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Citation for final published version:

Thornbush, Mary and Golubchikov, Oleg 2021. Smart energy cities: the evolution of the city-energy-sustainability nexus. Environmental Development 39 , 100626. 10.1016/j.envdev.2021.100626

Publishers page: http://dx.doi.org/10.1016/j.envdev.2021.100626

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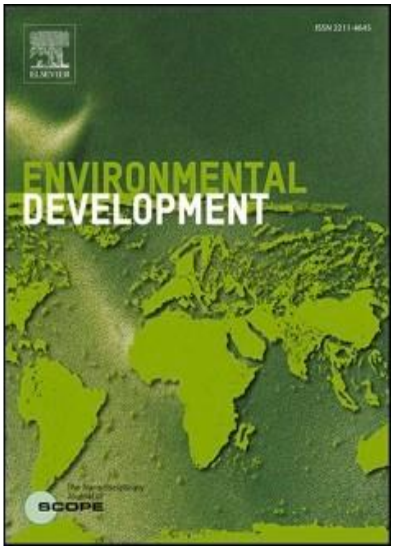

Cites as: Thornbush, M. and **Golubchikov, O.** (2021) 'Smart energy cities: The evolution of the energy-city-sustainability nexus', *Environmental Development*, 100626, doi: 10.1016/j.envdev.2021.100626

Title: Smart energy cities: The evolution of the energy-city-sustainability nexus

Authors: Mary Thornbush and Oleg Golubchikov

Abstract. This paper reviews the emergence and development of the "smart energy city" as an academic, Smart city normative, and applied concept. An examination of the academic literature since the early 2000s reveals the unfolding of spatiotemporal trends relating to this concept. It has been emerging to represent a sector-specified version of its sister concept of smart cities, also popularized in the past decade. However, the idea of the smart energy city has its own historic precursors and nationally specific trajectories. It rose from concerns with energy efficient/green buildings as well as smart grids for low carbon and distributed energy generation and distribution, which were later scaled up to the whole urban scale, and to embrace multiple other urban sectors and urban domains. By so doing, and 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. It can, thus, be conceptualized as a blend of smart cities and low carbon cities. National and urban case studies help to further distinguish "actually existing" projects, patterns, and conceptualization relating to both smart cities and smart energy cities and barriers to their practical integration. A greater focus on intersystem integration and a multistakeholder approach more recently offers a stronger representation of interdisciplinarity and conveys the complexity of the system involved, where humans and social systems become increasingly more central.

Keywords: smart city; smart sustainable city; smart energy city

1. Introduction

The rapid expansion of digital technologies – including digital communication and infrastructure and other frontier technology – has restructured many domains of social life, such as production and consumption, how people interact with each other, and how people work and behave. Technologies like high-speed Internet and mobile broadband networks, IoT, and big data play an increasingly important role in sustainability innovation. Most of these trends are more pronounced in cities due to a particular concentration of demand for these technologies in this context. Technical innovation and ICTs offer new opportunities for managing cities more effectively and holistically and transitioning towards "smart cities."

The rise of smart cities has also made its impact on the conceptualization of sustainable cities, bringing the "smart" dimension as a new claim of normativity. Over the past two decades or so, "smart cities" have proliferated as a way to build more efficient and liveable urban environments. This trajectory acknowledges the role of ICT in the making of urban infrastructure, decision making, and management systems that are more efficient, environmentally-friendly, and economically sensible. While the concept of the smart city has been certainly critiqued from many different perspectives, particularly in terms of its technocratic biases and its ambiguities (e.g. Kitchin, 2015; Cugurullo, 2018; Yigitcanlar et al., 2019; Luque-Ayala and Marvin, 2020; Thornbush and Golubchikov, 2020), it has also become more specified and particularised vis-a-vis key urban systems. One of such critical urban systems to interplay with the ideas around smart cities is *energy*.

This paper tracks the evolution of what is now termed as the "smart energy city," from its origins as a conceptualization to its more recent representations and applications. By tracking the evolution of the concept through publications in English, we discern interdisciplinary development, involving a diversity of insights. It is also possible to consider the transformation of this concept cross- temporally: from technology-driven performance and energy-efficient buildings, to low carbon urbanism and sustainability, and up to more recent articulations of smart energy cities. Of particular consideration is the national specificity of priorities governing the actual emergence of smart cities. Such an emphasis helps to better understand the deployment of the concept, which is often seen as lacking concreteness, being based on what "should be," from idealistic or normative conceptualizations, rather than on the actualities of "what is" – of which "actually existing" case studies can be illuminating.

