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Data-driven smart eco-cities and sustainable integrated districts: A best-evidence synthesis approach to an extensive literature review

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Abstract

As materializations of trends toward developing and implementing urban socio-technical and enviro-economic experiments for transition, eco-cities have recently received strong government and institutional support in many countries around the world due to their ability to function as an innovative strategic niche where to test and introduce various reforms. There are many models of the eco-city based mainly on either following the principles of urban ecology or combining the strategies of sustainable cities and the solutions of smart cities. The most prominent among these models are sustainable integrated districts and data-driven smart eco-cities. The latter model represents the unprecedented transformative changes the eco-city is currently undergoing in light of the recent paradigm shift in science and technology brought on by big data science and analytics. This is motivated by the growing need to tackle the problematicity surrounding eco-cities in terms of their planning, development, and governance approaches and practices. Employing a combination of both best-evidence synthesis and narrative approaches, this paper provides a comprehensive state-of-the-art and thematic literature review on sustainable integrated districts and data-driven smart eco-cities. The latter new area is a significant gap in and of itself that this paper seeks to fill together with to what extent the integration of eco-urbanism and smart urbanism is addressed in the era of big data, what driving factors are behind it, and what forms and directions it takes. This study reveals that eco-city district developments are increasingly embracing compact city strategies and becoming a common expansion route for growing cities to achieve urban ecology or urban sustainability. It also shows that the new eco-city projects are increasingly capitalizing on data-driven smart technologies to implement environmental, economic, and social reforms. This is being accomplished by combining the strengths of eco-cities and smart cities and harnessing the synergies of their strategies and solutions in ways that enable eco-cities to improve their performance with respect to sustainability as to its tripartite composition. This in turn means that big data technologies will change eco-urbanism in fundamental and irreversible ways in terms of how eco-cities will be monitored, understood, analyzed, planned, designed, and governed. However, smart urbanism poses significant risks and drawbacks that need to be addressed and overcome in order to achieve the desired outcomes of ecological sustainability in its broader sense. One of the key critical questions raised in this regard pertains to the

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very potentiality of the technocratic governance of data-driven smart eco-cities and the associated negative implications and hidden pitfalls. In addition, by shedding light on the increasing adoption and uptake of big data technologies in eco-urbanism, this study seeks to assist policymakers and planners in assessing the pros and cons of smart urbanism when effectuating ecologically sustainable urban transformations in the era of big data, as well as to stimulate prospective research and further critical debates on this topic.

Keywords: Eco-cities, Smart eco-cities, Data-driven smart eco-cities, Sustainable integrated districts, Urban planning, Urban management, Smart governance, Eco-urbanism, Sustainable urbanism, Sustainability, Data-driven technologies

Introduction

Urbanization is creating greater pressure on limited resources. Already, cities consume more than 75% of the natural resources available globally. This is estimated to increase by 90 billion tons by 2050 compared to 40 billion tons in 2010 [1]. As an irreversible global trend, urbanization involves a multitude of environmental, economic, social, and spatial conditions, which pose unprecedented challenges to politicians, policy makers, and planners. Nonetheless, it can have many positive outcomes by creating changes out of these challenges and as a response to external factors. These changes provide great opportunities for advancing sustainability in terms of applying innovative technologies to use resources more efficiently and control them more safely, to promote more sustainable land use, and to preserve the biodiversity of natural ecosystems and reduce pressure on their services, with the aim to improve economic and societal outcomes. In a nutshell, cities across the globe hold the potential to maximize the benefits of urbanization and offset its negative consequences by relying on emerging and future information and communication technology (ICT). In fact, urbanization has become a popular discourse in urban policy and academic circles across the world due to the rising popularity of smart urbanism and its potential role in advancing urban sustainability.

As cities represent part of the problems and solutions in the quest for sustainability, they can function as one of the keys in the required transition toward sustainability thanks to their configuration and innovative potential. Therefore, numerous stakeholders and institutions have devoted much attention to sustainable development and allocated tremendous resources in an attempt to incorporate the ideas and visions of sustainability into the reality of cities. In fact, the increased pressure on cities has led to a stronger need to build sustainable cities that last. Designing sustainable cities of the future, educated by the lessons of the past and anticipating the challenges of the future, entails articulating a multi-scalar vision and these key principles—energy, ecology, infrastructure, waste, water, livability, mobility, accessibility, economy, and culture—while responding to major societal and intellectual trends and paradigm shifts in science and technology [2]. Sustainable cities have been the leading global paradigm of urbanism, and eco-cities are one of the most advocated models for sustainable urban development [3]. To totally change the pattern of urban development, and to implement the development strategy of the eco-city, is the most effective way to create sustainable development [4]. Therefore, eco-city projects are becoming increasingly prevalent in policy, environmental, and political-economic discourses worldwide and thus gaining strong momentum in research agendas in various disciplines (e.g., [5–7]; Simon and Molella [8–10]). It is important to take modern ecological civilization and ecological restoration to guide and manage all economic and social activities of the city. Especially, cities have become a focal point for efforts to transition toward a more sustainable, low-carbon society, with many city government or municipal agencies championing eco-city or eco-district initiatives of one kind or another.

In recent years, the development of sustainable urban districts, especially eco-city districts, has attracted increased interest and become an expansion route for many growing cities (e.g., Joss 2015 [11–13];) as well as a common way to address and implement sustainability in the built environment (Joss 2015 [11, 14]). However, the development of new sustainable urban districts is often subject to more rigorous sustainability objectives with respect to their evaluation in order to meet future challenges [13]. As a result, a recent wave of research has started to focus on improving the performance of eco-cities by partly or completely integrating their green design principles and environmental technology solutions with the design strategies of compact cities (e.g., [3, 15–17]). This relates to the mission of Urban Ecology as to creating eco-cities based on a number of principles [18] that are intended to achieve the goals of sustainability. This is at the core of emerging Eco-Compact or Eco-Density initiatives, which are seen as an unprecedented planning effort and a response to the deconcentration of land use due to urban sprawl. Accordingly, these initiatives use density, mixed-land use, and sustainable transportation as catalysts toward livability, affordability, and environmental sustainability. They aim to deliver more efficient land use, improve green energy systems, and build resilient and adaptable urban communities. Recent research within eco-urbanism tends to focus on the three dimensions of sustainability in terms of benefits and shortcomings (e.g., [19, 20]; Khan et al. 2020 [21, 22]). This relates to the integrated models for urban development, which explore the development of sustainable integrated districts (SIDs) as a model for high-density, high-liveability cities.

With the above in mind, the eco-city continues to strive toward reaching the status of urban sustainability by reducing material use, lowering energy consumption, mitigating pollution, and minimizing waste, as well as improving social equity, well-being, and the quality of life. Eco-urbanism has taken on a salient position in policy and political discourses focused not only on the environment, but also on economic, social, and technological transitions (e.g., [6, 7, 19, 23]; Khan et al. 2020 [21, 24]). The motivation for achieving the Sustainable Development Goal (SGD) 11 of the United Nations' 2030 Agenda—Sustainable Cities and Communities in terms of making cities sustainable, resilient, inclusive, and safe [25] has increased the need to understand, plan, and manage eco-cities in new and innovative ways. These are increasingly based on more advanced forms of ICT, especially the Internet of things (IoT) and big data technologies. The United Nations's 2030 Agenda regards advanced ICT as a means to promote socio-economic development, restore and protect the environment, increase resource efficiency, upgrade legacy infrastructure, and retrofit industries based on sustainable design principles [26]. This relates to the multifaceted potential of smart cities with respect to the growing role of big data technologies and their novel applications in strategic sustainable development. The main objective of the smart city is achieving heightened economic development, the quality of life, and different sustainability targets through the use of data and technology (e.g., Ahvenniemi et al. [27–32]). The explosive growth of urban data, coupled with their analytical power, opens up new windows of opportunity for innovation in eco-cities. This means finding more effective ways of incorporating sustainability into the physical, spatial, environmental, economic, and social forms of eco-cities.

The conscious push for eco-cities to become smarter and thus more sustainable in the era of big data is due to the problematicity surrounding their development planning approaches and operational management mechanisms, as well as their governance models. This has had a clear bearing on their performance with respect to sustainability. In order to deal with these problems, issues, and challenges, advanced forms of ICT are required. The underlying argument is that more innovative smart solutions are needed to enable eco-cities to tackle the kinds of complexities and conundrums they embody. In fact, smart technologies are socially constructed as the response to almost every facet of the contemporary urban questions [33], and smart urbanism is being represented as a panacea to the majority of problems facing contemporary cities. As enacted by national governments, supranational agencies, and technology companies, the discourse of smart urbanism claims a supremacy of urban digital technologies for managing and controlling infrastructures, achieving greater effectiveness in managing service demand and reducing carbon emissions, developing greater social interaction and community networks, providing new services around health and social care, and so on [34].

