part III: Technologies and data for smart and low-carbon urban futures.

Below the contribution of each chapter in these three Parts is considered in more detail.

1.3 Imagining Smart Urban Energy Systems

Part I of the book examines the different ways that smart cities, in particular smart urban energy systems, are imagined (or socially constructed) and operationalised. This Part introduces the varieties of socio-technical visions for the sustainable and smart urban futures.

Against the preponderance for one-size-fits-all approaches to smart energy transitions, with cities often framed merely as spaces for experimentation, Britton and Judson (Chapter 2) stress the importance of the geographical and historical contexts on which smart energy developments are being based. The UK government's 'smart local energy systems' (SLES) initiative, for example, emphasises the decarbonisation potential of more distributed energy systems and scalable local energy business models. Local and specific materiality of place are important for SLES in terms of developing functionality, but the overall logic is to homogenise this materiality into scalable business models. Nevertheless, the development of local public-private partnerships and initiatives around SLES already demonstrates a great deal of local divergence in terms of how different cities foreground priorities and 'internalise' SLES differently. The authors argue that national narratives prioritising market-based solutions and end-consumer benefit may conflict with these local narratives and priorities.

Holmes et al. (Chapter 3) discuss the relationships between smart city governance and inherited electricity infrastructures. Taking inspiration from science and technology studies (STS), the authors consider the electricity system as a multitude of interrelated socio-technical components, each with its specific affordances and path dependency. They unpack electricity infrastructure decision-making processes in Manchester. Their study highlights the reliance of Manchester's smart sustainable city aspirations on the material conditions of electricity connections, grid extensions and generation investment. These elements, in turn, depend on the actions of a range of different interest groups, many of whom are outside of the control of the city and even geographically located outside of the city. Local policies are circumscribed by the existing ordering and management of these electricity systems.

Ray et al. (Chapter 4) delve into the topic from the perspectives of West Africa. Physical access to basic services, including electricity, remains among key priorities for the urban poor. The use of 'smart' technologies – particularly mobile-based services or off-grid electricity – allows leapfrogging some stages in traditional infrastructure development. Leveraging technologies such as smart grids, meters and mobile phones to access and pay for energy services is one of the ways to offer services to even the poorest communities. But communities on the fringes are often left out of the debates and access to such technologies and energy services. The discourse on a smart city has rather been dominated by the urban middle class and development agencies who foster their own vision and imaginaries, often prioritising high-tech solutions rather than smartness for the 'masses'.

Rohracher et al. (Chapter 5) take up the issue of upscaling of smart grid experiments. Smart grids are expected to radically change the electricity systems, especially at the local grid level. However, how such grids will be organised in practice (including their institutional configurations) still remains to be decided, with a number of possible alternatives currently being tried in pilot or demonstration projects. Similarly to Chapter 2, the authors argue that upscaling and replicating tend to privilege standardisation and interoperability. However, implementing the same type of projects somewhere else involves cross-contextual translation or disembedding projects from their place-specific conditions and re-embedding emerging new systems into local contexts. This is nothing less than innovation in itself, which also requires mobilisation of stakeholders, as well as negotiation, contesting and reshaping new systems. The cases of two demonstration sites in Sweden (Hyllie in Malmo) and Austria (Okopark Hartberg) show that there are numerous factors which make experimentation projects highly unique and highly embedded in local contexts.

O'Sullivan et al. (Chapter 6) bring the concept of active homes into the conversation with smart city and smart energy. Enabled through ICT-based smart energy grids and in-house smart technologies, active homes have the capacity to produce and store energy, use energy more efficiently and communicate with other infrastructure (e.g. transport and industry). Active homes are also imagined as sites of improved liveability, due to the streamlining of occupant activities and daily needs by smart technologies. However, the authors argue that such assumptions are based on 'generic' occupant lifestyles and behaviours, as well as assumptions about household capability to both understand and digitally manage their energy systems. The authors identify a number of real-life challenges surrounding these imaginaries. For example, smart technologies do not necessarily work as expected; assumptions may not be completely accurate; household needs change over time; households also circumvent their smart energy system to achieve required comfort needs. This highlights the importance of appreciating the role of both occupants and other agents and intermediaries who support them.

Cugurullo and Gaio (Chapter 7) introduce another set of imaginaries – autonomous cities, where AI plays a key role. AI is enabled by traditional smart tech, but it also transcends smart cities in its capacities to learn, think and make decisions, including in normative and ethical domains. However, the authors remind us that there is no one universal AI, there are myriads of different AIs. This is important as it is erroneous to assume the same quality to all AIs, for example, whether they are sustainable or not. By the same token, the same AI can manifest itself differently in different places. The chapter specifically discusses urban mobility in the autonomous city. Autonomous cars can enable a new kind of urbanism, often of a contradictory nature. On the one hand, they may trigger even further suburbanisation; on the other, they may also help vacate parking space for other needs. One possible unintended outcome is marginalisation of cycling. The authors come to the conclusion that AI-enabled city should be rethought in a way that would open rather than close space for deliberative participation and human-centred principles.