In what follows, we start by exploring the development of the "smart energy city" from disparate perspectives. To begin with, it is necessary to recognize the role of technology that shapes "smartness" and infrastructural interconnectedness. Integrated, interdisciplinary and multistakeholder approaches are then addressed in the emergence of smart energy cities within sustainable pathways. National initiatives are considered for their specificity in terms of priorities set by different countries pertaining to the implementation of smart cities in both emerging and advanced economies.

2. Technology-driven origins

The concept of the "smart energy city" certainly represents an extension from its sister concepts of "smart city" and its variations. As noted by Albino et al. (2015), the latter emerged in the 1990s with the development of a "new ICT" that shaped modern urban infrastructure. This indicates that "smartness" in this connotation tends to depend on technology (including smart devices) that contributes toward improved urban interconnectivity and performance. However, is it possible to have a smart city devoid of technology and rather conditional on knowledge of what works to enhance performance? Anthopoulos

(2014) argued that smart cities stem from an expanding urbanization and were from the beginning defined according to the innovative use of urban spaces and, rather than merely based on ICT, based on aspects of the environment, people, living, economy, governance, and mobility (also Anthopoulos et al., 2015). Pizzo (2015) contemplated smart cities as a young mainstream idea relative to the more established concept of urban sustainability, indicating that it could be a figment of modernization. Others, such as Angelidou (2014), have classified it as either hard or soft infrastructure, suggesting nontechnological ("soft") options alongside "hard" options.

However, overall, there still seems to be a strong sense of physicality to the way that the concept has been developed based on information technology. Authors, such as Annaswamy et al. (2016), have espoused that the use of sensors is necessary to collect information about people's movements and other details that are essential in monitoring for "smart cities." As smart systems become more complex, they require intricate, stringent performance specifications, such as the real-time gathering of information concerning system behavior and for management purposes.

Examining 314 EU cities, Caragliu and del Bo (2016) found that smart city policies are more likely to appear in cities that already possess "smart potential" – as for instance in denser and wealthier cities. Their empirical results stemmed from an earlier definition by Caragliu et al. (2011), that a city is smart if "investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (p. 70). However, rather than finding their roots as green and ecocities, it has been suggested that smart cities evolve as technology for urban growth (Anthopoulos and Fitsilis, 2015).

Technology-driven smart cities can be conceived not only as the retrofitting of existing cities, but also involving entirely new developments, including greenfield sites and planned cities (Angelidou, 2014). Examples of greenfield initiatives are found in a variety of contexts, as for example in Abu Dhabi-UAE (Masdar City), China and Hong Kong (Cyberport Hong Kong), Malaysia (Cyberjaya), Portugal (PlanIT Valley), Russia (Skolkovo Innovation Center), and South Korea (Songdo International Business District; see Sonn et al., 2017). The situation in China, where more than 80 new cities are planned by 2025 (McKinsey Global Institute, 2009) is often portrayed as problematic because of the risk of producing "ghost cities," as for example reported for Bayannoao'er, Dantu, Erenhot, Kangbash, Tunnan University Campus, Zheng Zhou New District, and Zhengdong New District. This puts into question whether such initiatives are really part of sustainable development – which is how they are often framed and justified.

The technicality of the term "smart cities" also hinges upon its emergence from the literature on building efficiency that has been referred to in different ways, including energy efficient/green buildings and low carbon development. Building energy efficiency was, for example, addressed by Battista et al. (2014) by looking at energy demands, using energy savings to evaluate interventions. Such studies are focused on a single building rather than as part of a city or an entire city. However, more recent studies examining entire city districts (e.g., Deakin and Reid, 2018) convey an energy saving of 65% and 78% of CO_2 reduction associated with retrofitted micro (smart)gridding. The Specification and Description Language (SDL) model, among other models can help the "smart home" achieve its potential as "a house where almost everything can be controlled [using hardware and software], including the windows, doors, temperature, etc." (Casas and Casas, 2017, p. 12).

The term "*smart energy city*" has arisen in parallel with these developments, notably since at least the turn of the 2010s in connection with the energy-relevant components of smart cities. This is certainly to recognize the core role that energy plays in urban systems (Castan Broto, 2019). Übelmesser et al. (2020), for example, have offered the following definition for smart energy city (SEC): "*SEC is a concept at the core of the smart city, that uses technology, including ICT, to address the challenges of increasing urban energy demand and climate change, while ensuring the quality of life of its citizens … the SEC uses ICT to integrate different domains, resulting in a holistic view of the energy system*" (p. 1). In one of the most comprehensive studies on this term to-date, Mosannenzadeh et al. (2017a) offered the following definition: "*Smart energy city development is a component of smart city development aiming at a site-specific continuous transition towards sustainability, self-sufficiency, and resilience of energy systems, while ensuring accessibility, affordability, and adequacy of energy services, through optimized integration of energy conservation, energy efficiency, and local renewable energy sources*" (p. 57).