Therefore, eco-cities across the globe are increasingly embracing and leveraging what smart cities have to offer in terms of advanced ICT, especially big data technologies and their novel applications, in an effort to monitor, evaluate, and improve their performance with respect to sustainability, especially its environmental and economic dimensions (e.g., [23, 35–44])—under what has been termed "smart eco-cities" or "data-driven smart eco-cities." It has become increasingly feasible to attain important improvements of sustainability by integrating eco-urbanism and smart urbanism thanks to the proven role and untapped potential of data-driven technologies for maximizing the benefits of sustainability. This pertains to the question involving the weak connection between sustainable cities and smart cities as prevalent models of urbanism and their extreme fragmentation as landscapes, both at the technical and policy levels, adding to their opposite conceptual characteristics and existing tensions (e.g., [3, 29, 45–49]). An "either/or" approach will hamper progress toward urban sustainability, as the huge challenges facing eco-cities within many of their administration spheres (transport, traffic, mobility, energy, environment, waste, healthcare, public safety, etc.) require an integrated approach to urbanism.

The emerging area of data-driven smart eco-cities is a significant gap in and of itself that this paper seeks to fill together with to what extent the integration of eco-urbanism and smart urbanism is addressed in the era of big data, what driving factors are behind it, and what forms and directions it takes. Employing a combination of both best-evidence synthesis and narrative approaches, this paper provides a comprehensive state-of-the-art and thematic literature review on sustainable integrated districts (SIDs) and data-driven smart eco-cities. The value of this review resides in its topicality, thoroughness, substantive nature, as well as original contribution in the form of new insights and perspectives as a result of synthesizing a broad range of literature characterized by various disciplinarities.

The remainder of this paper is structured as follows: "Research Methodology" section details and justifies the literature review methodology. "Conceptual, theoretical, discursive, and practical foundations of eco-city/eco-urbanism" section describes and discusses the conceptual, theoretical, discursive, and practical foundations of eco-city/eco-urbanism. "Analysis, evaluation, synthesis, and discussion" section provides a thorough analysis, evaluation, synthesis, and discussion of the emerging phenomena of SIDs and data-driven smart eco-cities. "Knowledge gaps in the area of data-driven smart eco-cities" section identifies and enumerates the relevant topics related to the key knowledge gaps in the area of data-driven smart eco-cities. Finally, this paper concludes, in "Conclusions" section, by providing a summary of the key findings, highlighting the main contributions, and suggesting some future research directions.

Research Methodology

Interdisciplinarity and transdisciplinarity

Research review has long been one of the most important scholarly activities in all academic disciplines or branches of science. This literature review analyzes, evaluates, synthesizes, and discusses a large body of research done on the burgeoning field of data-driven smart eco-urbanism. In doing so, it draws on a number of city-academic or scientific disciplines and their integration and fusion, as well as on practical insights from numerous case studies.

Interdisciplinarity and transdisciplinarity have become a widespread mantra for research within diverse fields, accompanied by a growing body of scholarly publications. The research field of data-driven smart eco-urbanism is profoundly interdisciplinary and transdisciplinary in nature. It operates out of the understanding that advances in knowledge necessitate pursuing multifaceted questions that can only be resolved from the vantage point of interdisciplinarity and transdisciplinarity. This in turn implies that the research problems within this field are inherently too complex and dynamic to be addressed by single disciplines. This is clearly reflected in the literature on eco-cities and smart eco-cities in the era of big data.

Accordingly, the interdisciplinary and transdisciplinary approaches to scholarly research apply by extension to the review of this literature. The former insists on mixing disciplines, and crosses boundaries between different disciplines to create new perspectives and insights on the basis of interactional knowledge beyond these disciplines. Its strength lies in the ability of interlinking different analyzes using insights and methods from different disciplines in parallel and spilling over disciplinary boundaries. The latter insists on fusing different disciplines and thus using insights and methods from these disciplines in conjunction—with a result that exceeds the simple sum of each of them. Transdiciplinarity concerns that which is at once between, across, and beyond single disciplines.

Approaches and objectives

Reviews are generally categorized into different types, each with own qualities and perspectives on reviewing a topic, namely systematic review, best-evidence synthesis, narrative review, meta-analysis, scoping review, umbrella review, and rapid review. As a rigorous approach, a systematic review is best suitable for focused topics, which is not the case for data-driven smart eco-cities and SIDs. Indeed, this emerging area of research involves multifaceted questions and remarkably heterogeneous research programs. As regards the narrative approach to literature review, which is applied in this study, it is of a wide scope and non-standardized nature and does not follow an established procedure. A narrative review summarizes different primary studies from which conclusions may be qualitatively drawn into a holistic interpretation contributed by the reviewers' own experiences, existing theories, and models [50]. It also proposes to comprehend the diversities and pluralities of understanding around scholarly research [51, 52]. Narrative reviews are best suitable for comprehensive topics [53].

As regards the best-evidence synthesis approach to literature review, which complements the narrative approach in this study, it draws on a wide range of evidence and explores the impact of context. As such, it brings together all relevant information on a research topic. This can be useful to identify gaps in knowledge, establish an evidence base for best-practice guidance, or help inform policymakers and practitioners. Furthermore, the best-evidence synthesis approach offers an alternative to a narrative review, giving attention to substantive issues of a narrative point of view, adding a rational for study-selection and effectiveness of treatment, and emphasizing the importance of well-justified inclusion criteria [2]. By providing the reader enough information about the primary research, they must be able to reach independent conclusions, as far more information is extracted from a large body of literature by clearly describing the best evidence on a topic. Overall, this study intends to demonstrate the usefulness of combining the two substantive categories of literature review.

Generally, there are different objectives of literature review, including methodological, theoretical, thematic, and state-of-the-art. This literature review is concerned with the state-of-the-art and thematic objectives. The former considers mainly the most current research and summarizes emerging research priorities and academic trends in the field. It provides a critical survey of the extensive literature produced in the past decade or so, a synthesis of current thinking in the field, and also offers new perspectives. The latter describes particular areas of the literature (e.g., emerging models of urbanism), where the intent of the outcome is to identify weaknesses and disseminate the path toward improvements. It also provides an in-depth examination of the principles underlying the phenomenon under study through the evaluation of its objectives.

Hierarchical search strategy and scholarly sources

A literature search is the process of querying quality scholarly literature databases to gather the research publications pertaining to the topic under review. A search strategy was used, covering several electronic search databases, including Scopus, ScienceDirect, SpringerLink, and SageJournals, in addition to Google Scholar. The main contributions came from the leading journal articles. The hierarchical search approach adopted consists of:

- searching databases of reviewed high quality literature;
- searching evidence-based journals for review articles; and
- routine searches and other search engines.

In addition, the collection process is based on Scott's (1990) four criteria for assessing the quality of the targeted material, namely:

1. Authenticity: the evidence gathered is genuine and of unquestionable origin.
2. Credibility: the evidence gathered is free from error and distortion.
3. Representation: the evidence obtained is typical.
4. Meaning: the evidence gathered is clear and comprehensible.

Selection criteria: inclusion and exclusion

To find out what is known about the field of data-driven smart eco-urbanism, the above search approach was adopted with the objective to identify the relevant studies addressing the various strands of research within this field that cover the questions being addressed. Accordingly, the preliminary selection of the available material was done in accordance with the problems under study. In this respect, it is feasible to refine and narrow down the scope of reading, although there may seem to be a number of information sources that appear to be pertinent to the topic on focus. With that in mind, for a document to be considered as to its potential to provide any information of relevance, it should relate to one of the conceptual subjects and thematic categories specified in regard to the questions being addressed. The focus was on the documents that provided definitive primary information, typically from the following scholarly perspectives:

- Cross-disciplinary: viewing one discipline from the perspective of another
- Interdisciplinary: integrating knowledge and methods from different disciplines based on a synthesis of approaches
- Transdisciplinary: creating a unity of intellectual frameworks beyond the disciplinary boundaries

Overall, scoring the documents to be selected was based on the inclusion of the problems being addressed, though to varying degrees with respect to the conceptual subjects and thematic categories decided on. The latter was meant to emphasize the quintessential aspects of data-driven smart eco-cities and SIDs. Conversely, the documents excluded were those that did not meet the specific criteria as regards their relevance to the questions being addressed. Nonetheless, a few of these documents provided some insights related to the paradigms of urbanism underpinning data-driven smart eco-cities as an integrated model. Furthermore, the abstracts were reviewed to assess their pertinence to the topic on focus, as well as to ensure a reliable application of the inclusion and exclusion criteria. Inclusionary discrepancies were resolved by the re-review of the abstracts. The process allowed to further refine and narrow down the scope of reading.