1.4 Urban Design, Planning and Policies

Part II of the book includes chapters that are focused on interplay of climate governance, smart systems and energy transitions with urban planning, urban modelling and urban policies.

Fallmann et al. (Chapter 8) put the future city in the context of the interface between climate assessment, climate modelling and urban planning. Sustainable urban planning needs to be 'fit-for-purpose', i.e. recognise both local climate conditions and the historical development of a particular city or region. The chapter reiterates a number of practical solutions for building design, city planning and national infrastructure. It also explores the interrelationships of different urban systems. One example is that a reduced heat island effect in cities (due to adaptation to climate change) will reduce thermally driven vertical ventilation in cities; this will lead to a higher pollutant concentration. It is important that future cities at the same time work on reducing car exhausts to prevent harmful effects on health. Modelling approaches have seen a steady trend towards smaller scales and increased complexity, but the question remains how to facilitate those tools for sustainable planning and development.

Hirschl (Chapter 9) further demonstrates challenges in executing climate governance at the city level. There are no universal standards that can be applied to municipalities to establish their carbon budget. In their absence, arbitrary target years are set for achieving carbon neutrality. Contrary to many cities targeting earlier achievement of carbon neutrality (e.g. 2025–2030), Berlin lacks renewable energy and would struggle with implementing earlier energy transition goals. The chapter shows considerable hurdles for the city economy to restructure itself to accommodate climate neutrality targets. The scenarios show that achievement of climate neutrality is scarcely feasible for the 2030s, but could be done in the 2040s if considerable effort is made, including a much more ambitious rollout at the national level. There is no single sector that can undertake significant reductions on behalf of the others, but each and every sector will have to contribute to a similar extent.

Creasy et al. (Chapter 10) explore the 20-minute city ideas in the context of Edinburgh. The idea is also often connected to smart city, focusing on the decentralisation of cities by bringing essential services into neighbourhoods. However, the infrastructure development is unevenly distributed in the city, so that in combination with a socially fragmented community, the very idea confronts historic spatial and systematic environmental, economic and social justice issues. This chapter also brings examples such as Portland in the United States or Melbourne in Australia to unpack those issues and point out the importance of citizens' involvement and co-design. The chapter then uses the case of Edinburgh to show how a more inclusive 20-minute neighbourhood can be achieved. This essentially requires the development of multi-service 'hubs' located with the historic levels of service development in mind. The use of digital techniques in city analysis and planning may facilitate an understanding of where pedestrian infrastructure upgrades would have the most impact.

Sustainable and smart urban mobility should be seen as a crucial part of urban climate governance and energy transitions, which can also improve social aspects of sustainability. Garau et al. (Chapter 11) review the city-level guidance for the Sustainable Urban Mobility Plan of the Metropolitan City of Cagliari. The chapter identifies a number of gaps in the analysed guidelines, including the discrepancies between the contextual conditions of the city (such as being a maritime location) and the guidelines' actions. The authors also note the absence of info-mobility and innovative intelligent transport solutions. These gaps call for a more targeted approach to urban mobility planning that takes into account the unique characteristics and needs of a city.

India's Smart City Mission (SCM) has been the most ambitious national-level plan to address the problems of urbanisation by making 100+ smart cities. Praharaj (Chapter 12) reviews the policy. The SCM outlines area-based smart cities development components, including, principality: city improvements (e.g. intelligent traffic management, CCTVs), city renewal (e.g. urban density, mixed-use development, cycle infrastructure development) and city extension (e.g. development of urban peripheries and growth attraction). Integrated command and control centres seek to build synergies between various projects and monitor the performance of urban services and infrastructure. The author analyses existing smart city policy documents to assess the four pillars of sustainability – social, environmental, economic and institutional. The author reveals that cities have ventured into the development of a few handpicked technological fixes and the majority of investments are skewed towards exclusive enclaves. This helps little to negate regional disparities across the country and the varying levels of capacities and needs of the different scales of cities.

Ilina and Kohno (Chapter 13) take the case of Russia and investigate the relationships between national climate governance and the development of smart city solutions to tackle climate and energy issues. Cities like Moscow pioneer many technologically sophisticated solutions, with a focus on citizens and their comfort, while the federal government is central for replicating and upscaling smart city solutions from pilot cities to places across the country. The authors demonstrate that heating is one of particularly challenging areas for Russian cities. ICT solutions are also combined with more traditional urban planning solutions for climate mitigation and adaptation measures.