While presenting certain differences, it is clear from both of these definitions that the smart energy city model is closely associated not only with smart cities, but also with the idea of the climate-neutral city (Golubchikov, 2011) and its variants – such as post-carbon, low carbon, and net-zero cities. What is yet different is that the latter is now enveloped into a distinctive "digital skin" (Rabari and Storper, 2015) pertaining to ICT/smart city development. Here, smart energy cities can be seen as a blend of smart cities and low carbon cities.

Indeed, while discussing smart energy cities, an important focus has been placed on ICT-mediated energy flows (e.g. smart grids), along with the switch to renewable and distributed energy generation as well as district heating (DH) grids (Dominkovi´c et al., 2017). But more than power and heat generation and distribution, the focus on energy transcends many sectors of cities – such as industry, buildings, transport, food, waste, other municipal services, people's lifestyle and consumption, and urban planning more generally (Thornbush and Golubchikov, 2020). This requires insights not only on specific urban sectors, but also across them. This is important in light of the recognized role of cities in responding to climate change (Bulkeley et al., 2012), particularly where municipal governance (Broto and Bulkeley, 2013) and low carbon policies and targets at the urban level are concerned (Table 1).

An integrated focus for the smart energy city has, thus, been advocated that includes heating and cooling as well as electricity, but also buildings, industry, transportation, and other sectors and infrastructures (e.g. Lund et al., 2017; Mosannenzadeh et al., 2017a). This, however, still poses a challenge, given that different urban systems traditionally follow different organizational models of management and operation – with little connection between them in practice. The interoperability of urban subsystems based on the advancement of smart cities technologies (e.g. city operation systems) is considered as an important mechanism of the integrated approach.

3. Towards a more holistic and multistakeholder approach

An integrated approach tallies well with a more holistic, broader sustainability lens on smart energy systems, making urban systems part of global strategies to tackle the challenges prevalent in the 21st century, while also addressing livability – and even moving towards what Golubchikov (2020) has termed "people-smart sustainable cities." Oberti and Pavesi (2013) discussed the challenge of expanding urban areas and the need to improve the quality of life for citizens through the integration of technology in smart cities to promote efficiency as well as sustainability. Perboli et al. (2014) have encouraged the monitoring and benchmarking of smart cities initiatives in order to define similar projects and create coherence and assess their effectiveness so that we can learn from them. This has been expressed by others as the notion of the "actually existing" smart city, that deviates from an emphasis on merely paradigmatic (and to many authors, controversial) "smart cities," such as Living PlanIT Valley, Masdar, and Songdo (Shelton et al., 2015).

Schmidt et al. (2012) stipulated the integration of intelligent thermal networks to connect the smart city concept with urban planning and urban energy systems, including supply-demand management. By adopting such a “futuristic approach” to solving the challenges triggered by population growth and increasing urbanization (Sujata et al., 2016), it is possible to improve socioeconomic development and the quality of life in cities as they become more efficient and sustainable. This is made possible with monitoring and integrated functionality to optimize resources based on pillars that include economic, legal, management, social, technology, and sustainability.

According to Mosannenzadeh et al. (2017a), the smart energy city uses opportunities in technology, but also economy, to improve the quality of life for citizens. It also addresses energy challenges associated with climate change, energy resources, and infrastructure.

Table 1

Examples of targets for climate-neutral cities.

100% Renewable energy targets	Climate neutrality targets
100% renewable energy targets – either for municipal operations or city- wide (ICLEI, 2020) – in the majority of cases, targets are restricted to electricity use, but occasionally cover heating and cooling, transport, and other end-use sectors	Copenhagen (Climate Plan) – world’s first carbon-neutral capital city by 2025 (City of Copenhagen, 2012); Uppsala’s Fossil Fuel Free 2030 – Climate Positive 2050 plan (Uppsala kommun, 2020); Barcelona, Paris, Berlin – target to become climate-neutral by 2050
Germany – 150 districts and cities adopted 100% renewable electricity targets, including Hamburg and Munich (by 2025) and Frankfurt (by 2050); Hassfurt achieved 100% renewable electricity in 2017 and aims to scale up renewables in other sectors, as by expanding its district heating capacity	Pledges to become carbon-neutral include Boulder, San Francisco, Glasgow, and Oslo (by 2030), Helsinki (by 2035), Stockholm (by 2040), Amsterdam, Hamburg, London, Toronto, Vancouver, Minneapolis, New York City, Portland, Seattle, Washington DC (by 2050) – according to the Carbon Neutral Cities Alliance (2019)
In the US, several cities transitioned to 100% renewable power, including Aspen (Colorado), Burlington (Vermont), and Greensburg (Kansas), according to REN21 (2019, p. 53)	REN21 (2019) listed cities that have introduced city-wide net-zero/carbon-neutrality targets by 2050 or earlier: Montreal, Heidelberg, Bristol, Manchester, Nottingham, Austin, Boston, and Los Angeles