The keywords searched for included "eco-cities," "compact cities," "sustainable cities," "smart eco-cities," "data-driven smart cities," "data-driven smart sustainable cities," "sustainable urbanism," "eco-urbanism," "smart urbanism," "data-driven urbanism AND sustainability," "sustainable urban districts," "urban planning AND big data technology," "data-driven solutions AND eco-city," "smart planning AND eco-city," "data-driven management AND eco-city," "smart city governance," "smart governance AND eco-city," and "eco-modernization AND eco-city." These were used to search against such categories as the articles' keywords, title, and abstract to produce some initial insights. Due to the limitations associated with relying on the keyword approach, backward literature search (backward authors and backward references) and forward literature search (forward authors and forward references) were used, when appropriate, to enhance the search approach.

Purposes and organizational approaches

The literature review is typically performed for various purposes. This depends on whether it is motivated by, or an integral part of, a research study and thus its scope or area of focus. This explains the extent to which the research area will be explored in the study, which basically means defining what the study covers and what it focuses on. This literature review is for publication and carried out to:

- describe and discuss the conceptual foundation of data-driven smart sustainable eco-urbanism;
- analyze, evaluate, and synthesize the existing knowledge in the field;
- highlight the strengths, weaknesses, and contradictions of the existing knowledge in the field, thereby providing a critique of the research that has been conducted so far;
- discuss the identified strengths and weaknesses with respect to sustainability and data-driven smart technologies and their relationships;
- identify the opportunities, potentials, and prospects offered by data-driven smart technologies in terms of improving and advancing the goals of sustainability; and
- identify the key relationships between the relevant studies addressing the different aspects of the topic on focus by comparing, linking, and enhancing their results, as well as reinterpreting their conclusions.

This review is structured using a combination of two organizational approaches: thematic and inverted pyramid. That is to say, it is divided into a number of sections representing the conceptual subjects and thematic categories for the topic of data-driven smart eco-cities and SIDs. The analysis, evaluation, synthesis, and discussion of the relevant issues are organized accordingly while, when appropriate, starting from a broad perspective and then dealing with a more and more specific perspective with respect to the selected studies.

Conceptual, theoretical, discursive, and practical foundations of the eco-city/eco-urbanism

Definitional issues, initiatives, and categories

Over the past two decades, eco-urbanism has gained significant traction and its scope has been expanded to cover multiple aspects of sustainability. Generally, eco-urbanism focuses on developing urban environments based on the principles of ecological sustainability, i.e., multi-dimensional sustainable human communities within harmonious and balanced built environments. According to Spirn [54], eco-urbanism weds the theory and practice of urban design and planning, as a means of adaptation, with the insights of ecology and other environmental disciplines. The author describes the roots of eco-urbanism and identifies fundamental concepts and principles, as well as provides a framework to guide more comprehensive reviews of the literature and to advance the practice of eco-urbanism, i.e., eco-city planning and development.

The term "eco-city" can be traced back to the mid-1970s, when it was first coined by Richard Register through his Urban Ecology Initiative. Since the late 1980s, the eco-city concept has gained worldwide recognition thanks to the advocacy of interdisciplinary co-operation. The practice of eco-city planning and development has been carried out in many countries across the globe (see, e.g., [9, 55, 56]). The eco-city has recently built great momentum in international research areas in response to the rising concerns about the environment due to the escalating rate and scale of urbanization. The idea of the eco–city is widely varied in conceptualization and operationalization. In particular, there are multiple definitions of the eco-city, depending on the context where it is embedded in the form of urban projects and initiatives in terms of the practices and strategies adopted to achieve the goals of the eco-city. Roseland [18] argues that there is no single accepted definition of the eco–city, but more a collection of ideas about concepts. Joss [55] substantiates the conceptual diversity and plurality of the initiatives and projects using the term across the globe. Bibri [57] provides a detailed discussion of the definitional issues of the eco-city. Nonetheless, there is some consensus on the basic features of the eco-city among common definitions (Table 1). Furthermore, Joss [56] provides a full discussion of the history and recent international development of eco-cities. Rapoport [10] traces the evolution of the eco-city as a concept and an urban planning model over the last 40 years, outlining the various definitions, applications, and critiques of the term. In this regard, Caprotti [6] argues for the need to interrogate the multiple definitions of the eco-city, evaluation methods, and performance frameworks as a tool for critically analyzing the marketing, presentation, and actual built urban environments in eco-city projects.

The concept of the eco-city has been used to describe a wide range of urban projects and initiatives, mostly large-scale new districts, encapsulating a diversity of

Table 1 Common definitions of the eco-city

An eco-city is "an urban environmental system in which input (of resources) and output (of waste) are minimized" [58].
"The eco-city is an umbrella metaphor that encompasses a wide range of urban–ecological proposals that aim to achieve urban sustainability. These approaches propose a wide range of environmental, social, and institutional policies that are directed to managing urban spaces to achieve sustainability" Jabareen ([59], pp. 46-47).
"An eco–city is a human settlement which emphasizes the self–sustaining resilient structure and function of natural environment and ecosystems. It seeks to provide a healthy and livable human environment without consuming more renewable resources than it replaces" ([60], p. 7).
An eco-city is "a human settlement that enables its residents to live a good quality of life while using minimal natural resources" [61].

conceptualizations and pulling together an ensemble of normative values and prescriptive principles supported by various policies about how to develop and design sustainable urban areas. There is a need to engage with the issue of defining the eco-city, an emphasis which can be, at the most basic level, based on performance indicators.

In recent years, the world has witnessed the emergence of numerous eco-districts and eco-cities, which are still under the banner of experimentation, or seen as sites of innovation. The rise of eco-city initiatives serves as a sign or evidence of renewed attempts to experiment in designing urban futures [5] or engineering urban zones. These initiatives have promoted a number of alternative models of eco-city development capable of, in some instances, creating sustainable urban districts. There is a wide range of eco-districts or cities across the globe, with high-profile examples being Western Harbour in Malmö, Sweden; Hammarby Sjöstad and Royal Seaport in Stockholm, Sweden; and Masdar City in Abu Dhabi, United Arab Emirates (UAE). In a global survey of eco-cities conducted by Joss [55], 178 eco-cities are spread around the globe, with a concentration in Europe and Asia in terms of higher project intensity. China has plenty of eco-city projects (see, e.g., [62, 63]) as a result of embarking on an ambitious program to build new eco-cities for quite sometime. In Europe, according to Joss [55], only in 2009, it was announced that Paris would become the first "post-Kyoto eco-city," and later that year, the British government decided to build four new "eco-towns" across England. The eco-city stands out in terms of geographical diffusion among the existing models of sustainable urbanism, and its advocates hails it as the mark of urban innovation. However, Joss [55] identifies three categories through which eco-cities can be analytically approached and segmented, namely type of development, the development phase, and the implementation focus. The first category is inherently scalar: (1) a city built from scratch; (2) the expansion of an existing urban area; and (3) retro-fitting existing urban structures and environments through sustainability-focused innovations and adaptations. Also an eco-city is based on three analytical categories: (1) a development on a substantial scale, (2) occurring across multiple domains, and (3) supported by policy processes [64].

In view of the above, what exactly constitutes the eco-city as an overarching approach to sustainable urbanism seems to be even more unclear. Today, an ever-increasing range of existing cities, districts, and new or planned urban projects, from minor retrofits to large-scale new-towns, are labeled eco-cities. Conceptualizing an eco-city is a key question in any study focused on eco-urbanism and on tracking its impact and performance across a range of sustainability indicators. The way eco-city projects conceive of the eco–city status reflects more divergences than convergences. In other words, the guiding planning documents related to these projects tend to be largely developed as independent islands of locally oriented ecological sustainability. Still, holding eco-city projects up to scrutiny according to existing norms and standards is crucial for the critical analysis of these projects given their flagship nature. In addition, it is more appropriate to think of the eco-city as an ambition that can be achieved through multiple ways, or adapted to different urban contexts. Overall, with the label of the eco-city being used to describe a wide range of urban initiatives and projects, the eco-city is best to be viewed as an umbrella term so as to encapsulate the underlying diversity, bringing together an amalgam of procedural principles, scientific approaches, and normative visions about how to build more sustainable urban environments. Regardless, failing to consider a holistic approach into the local or national planning of the eco-city is likely to increase the risk potentiality of future lock-ins and targets being missed on a higher level. Also, analyzing the eco-city according to its marketed performance targets in terms of environmental sustainability stimulates further discussion and helps critical analysis by highlighting the actual performance behind the often glitzy branding and marketing characterizing eco-city projects.