Della Valle (Chapter 14) discusses measures to address energy poverty, basing the analysis on behavioural science. The author argues that policy interventions cannot afford to be designed without detecting the context-specific energy needs and practices. Context-specific conditions may make people act or abstain from acting, which may be further sustained by other people's approval and disapproval. Thus, depending on the prevalent behaviour in the context, social norms may prescribe behaviours that exacerbate suboptimal conditions. Smart solutions that delegate tasks to home automation technologies and make decisions 'easy' can help make optimal choices as a 'default'; but they also reduce people's autonomy and agency. As the condition of deprivation already negatively affects how people perceive the way they control their lives, it is important that behaviour change strategies empower one's agency. For example, people can be trained to design daily environments that induce them to make optimal decisions.

1.5 Technologies and Data for Smart and Low-Carbon Urban Futures

Part III of the book addresses the disruptive potential, but also complexities and challenges, of smart technologies and other innovations, particularly with respect to facilitating low-carbon urban futures.

Strielkowski (Chapter 15) reminds the readers about the role of cities as catalysts for innovations and highlights some of the new opportunities and tensions emerging with smart energy systems within cities. As the IoT is combined with the Internet of Energy (IoE), this brings new considerations for the planning and operation of energy infrastructure. Smart cities need to maintain secure and reliable energy infrastructures that are resilient against a broad spectrum of adversities, both natural and anthropogenic. For example, with increasing digitalisation, the concept of energy security is acquiring a new meaning.

Jolly (Chapter 16) explores the role of the so-called 'field-configuring events' (industry-organised events such as special exhibitions and trade shows) in shaping common understanding and potential of smart grids. Such events not only demonstrate the latest technological trends and stimulate business networks but also propagate different narratives to disrupt the institutional status quo and to shape new agendas.

Pouran et al. (Chapter 17) discuss how the blockchain platform and distributed ledger technology can be used to ensure more transparency in carbon emission data reporting by creating a digital flow of information alongside the physical flow of fossil fuels from the source to end users. The technology can also improve the reliability of smart grid and facilitate the 'prosumer' concept in energy governance and peer-to-peer (P2P) energy transactions. The chapter concludes that in order to make this technology play a significant role in decarbonisation, the challenges related to socio-economic issues, commercial viability, legal complexities and technological shortcomings must be addressed.

Baker and Mould (Chapter 18) note that district heating was already used in the Middle Ages, but remains an attractive option for more energy-efficient and sustainable futures. The penetration of urban district heating and cooling systems is considerable in 'state-managed' societies but represents a remarkable failure in more 'liberal' economies. The impact of policy silos and the lack of a strategic approach to developing new fuel chains still remain a major hindrance for district heating and cooling networks. However, as post-carbon transition reintroduces government interventions in the energy demand-supply relationships (e.g. in the form of subsidies and regulation), a more coordinated approach may be 'retrofitted' into urban economies. This is not straightforward, however. Using the example of Denmark, the chapter stresses the legislative and ownership context for the development of the technical systems, which limits the direct replicability of 'best practices'. Furthermore, ensuring that the system is just (e.g. in terms of mitigating energy poverty) represents an additional challenge.

Reducing energy demand in buildings and improving energy efficiency measures are essential in climate mitigation. Furthermore, with global warming, there is a growing need for cooling in buildings and the use of air conditioning. Pignatta and Naderi (Chapter 19) discuss different technical and building design solutions to shift energy demand from peak to off-peak periods, to reduce energy demand, as well as to generate energy. The chapter then highlights that attention is also now being directed towards the energy performance of building complexes and districts, rather than individual buildings. This shift allows for the economies of scale to be leveraged while highlighting the role of the urban scale as an 'energy collective'. One of the key takeaways is the importance of collaboration, education, awareness and incentives in the transition to a post-carbon future through net-zero and positive energy buildings and communities.

De Souza et al. (Chapter 20) consider users' data collection and how it can inform technical decision-making. The chapter focuses on two approaches to bottom-up data collection: when data are collected by digital sensors 'on behalf' of people and when data are collected by citizen scientists using digital technologies. Through two distinct case studies from Germany and Italy, the chapter discusses some key techniques for data collection as well as the problems that technicians face when translating this data into 'useful' decision-making, which vary from data quality and inferred meaning to making a single holistic view out of disjoint data. Both case studies illustrate how bottom-up and citizen-centric data collection can help decision-making processes and reduce costs involved in data collection. The chapter ends by arguing that a set of 'standardised' guidelines on how data are to be gathered by citizen scientists is required to represent community aspirations and needs.

Finally, Thornbush and Golubchikov (Chapter 21) analyse the role of smart street lighting technologies in making energy efficiency gains. Switching to more efficient