Their conceptualization from a multistakeholder approach integrates new technologies for sustainable and collaborative smart energy city development that is capable of providing combined (common and comprehensive) and practical smart energy solutions.

Salvia et al. (2016) recognized the function of smart cities in the making of sustainable and resilient cities and noted new business models promoting community participation. The community level was also examined by Ceglia et al. (2020), who envisioned the role of multidisciplinarity in shaping both technical and socioeconomic aspects associated with territorial planning. Such a “smart energy community” is regarded as essential to establishing sustainable renewable energy systems, affecting energy storage and sharing, as well as instigating economic efficiency and viability. As regards data sharing, however, there are emerging concerns regarding data privacy, as there are the implications for planning and operating technologically monitored systems of coordination, management, and control (Thornbush and Golubchiov, 2020). This leads to the questioning of what is private versus public and, therefore, what should remain in private or public domains.

Having multiple stakeholders involved in upholding the emergence of smart development helps to foster an interdisciplinary perspective that is evident in the sustainability framework adopted. However, because of the ICT lead on smart development, early attempts for such an interdisciplinary approach were limited by technological stances at the expense of the citizen and social dimension. More recent research addresses social dimensions (cf. Thornbush et al., 2013), such as socioenvironmental justice and digital citizen participation/community engagement within social sustainability (e.g. Bouzguenda et al., 2019). This is facilitated through an interdisciplinary approach that allows different stakeholders (and sectors) to be represented and act together to define and develop smart development.

4. National varieties

In the absence of international agreement on the development of smart cities, countries and, in many cases, only cities are responsible for their own priority-setting and specifications. Italy, for instance, has dedicated much to this effort, where cities like Bari (Paris and Bagnato, 2012) are headlined as having a strategic plan for their transformation as sustainable cities and for smart development. Along with more than 250 European cities, Bari is aiming to improve the quality of life, while reducing energy consumption and resource use. Albino et al. (2015) conveyed the Italian strategy to use smart city indicators as part of a sustainability approach to urban development.

American cities, such as Baltimore, have a performance strategy based on five features and 20 featural subtraits of CitiStats (Abramson and Behn, 2006). Such a performance-based approach to establishing smart cities demonstrates the emphasis on data collection for functionality and performance assessment. Another initiative has been SusCity, which focuses on urban interventions in Lisbon, Portugal, including with respect to energy systems (Aelenei et al., 2016). Urban energy systems have been delineated as energy efficient buildings, but also as urban energy networks and from the framework of supply technologies in more integrated and application-oriented approaches. The focus has been, for example, on smart mobility, smart buildings, and smart grid solutions.

In Spanish Smart City initiatives, six clusters were deployed to classify city projects, including mobility, economy, environment, government, living, and people, with 62 cities (having over 50,000 inhabitants) included in the network of Spanish cities (RECI) (Aleta et al., 2017). This has converged on smart mobility and environment in the +CITIES project, with smart environment assessed through energy and water consumption efficiency as well as reduced emissions. These authors discovered Barcelona and Madrid among the top-rated cities, with Valencia being top in mobility – the latter was established based on alternative modes, ICT traffic control, integrated payment, and sustainable mobility plans. According to Aleta et al. (2017), Spanish smart cities are successful in terms of mobility and the quality of life.

The scale of application of smart energy city ideas varies from that of individual buildings to entire neighborhoods and from historic districts to new developments or “new metropolitan areas” (Antoniucci et al., 2015). Consideration of smart grids to connect buildings is a basis for shared energy production and management, removing the isolation of urban areas and especially tall buildings. Integrated systems have been specifically recognized in Genoa as a demonstrator city (Borelli et al., 2015), where there is smart recovery (and smart systems integration) of waste energy through the Combined Efficient Large Scale Integrated Urban Systems (CELSIUS) project based in five European cities (Cologne, Genoa, Gothenburg, London, Rotterdam).