Principles and strategies

The principles and strategies of the eco-city have been approached from different perspectives based on the multidimensional context this model of sustainable urbanism is embedded. Register (1996) puts forward several principles of the eco-city, including land development, transportation, natural environment, resource utilization technology, production and consumption patterns, ecological awareness and social equity, and government management. Kenworthy [17] argues that the eco-city should incorporate 10 key principles, with sustainable urban form and transport at the core of the model (Fig. 1). This relates to the emerging integrated models for sustainable urban development, which is to be discussed further in the next section.

Based on a recent case study conducted on two Swedish eco-city districts in Malmö and Stockholm, Bibri and Krogstie [15] distill, integrate, and enumerate their key strategies in accordance with the three dimensions of sustainability (Table 2). This is linked to what is known as sustainable urban districts or SIDs.

Models and practices

The eco-city focuses more on the environmental dimension of sustainability in terms of the natural environment and ecosystems than on the economic and social

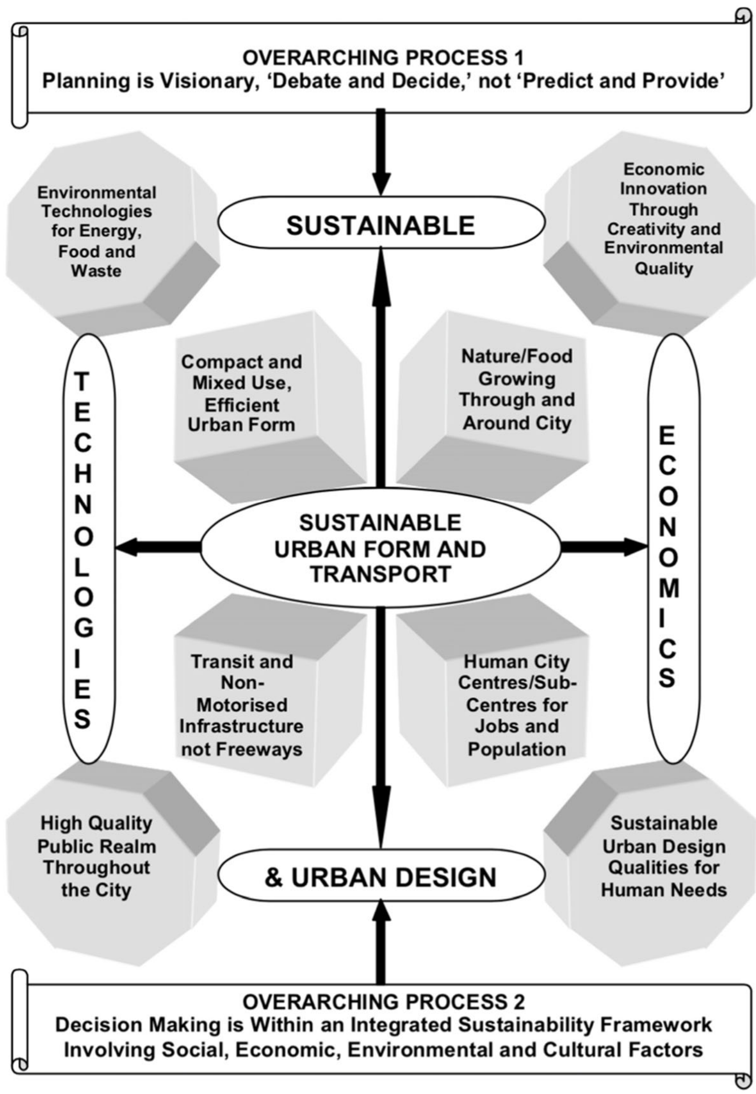

Fig. 1 A conceptual model for the eco-city based on 10 key principles in urban planning, urban transport, urban design, and planning process considerations. Source: Kenworthy [65]

dimensions of sustainability (e.g., [20, 24, 66]). While the natural environment has been a common concern throughout the history of urban planning, eco-cities bring this concern to the forefront of planning, engineering, and design. In addition, the increasing, global proliferation of eco-cities can be placed in a variety of theoretical and interpretive contexts. On the one hand, eco-cities can be seen as a continuation of planning, architecture, and design trends which have sought to reconcile nature and the city from Garden City movement, to New Towns, to the "techno-cities" of the twentieth century [67], to the more dystopian "emerald enclaves" conceptualized as green and sustainable islands in a broader global scenario characterized by environmental degradation and contamination ([68]; Pow and Neo 2010 [69]).

There are many models of the eco-city, which can be caterogarized into three types: (1) emphasizes passive solar design, (2) combines passive solar design and greening, and (3) focuses on green energy technologies and/or smart energy and environmental technologies (Table 3) [2]. Type 3 relates to the concept of the smart eco-city, which captures the recent trend of future-oriented urban development schemes that display both green and smart ambitions.

With the above in mind, the eco-city goes beyond the iteration of the nature-city relationship to contain novel and innovative components. The practice of eco-city development depends on the strategies and solutions that the cities badging or regenerating themselves as ecological or smart ecological prioritize with respect to both ecological sustainability and applied smart technology in

Table 2 The key strategies and solutions of the eco-city district for achieving the three goals of sustainability

Environmental sustainability	
Sustainable energy systems	• 100% locally generated renewable energy—sun, wind, and water • Local production of electricity—solar energy • Passive, low-energy, and net-zero buildings/houses • Bio–fueled CHP system
Sustainable waste management	• Convenient and smart waste collecting system • Vacuum waste chutes • Food waste disposers • Wastewater and sewage treatment system • Biological waste separation procedures • Biogas digesters • Behavioral change
Sustainable materials	• High performance materials • Resource-efficient (recycled and reused) materials • Minimized building waste • Pollution prevention
Sustainable transportation	• Cycling and walking • Public transport (metro, buses, tram, etc.) • Car pools (biogas and electric) • Private cars (biogas and electric) • Mobility management • Smart transport management • Smart traffic management • Behavioral change
Green and blue infrastructure	• Greening • Rainwater harvesting • Ecological diversity • Biodiversity • Green factor supplemented with green points • Green parks • Green streets and alleys • Green roofs • Rain gardens • Bioswales • Permeable Pavements
Economic sustainability	
Multidimensional mixed uses	• Physical land use mix (vertical and horizontal, amenities, facilities, public spaces, etc.) • Economic mix (business activity, production, consumption, etc.) • Some aspects of social mix (housing, demography, lifestyles, visitors, etc.
Economic growth and business development	• Green-tech innovation • Green-tech production and export • R&D activities • Entrepreneurial and innovation-based startups • Industrial and technological investment • Job creation and skill development • Government, industry, and academia collaboration • International cooperation
Social sustainability	
Equity	• Equal access to basic services • Reduction of socio-spatial segregation • Flexible design of housing in terms of tenures and forms • Affordable housing for all by means of efficient, careful processes
Life quality	• Material living conditions • Employment • Meeting places for social interaction • Ready access to facilities and public spaces • Recreation and leisure time • Natural surveillance • Security and safety of individuals and their living environment • Physical and mental health • Quality education • Social belonging and cohesion • Housing design enabling residents to remain throughout all stages of life

Table 2 The key strategies and solutions of the eco-city district for achieving the three goals of sustainability *(Continued)*

Citizen participation	• Citizen involvement and consultation as to decision-making • Citizenship plurality consolidation • Citizen empowerment for community engagement and co-creation

response to the kind of the challenges they deal with within a particular context in a given period of time. For example, Cai and Tang (120) review the development of eco-cities in China, and take several typical eco-cities as case studies to illustrate the practices of the eco-city construction. The authors show that there are three periods of eco-city practice development in China: eco-cities (1990s), low-carbon cities (2000s), and smart-eco cities (2010s). During 1990s, the focus was on ecological and environmental issues, and the concept of "harmony between humans and nature" was widely applied to guide eco-city construction. During 2000s, the focus shifted to cutting greenhouse gases (GHG) amid the severe domestic environmental situation and international societal pressure. During 2010s, great importance was attached to the city with green and ecological concepts in an attempt to integrate eco-cities and smart cities.

Design principles

As mentioned previously in relation to type 1 and type 2, there are two key distinctive design principles associated with the ecological agenda promoted by the early models of the eco-city along with the associated policy instruments related to environmental planning and management.

Ecological design—greening

Ecological design is a form of design which integrates itself with living processes to minimize environmentally negative or destructive impacts. As an integrative, ecologically responsible approach, ecological design involves greening as an important design concept for sustainable urban forms. Green space has the ability to contribute positively to the key agendas of sustainability in urban areas [70]. It refers to the areas of nature found in the urban landscape, including trees, grassy patches, flowerbeds, rock gardens, sports fields, woods, lakesides, and water features. Green space has numerous benefits, including improving health and wellbeing, ameliorating the physical urban environment by removing CO_2 emissions and other toxins from the air, enhancing the esthetics of urban areas and thus making them more pleasant, increasing the urban image and economic attractiveness, as well as controlling storm runoff. In particular, the research in this area tends to focus on the health advantages of urban green space (see, e.g., De Vries et al. 2003 [71]).

At the core of ecological design is green structure, a strategically planned network of natural and semi-natural areas with other environmental features that are designed and managed to deliver a wide range of ecosystem services, including water purification, air quality, space for recreation, climate mitigation and adaptation, flood protection, temperature regulation, biodiversity, and local stormwater management. Green structure encompasses large green spaces, waterways and streams, shorelines, parks, natural land, and forests as one common structure. Swedish cities, for example, operate with the concept of "green structure" when it comes to sustainable (green and compact) urbanism (e.g., [57, 60, 72–74]). As an ecological strategy, green structure emphasizes the benefits and losses of natural environmental and map green resources by assessing the associated natural and recreational qualities. This strategy can be broken into the following substrategies [15]:

- Greening
- Rainwater harvesting
- Biodiversity
- Green parks
- Green streets and alleys
- Green factor and green points

Table 3 Three types of eco-city models

Type 1	Type 2	Type 3
• Eco-village • Solar city • Solar village • Cohousing • Sustainable housing	• Eco-city • Eco-district • Environmental city • Green city • Garden city • Sustainable neighborhood • Sustainable community • Sustainable urban living • Living machines • Techno-city • New town	• Symbiotic city • Carbon neutral city • Zero energy city • Zero carbon city • Net zero carbon community • Low carbon city • Energy efficient city • Ubiquitous eco-city • Smart eco-city • Data-driven smart eco-city

Source: Adapted from Bibri [2]

- Green roofs and rain garden
- Bioswales and permeable pavements

The green structure strategy relates to the idea of letting nature do the work by designing multifunctional green infrastructure to provide important ecosystem services of various categories, including provisioning, regulating, cultural, and supporting services. This idea involves ensuring that greenery and water are used as active components in urban design. Green structure replaces and complements technical systems, creates a richer plant and animal life, and contributes to human health and well-being. On the whole, ecological design has a tremendous potential for reducing the environmental impacts of the built environment.

Passive solar design

Passive solar design is one of the key design concepts for achieving sustainable urban forms. It is about reducing the demand for energy and using the solar energy through particular design measures. The orientation of buildings and urban densities as a design feature affects the form of the built environment [75]. The environmental impacts and contextual implications of the building in relation to the site are key criteria for the urban designer to look at, in addition to searching for different alternatives to orient the building according to the sun path for passive solar gain and daylighting [76]. By means of design, orientation, layout, and landscaping, solar gain and microclimatic conditions can be used in an optimal way to minimize the need for buildings' space heating or cooling by conventional energy sources [77]. Orientation and clustering of buildings determined by the settlement formation of a city affects the microclimatic conditions [59]. The built form, coupled with the street widths and orientation, largely determine urban surfaces'exposure to the sun. Yannas ([78], cited in [59]) summarizes six design parameters for achieving environmentally sustainable urban forms and improving urban microclimate:

1. Built form—density and type, to influence airflow, view of sun and sky, and exposed surface area
2. Street canyon—width-to-height ratio and orientation, to influence warming and cooling processes, thermal and visual comfort conditions, and pollution dispersal
3. Building design—to influence building heat gains and losses, albedo and thermal capacity of external surfaces, and use of transitional spaces
4. Urban materials and surfaces finish—to influence absorption, heat storage, and emissivity
5. Vegetation and bodies of water—to influence evaporative cooling processes on building surfaces and/or in open spaces
6. Traffic—reduction, diversion, and rerouting to reduce air and noise pollution and heat discharge.

Moreover, the interaction between energy systems and urban structures occurs at different spatial scales, ranging from the region, city, and neighborhood to the building. Also, passive solar design techniques can be applied to both new buildings as well as existing buildings through retrofitting. The major themes evident in the current debates on passive solar design include [59]:

- Influencing building heat gains and losses
- Influencing warming and cooling processes
- Influencing evaporative cooling processes on building surfaces and/or in open spaces.
- Influencing absorption, heat storage, and emissivity
- Influencing airflow, view of sun and sky, and exposed surface area
- Reducing and rerouting traffic to reduce air and noise pollution and heat discharge.

Analysis, evaluation, synthesis, and discussion

Eco-city ideals, benefits, and guiding principles

The image of the eco-city has proven to be a highly influential translation of what a sustainable city should be. Ideally, an eco-city secures environmentally sound, economically viable, and socially beneficial development that is supported by sustainable transportation and advanced applied smart technology. A well-designed eco-city should be able to achieve the benefits of sustainability in terms of its tripartite composition. In this respect, the eco-city becomes an all-encompassing concept for urban policymaking and planning practices. Indeed, the mission of Urban Ecology (1996) is to create eco-cities by following these 10 principles [18]:

(1). Revise land-use priorities to create compact, diverse, green, safe, pleasant and vital mixed- use communities near transit nodes and other transportation facilities
(2). Revise transportation priorities to favor foot, bicycle, cart, and transit over autos, and to emphasize 'access by proximity;
(3). Restore damaged urban environments, especially creeks, shore lines, ridgelines and wetlands
(4). Create decent, affordable, safe, convenient, and racially and economically mixed housing
(5). Nurture social justice and create improved opportunities for women, people of color, and the disabled

(6). Support local agriculture, urban greening projects and community gardening
(7). Promote recycling, innovative appropriate technology, and resource conservation while reducing pollution and hazardous wastes
(8). Work with businesses to support ecologically sound economic activity while discouraging pollution, waste, and the use and production of hazardous materials
(9). Promote voluntary simplicity and discourage excessive consumption of material goods
(10). Increase awareness of the local environment and bioregion through activist and educational projects that increase public awareness of ecological sustainability issues

Irrespective of the way the idea of the eco-city has been conceptualized and operationalized, there are still criteria that have been proposed to identify what an ideal eco-city looks like, comprising the environmental, social, and economic dimensions of sustainability (Table 4):

As added by Graedel [80], the eco-city is scalable and evolvable in design in response to urban growth and socio-economic need changes. Achieving urban sustainability requires all its dimensions be in balance. Whether this is actually the case in existing or ongoing eco-city projects varies from one eco-city to another based on the multidimensional context these projects are embedded. A large body of work has investigated the presumed outcomes of the eco-city. More specifically, scholars and practitioners have discussed to what extent the model of the eco-city produces the expected environmental, economic, and social benefits of sustainability in different urban contexts (see, e.g., [6, 20]; Khan et al. 2020 [9, 13, 21, 66, 81]).

Table 4 Criteria of an ideal eco-city

• Operates on a self-contained local economy that obtains resources locally
• Maximizes energy and water efficiency, thereby promoting conservation of resources
• Manages an ecologically beneficial waste management system that promotes recycling and reuse to create a zero-waste system
• Promotes the use and production of renewable energy, thereby being entirely carbon–neutral
• Has a well-designed urban city layout that promotes walkability, biking, and the use of public transportation systems
• Ensures decent and affordable housing for all socio-economic and ethnic groups and improves jobs opportunities for disadvantaged groups
• Supports urban and local farming
• Supports future progress and expansion over time

Sources: Roseland [18] and Harvey [79]

Sustainable integrated cities or districts

Integrating eco-cities and compact cities

Shortcomings and deficiencies Sustainable development has undoubtedly inspired a whole generation of urban scholars and practitioners into a quest for the fascinating opportunities that could be explored by, and the enormous benefits that could be realized from, the planning and design of the existing models of sustainable cities, notably eco-cities. Sustainable urban development is seen as one of the keys toward unlocking the quest for a sustainable society. Therefore, it is promoted by global, national, and local policies alike as the most preferred response to the challenges of sustainable development. The eco-city is one of the central paradigms of sustainable urban development and the most prevalent and advocated models of sustainable urban forms. Numerous recent national and international policy reports and papers state that this model contributes to resource efficiency and reliability, environmental protection, socio-economic development, social cohesion and inclusion, life quality and well-being, and cultural enhancement. It is argued that the eco-city model is able to achieve the key objectives of environmental sustainability and to produce some economic and social benefits of sustainability (e.g., [9, 15, 17, 24, 81]). The environmental goals of sustainability dominate in the discourse of the eco-city (e.g., [13, 20, 66, 82]) compared to the economic and social goals of sustainability [15]. Furthermore, Jabareen [59] addresses the question of whether certain urban forms contribute more than others to sustainability, and subsequently proposes a matrix of sustainable urban forms that aims to help practitioners and policy makers in analyzing and assessing the contribution of these forms to sustainability according to their design strategies. The eco-city is ranked in a second position after the compact city. However, debating the most desirable sustainable urban form has been a longstanding scholastic question. Indeed, while the compact city has more economic benefits than the eco-city, it is far from certain that it provides the expected benefits of environmental and social sustainability. Indeed, the economic goals of sustainability seem to dominate over the environmental and social goals of sustainability with respect to the compact city model [2, 83]. This is also in line with the conclusion drawn by Hofstad [74], in a case study performed on two Swedish cities and two Norwegian cities, that the economic goals remain at the core of planning, while the environmental and social goals play second fiddle. The eco-city is not immune to such criticism either.