Some believe in small technological improvements to cities without them becoming actual smart cities. Gradual (or slow) evolution into a smart city is possible by becoming resilient first and then more technologically advanced to merit "smart city" status. This is made possible through a potentially piecemeal upscaling, from buildings to ultimately encompass entire cities. This has been advocated by Cellucci et al. (2015), who thought of inputs to the smart grid through an electrical system that provided smart lighting to a small town on the Italian coast. Through retrofitting intervention, these authors introduced new services through ICT without evoking deep changes, conveying the possibility of smart-grid planning at the town scale.

Comodi et al. (2016) have likewise promoted the use of smart electricity in Italian cities, as through electric mobility, namely electric vehicles (EVs), whose implementation will depend on the availability of charge stations. This can be managed by local grids that have invested in infrastructure to accommodate such vehicles, which the authors found to be a profitable investment with a payback period of 4–5 years. As in the Lazio region of Italy, balanced energy production and consumption is a necessary precursor to the evolution of efficient urban cells and energy network optimization and integration – and the basis for development as smart energy cities.

Since urban energy use represents some two-thirds of global primary energy consumption, it is not only vital that cities become increasingly more energy efficient, but also that renewable energy sources (e.g., rooftop PV) are exploited wherever possible, and that modern technology is deployed (e.g., EVs), along with the citizen awareness required to reduce energy consumption. This has been envisioned for Sweden (Vassileva et al., 2016, 2017), for instance, where energy savings and reduced emissions are being addressed through technology, such as smart meters and EVs – although raising information to citizens to augment their awareness of such options still needs work.

A framework energy plan is required for smart energy cities, as in the Reininghaus District (Maier, 2016) – a former brewery in the city of Graz, Austria – that uses optimal energy technology networks operating on decentralized technologies and considered to be financially most feasible for new buildings, so that this functionality can be implemented at the building scale. In a summative way, in such ways, smart energy districts become a part of smart energy systems making up these smart energy cities.

5. Barriers to smart growth

Some of the barriers that have been identified in the development of smart cities have revolved around financing and governance. Mosannenzadeh et al. (2017b) examined the implementation of smart energy city projects in Europe and, based on 43 communities of initiatives, found key barriers stemming from fragmented political support and project ownership, lack of external funding and skilled personnel, as well as poor cooperation in project partnerships. These problems stem from piecemeal development, necessitated by limited financial and political support as well as expertise (e.g., Yu et al., 2017) and innovation (e.g., Zygiaris, 2013), that constrain the formation of actually smart cities around the world (refer also to Golubchikov and Thornbush, 2020).

The review by O'Dwyer et al. (2019) captured the challenges associated with imposed barriers, as when dealing with stakeholder networks while considering design and systems operations (e.g., the energy management system – see their Fig. 2, p. 592). Their article conveys the complexity of implementing technology alongside the decision-making framework, among other interacting factors that make it multifaceted as part of the smart energy systems.

Many authors have recognized the importance of economic development in driving smart cities, although this alone is not the only component, and both sustainability and economic competitiveness could come together through an urban focus (Monfaredzadeh and Berardi, 2015). Otherwise, as indicated by a review by Yigitcanlar et al. (2019), it becomes difficult to make smart cities sustainable.

Contemporary initiatives are gearing more from city to regional scale, so that the global scale will eventually be reached – although that remains in the future (see also Golubchikov and Thornbush, 2020). When scaling up from the building scale, we have been cautioned against a building-centric approach, which can be circumscribed in its ability to encapsulate sustainability from a citizen perspective (Berardi, 2015). Golubchikov (2020) has similarly introduced the notion of "people-smart sustainable cities," which is more equity-oriented.

6. Conclusions

The literature reviewed here has encompassed several themes. First is the evolution of the concept of smart energy cities. The temporal dimension through which the concept has evolved (and continues to emerge) can be summarized by the following trends:

- Since the early 2000s, there has been a focus on buildings and smart grids that has been upscaled to the city level and multiple urban sectors at the end of that decade.
- In parallel, there emerged a strong focus on low carbon urban futures, with policy support from climate change.
- "Smart energy cities" is a more recent development since the 2010s that is rooted both in the development of the "smart city" ideas and in a sustainability framework; and the concept has developed to represent digitally-enhanced low carbon cities.

The city scale is the most congruent, especially as mayors have taken control of the inception of smart cities, devising strategies for their implementation and growth. Such "piecemeal" development makes it difficult to discern trends at the global scale. At the building scale, however, many studies have supported energy efficiency in buildings and represent the early foundation of the smart city through efforts at this scale operating towards reaching energy efficiency from building scale on up.

The evolution of the concept represents an environmentally-adapted perspective on the city that has evidently emerged from the sustainable city. More integration offers a greater representation of the interdisciplinarity of the work and also conveys the complexity of the system involved, where humans are more central in the smart environment.

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