In the eco-city, the discourse of environmental sustainability clearly dominates over that of economic sustainability and that of social sustainability. Indeed, the eco-city brings the concern for various environmental foci to the forefront of sustainable urbanism practices. Accordingly, the contours of a goal hierarchy are evident in eco-urbanism. Bibri and Krogstie [15] conclude that the environmental and some economic concerns are at the top of the goal hierarchy supporting the eco-city district strategies in Stockholm and Malmö, Sweden, notwithstanding the claim about the three dimensions of sustainability being equally important at the discursive level. With reference to the eco-district of Stockholm Royal Seaport (SRS), Holmstedt et al. [20] point out that implementing sustainable solutions in the context of the eco-city is more difficult because no unified practical definition is still accepted, although the subject of sustainability has been hotly debated over the last four decades. The authors add that most of the eco-city projects act dishonesty in order to gain an advantage by not defining what is meant by sustainability and not meeting all its requirements. The concept of the eco-city has, in policy and planning, tended to focus mainly on the underlying structure of urban metabolism—sewage, water, energy, and waste [84], thereby falling short in considering economic and social issues. This is considered as a shortcoming when it comes to sustainability because the social and economic aspects are highly and equally important in the context of sustainable cities.

The hierarchy of sustainability goals in the context of the eco-city reflects particularly the challenge of incorporating the social issues into a design- and technology-led approach. Efforts to handle ecological challenges risk having negative impacts on equality and social welfare (Khan et al. 2020 [21]). The planners of the leading eco-city districts are perhaps more knowledgeable about and experienced with how to tackle the environmental issues of sustainability [15]. While the environmental goals of sustainability remain the key driver of contemporary eco-city projects, they are also mobilized in the pursuit of politico–economic ends. New eco-city projects are shaped in loci by policy agendas tailored around specific economic and political goals to be achieved through the strategies of urban sustainability adopted by eco-city development actors as reflections of broader policy priorities [7]. For example, an eco-city initiative could be the product of local government agendas seeking economic growth to preserve its political institutions. The eco-city model should go beyond the environmental and economic dimensions of sustainability to include the social aspects related to local communities. Attractiveness does not depend on the environmental performance and economic prosperity of districts, but rather on a broader agenda entailing a balanced form of the environmental, economic, and social concerns of sustainability. To fully achieve the goals of sustainable urban districts, the social and economic aspects of sustainability need to be supported by concrete planning practices and development strategies. Sustainable urban development is a matter of balancing short-term (e.g., equity, job creation, income equality, etc.) with long-term (e.g., resource management, pollution mitigation, waste minimization, etc.) aims so as to understand what kinds of investments in the physical and digital infrastructures and partnerships provide the best societal and environmental benefits. Randeree and Ahmed [22] examine the social sustainability effectiveness of eco-smart cities by using a case study approach to investigate the social, environmental, and economic performance of eco-city development. The authors found that eco-cities substantively contribute to environmental and economic innovation as part of sustainable urban development, and also have the potential to fuse achievements in innovation, technology, and economic enterprise with the social imperative of functional urban habitats. This is predicated on the assumption that successful sustainable urban development requires greater consideration for the social imperative.

When it comes to eco-urbanism, the least focus is on the social dimension of sustainability. Based on case study analysis of how ecological and social welfare concerns are being addressed and integrated into urban planning in three Swedish eco-cities, Khan et al. (2020 [21]) show that eco-social policy integration in practice is only established to a limited degree in terms of planning and development, and the issues of ecological justice and equity and the relationship between socio-economic factors and consumption-related environmental impacts are hardly addressed. A framework for social sustainability (Fig. 2) has been proposed by the Young Foundation in 2011 based on international experiences [19]. It consists of four essential dimensions, namely amenities and social infrastructure, social and cultural life, voice and influence, and space to grow. This framework can be considered in the ongoing eco-city district projects across the globe in terms of guiding eco-urbanism as a way of taking into account the needs of residents and the significance of their participation and engagement in decision-making processes pertaining to the development and management of the eco-city districts that are actually built for them. These four dimensions play a key role in designing eco-city districts into socially sustainable communities, which incorporate physical and technological interventions as well as social services and practices.

Emphasizing one of the dimensions of sustainability remains a shortcoming (failure to meet certain standards in plans) and deficiency (lacking some necessary elements) in the urban context. Indeed, urban sustainability is a holistic approach to thinking, meaning that all the dimensions of sustainability are equally important. In fact, the debates about sustainable urban forms are rarely understood outside their expert communities. However, it is widely acknowledged that balancing the goals of sustainability is conflicting, as different aspects of sustainability rely on different criteria for success. Despite the enticing and holistic character of sustainability, the existing conflicts between its goals "cannot be shaken off so easily" as they "go to the historic core of planning and are a leitmotif in the contemporary battles in our cities," rather than being "merely conceptual, among the abstract notions of ecological, economic, and political logic" ([85], p. 296). Therefore, urban planners will in the upcoming years "confront deep-seated conflicts among economic, social, and environmental interests that cannot be wished away through admittedly appealing images of a community in harmony with nature. Nevertheless, one can diffuse the conflict and find ways to avert its more destructive fall-out" ([85], p. 9).

Emerging planning practices and development strategies The recent wave of research on integrated models for sustainable urban development tends to capture important aspects of the urban planning and design, architecture, social, environmental, economic, and governance systems performances of SIDs systematically through interdisciplinary and cross-disciplinary work. These models explore the development of SIDs as a model for high-density, high-liveability future cities through case study research allowing for an evaluation, comparison, and learning on how SIDs (e.g., green cities and dense cities) are best planned and realized in various human settlement systems. As part of the case study analysis conducted by Bibri [57], the Development Strategy Gothenburg 2035 states that the city will be able to attain both a green and compact city while taking into account potential conflicts such as access to green areas and risk issues as something of importance when building additional structures [86]. This research area also focuses on improving the performance of the eco-city by partly or completely integrating its green design principles and environmental technology solutions with the design strategies of the compact city. Indeed, it has become of high relevance and importance to integrate the eco-city and compact city models so as to consolidate and harness their strategies and solutions to deliver the best outcomes of sustainability. According to a recent literature review carried out by Bibri [2], this integration can be justified by the fact that:

- The eco-city needs to improve its social performance, which is better in the compact city;
- The compact city needs to enhance its environmental performance, which is of high focus in the eco-city; and
- Both models contribute differently to economic sustainability, with the former focusing on green-tech innovation strategy and the latter on mixed-land use strategy.

Another argument supporting the integration of these prevailing models of sustainable urbanism is that they have already many overlaps among them in their ideas, concepts, and visions, as well as their practices and policies. This means that these models are compatible and not mutually exclusive, yet with some distinctive concepts and key differences. Some of the attempts undertaken so far to integrate these models tend to provide ideal forms of human settlements, combine some ideas from each one of these models to form new partly integrated models, or strengthen one model through adding principles from the other, all with the objective to integrate and balance the dimensions of sustainability in order to harness its synergistic effects and thus boost its benefits. However, as this work is more often than not based on design with respect to the discipline of planning and architecture, it tends to focus more on creativity, common sense, ideal target pursuit, and future scenarios, rather than fact-based evidence explanation, empirically grounded research, or scientific finding-oriented exploration. This is in contrast to the eco-city and the smart city, which represent innovative models of urbanism based on a scientific approach to urban development.

Farr [16] discusses the combination of the different elements of eco-urbanism, sustainable urban infrastructure, and new urbanism, and extends this integrated approach to close the loop on resource use and bring everything into the city. The aim of the integrated approach to closure the cycles of natural resources, energy, and waste within cities involve minimizing the consumption of natural resources, essentially non-renewable and slowly renewable ones; minimizing the production of waste by reusing and recycling; lowering air and water pollution; and promoting natural and green areas and biodiversity. Integrating eco-urbanism and new urbanism also entails enhancing the quality of life by affording greater accessibility to activities, services, and facilities within a short distance. This is about proximity, i.e., how close jobs, amenities, and services are to where people live, which is generally calculated based on the travel time and distance to their homes. Register [87] is credited for coining the phrase "access by proximity," which suggests the closeness to important functions and activities, such as housing, work spaces, shops, educational and cultural facilities, places for socializing, as necessary to create ecologically healthy cities characterized by walkable centers, transit villages, discontinuous boulevards, and agricultural land close by. The International Economics and Finance Society (IEFS) [88] illustrates 15 interdependent dimensions to describe cities as interconnected urban ecosystems (Fig. 3).

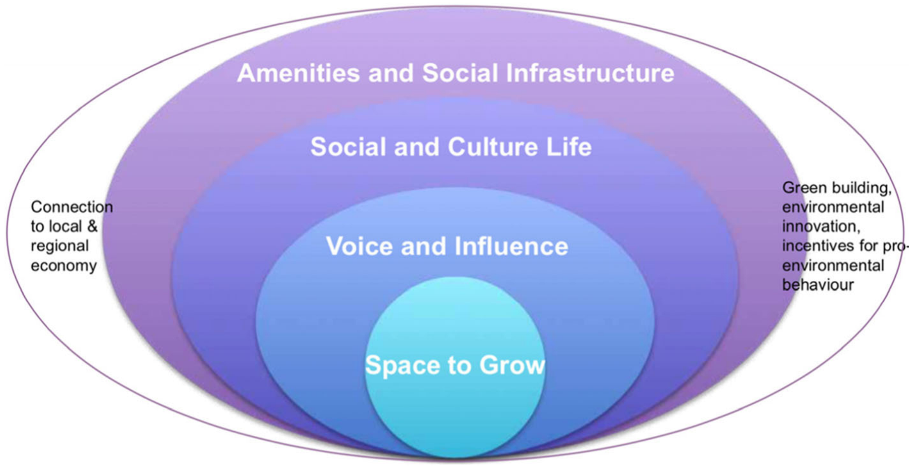

Fig. 2 A framework for social sustainability

Important to note is that access proximity is typically associated with the compact city under its mixed land-use strategy. This is adopted to achieve various benefits of environmental, economic, and social sustainability (e.g., [57, 74, 89]). Proximity enables the city to be self-sustaining by having everything that people need within the community, including stores, employers, service providers, energy generation, waste disposal and processing, and small-scale agricultural production (community gardens and/or vertical gardening). The latter is typically associated with the eco-city (e.g., [18, 79]).

Based on a case study analysis performed by Bibri and Krogstie [15], the mixed land use and social mix approaches are key to the planning and development strategies of the eco-districts of SRS and Western Harbor, Sweden (Table 5). These approaches are aimed at a lively and long-run sustainable city with a balance between environmental, economic, and social factors. Here, the diversity of functions and architectures gives a good base for services, retail trade, and public transport, and also induces people to live and work in the area. Mixed-land use has not only economic benefits, but also environmental and social benefits through sustainable travel behavior and equal access to services and facilities, respectively. Strong support for the sustainable development advantages of a diverse and vibrant built environment—a mixed-use city—is well reflected in a series of debates with politicians and experts and open community meetings with respect to Stockholm and Malmö's future and key urban development initiatives.

In addition, the aim of Western Harbor is to become an international leading example of an environmentally sound, densely populated district, integrating all three dimensions of sustainability. This also applies to SRS as the sustainability and environmental program for SRS states that this district "shall be developed into a world class environmental city district" ([90], p. 11), While the program is designed to be generic and with a continuous focus, it still includes some long-term specified goals given that SRS has been selected as one of 18 projects around the world to be part of the Clinton Climate Initiative (CCI), which aims to develop climate-positive urban districts [90]. Furthermore, the program states long-term goals within ecological, economic, and social sustainability [90], of which some examples are presented in Table 6.

Concerning environmentally efficient transport, for instance, a recent comparative study of the urban transport eco-urbanism characteristics of Malmö, Stockholm, and other Swedish cities compared to cities from the USA, Australia, Canada, and Asia, Kenworthy [65] found that while density is critical in determining many features of eco-urbanism, especially mobility patterns and particularly how much public transport, walking, and cycling are used, Swedish cities maintain healthy levels of all these more sustainable modes. Engwicht (1992) advocates eco-cities where people can move via walking, cycling, and mass transit without fear of traffic and toxins. Dongtan Eco-City, a 500,000 resident project, is planned to achieve densities of 84–112 people per acre, which will support efficient mass transit and land and social mixes, and also to have parks, lakes, and other public open spaces scattered around the densely designed neighborhoods [91, 92) underscores the risks involved in heavily marketing an eco-city project which fails to come to fruition, and assumes that it lost its momentum, and due to the delay of its construction, it has been given a mixed reception [92].

In addition, Bibri and Krogstie [93] suggest an integrated model of sustainable urban development comprising the design and technology solutions of the eco-city and the design strategies of the compact city. This suggestion is based on several reasons distilled from an extensive literature review, namely:

- Being one of the most significant intellectual and practical challenges for more than four decades, the development of a desirable model of sustainable urbanism continues to motivate and inspire collaboration between researchers, academics, and practitioners to create more effective design strategies and advanced environmental technology solutions based on a more integrated and holistic perspective.

- Different scholars and planners may develop different combinations of design concepts to meet the requirements of sustainability. They might come up with different forms, where each form emphasizes different concepts and contributes differently to sustainability.

- While there is nothing wrong with sustainable urban forms being different, it can be beneficial extremely and of strategic value to find innovative ways of combining their distinctive concepts and blurring their key differences toward an integrated model of urban development emphasizing the synergistic effects of the different dimensions of sustainability. Especially, sustainable urban forms are compatible and not mutually exclusive.

- Neither real-world cities nor academics have yet developed convincing models of sustainable urban form, and the components of such form are still not yet fully specified.

- More in-depth knowledge on planning practices is needed to capture the vision of sustainable urban development, so too is a deeper understanding of the multi-faceted processes of change to achieve sustainable urban forms. This entails conceptualizing multiple pathways toward attaining this vision and developing a deeper understanding of the interplay between social and technical solutions for sustainable urbanism.

- The compact city has a form and thus is governed by static planning and design tools, whereas the eco-city has no clearly defined form, thereby the relevance for the integration of these models of urbanism into one model that can accelerate sustainable development toward achieving the optimal level of sustainability.

With respect to the latter, for example, the eco-city has long been conceived as amorphous (formless), and the form has been of less focus in eco-urbanism. The eco-city has tended to focus on the way the urban landscape is organized and steered rather than the spatial pattern of the characteristic physical objects in built-up areas. What counts most is how the eco-city is managed and governed as a social organization. As argued by Talen and Ellis ([94], p. 37), social, economic, and cultural factors are far more important in determining the quality of the city than any choice of spatial arrangements. However, one consistent result emerging from the analysis of six eco-city projects performed by Rapoport and Vernay [24] is that design is much more

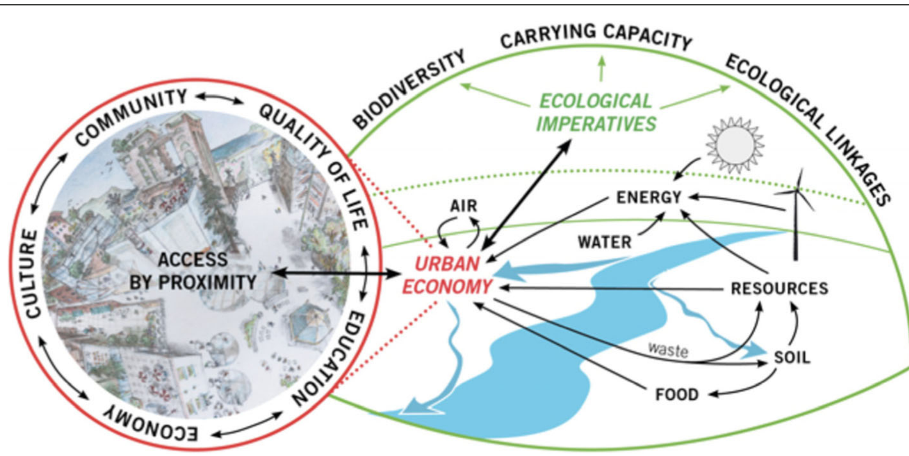

Fig. 3 Cities as interconnected urban ecosystems. Source: IEFS [88]

frequently mentioned than management as a driver of sustainability. Cheshmehzangi et al. (120) introduce the new concept of "eco-fusion" through an exploratory case study project, and suggest the importance of multi-scalar practice in the broader field of eco-urbanism. The authors point out the associations between eco-fusion and sustainable urban development in terms of integrating the natural and built environment as the best practice of eco-development in urbanism. In terms of findings, the authors highlight integrated methods in eco-urbanism and provide new avenues for eco-planning/eco-design strategies. Bibri [95] provides a detailed account of the synergistic effects and combined benefits of integrating eco-urbanism and compact urbanism in an attempt to improve and advance the environmental, economic, and social goals of sustainability. However, there is a need to develop new integrated planning paradigms, research methodologies, and implementation processes to support higher population densities, higher standards of environmental sustainability, and enhanced liveability.

Evaluation of sustainable urban districts The importance of the assessment of the results and progress of integrated models for sustainable urban development is justified by the resources involved in the associated endeavors. Generally, it makes it impossible, without any assessment, to ensure that investments are directed in the best possible manner and resources are allocated appropriately, to confirm that the practical endeavors are heading in the desired direction, and to avoid future mistakes and lock-ins [14, 96, 97]. Accounting for sustainable urban development will require incorporation of considerable additional aspects and parameters (Brandon and Lombardi 2005). Nevertheless, many of the components constituting the built part of modern cities are relatively well studied and understood as single units [14]. Conversely, unlike the systems and the interconnections between their individual constituents when assembled remain less explored and empirically underdeveloped. However, given their scale compared to cities, sustainable urban districts/SIDs can function as small-scale models with respect to developing evaluation processes and methods for assessing urban sustainability. The district scale is a good arena for deepening the knowledge base on urban sustainability, and recent evaluation programs in this regard are considered as a stepping stone toward a more systematic approach for evaluating sustainable urban districts [98]. Other evaluation improvements are evident in the growing number of district developments with the stated ambition of being sustainable (e.g., [55]). In addition, while many of these new developments attract attention and are marketed more strongly, creating pressure to demonstrate progress [99, 100] made in the area of evaluating and monitoring the built environment in relation to sustainability, many more challenges still remain and need to be addressed and overcome. These challenges pertain mainly to the concept of sustainable development being a value-based subject with multiple interpretations, which parameters to select in order to determine what urban sustainability entails, and the collection of evaluation information and its use and presentation, but to name a few. All in all, more studies are needed to investigate evaluation methods and strategies for determining progress toward sustainable urban district development. This research should capture important aspects related to design, architecture, social, environmental, economic, and governance systems performances systematically through more effective frameworks. Currently, it is difficult to evaluate how and to what extent sustainable urban districts contribute to sustainability. As a result, city governments, urban planners, and landscape architects are grappling with the dimensions of sustainable urban districts and forms by means of a variety of planning, design, and policy approaches [101, 102].

Eco-cities as techno-enviro-economic experiments for transition

The idea of eco-city experiment has become increasingly prevalent and popular as a guiding concept and trope used by scholars, policymakers, and corporate actors alike. Eco-cities have been conceptualized as materializations of trends toward developing and implementing urban socio-technical and enviro-economic experiments ([5]; Bulkeley et al. 2013). In turn, these experiments can be seen as part of transitions-focused theories and management approaches, which aim at economic and societal transitions toward low-carbon economies and cities [103]. Much of the recent focus on eco-cities has largely drawn on the role of specific techno-environmental solutions to notions of urban, climate, and energy crisis, which is part of the broader strategic policy and environmental discourse of ecological modernization. This concerns the policy and planning spheres pertaining to new-build eco-city projects where the modernizing strategies at a variety of scales focus on the eco-city as a techno-social response to environmental and economic concerns in modernization trajectories (see Simon and Molella 2013 [8]). Based on case study research, Cugurullo [7] investigates how new eco-city projects interpret and practice urban sustainability by focusing on the policy context that underpins their development. The author states that eco-city projects interpret sustainability as ecological modernization and practice urban environmentalism almost exclusively in economic terms. Generally, ecological modernization argues that the economy benefits from moves toward environmentalism. One of the basic assumptions of ecological modernization relates to environmental readaptation of economic development. While eco-city projects can be seen as manifestations of ecological modernization, they also need to be considered as attempts at fashioning urban techno-economic fixes to the problems of environmental despoliation, energy insecurities, and concerns over adaptation to climate change [68]. In this context, the ecological modernization approach "involve both structural change at the macro-economic level, through broad sectoral shifts in the economy, and at the micro-economic level: for example, through the use of new and clean technologies by individual firms" ([104], p. 66). Eco-cities depict new urban visions that jointly involve entrepreneurial states and capital in the engineering and envisioning of urban environments. Entrepreneurial governments from Asia to the United Arab Emirates (UAE) are often initiators of mega urban projects [105]. Seen from this perspective, the eco-city as an entrepreneurial city is dependent on the active remaking of urban environments and ecologies [106] and based on the integration of states and markets in the financing of new urban and infrastructure projects [107]. There is an intersection between the agendas of green urban entrepreneurship and ecological modernization and the creation of urban sustainability entrepreneurship. This draws on the long-standing concept of creative destruction in entrepreneurship research so that it becomes the driving force for the establishment of a sustainable economic–environmental–urban system.

As a form of green entrepreneurial urban enterprise, the eco-city constitutes a major force in the overall transition toward a more sustainable urban development paradigm, acting as exemplary solutions for social transformation. Transition denotes changes from one socio-technical landscape or regime to another. In recent years, there has been increased interest in academic and policy circles in the idea that long-term environmental problems entail fundamental transitions in socio-technical regimes. This builds on efforts to apply knowledge from empirical and theoretical analysis of the past socio-technical shifts of governing transitions in techno-urban systems. Recommendations for radical shifts to sustainable socio-technological regimes—transforming technological systems for ecological sustainability—entail, as stated by Smith ([108], p. 131), "concomitantly radical changes to the socio-technical landscape of politics, institutions, the economy and social values" ([108], p. 131). Socio-technological regimes [109]—are to be brought about by the actions and networks of existing actors within institutions in the ambit of emerging smart eco-cities. Established socio-technological regimes can induce and support the transformation of socio–technical constellations (e.g., industry associations, research communities, policy networks, and advocacy/special-interest groups) toward improving and advancing ecological sustainability at the macro level. Accordingly, the socio-technical landscape forms an exogenous environment beyond the direct influence of regime actors (macro-economics, deep cultural patterns, macro-political developments). Changes at the landscape level usually take place slowly (decades) [110]. This is due to the nature, scale, complexity, and intricacy of the landscape. That is, the overall socio-technical context which comprises societal beliefs and values and world views as intangible dimensions, as well as the material structures and mechanisms pertaining to various institutions and the functions of the economy and related marketplace dynamics as tangible aspects. The potential confines are predicated on the assumption that innovative technological niches are vital sources of innovation that may hold potential for providing solutions for tensions in the extant socio-technical regime. The adaptation process is confined by structures within existing, mainstream regime (Smith [108], p. 453). Indeed, it may be that existing socio-technical contexts close down spaces for alternative approaches, except at times of tension when new trajectories are actively being sought, as with the current concerns over climate change and the need to reduce carbon emissions. The latter applies to smart eco-cities as experiments for transition, as demonstrated by many studies across the globe.

Less clear has been how the transition to the eco-city may materialize. The extent to which ecologically sustainable urban transformation could be achieved can be usefully explored by drawing on research work on transition governance and innovative technological strategic niche development. Research within social studies of technology has dealt with the transformation of socio-technological regimes and highlighted the role and contribution of innovative technological strategic niches in transition governance [108, 111]. Transition governance is often discussed with reference to sustainable development as an alternative model of environmental governance and its possible use as an approach to change. It aims to direct the gradual, continuous process of the transformation of socio-technical practices and socio-political landscapes from one equilibrium to another [112, 113]. It indirectly influences and redirects the choices and decisions of strategic actors toward various forms of sustainability, instead of seeking to control the uncertainties of change [114]. In this respect, it seeks the outcome of change to mitigate inherent uncertainties, generate desirable or anticipated socio-political outcomes, and augment resilience capabilities during the transformation of socio-technical regimes [112, 113]. These denote "interconnected systems of artefacts, institutions, rules, and norms" ([109], p. 3). Socio-technical

Table 5 Mixed land use dimensions in SRS and Western Harbor as eco-city districts

Eco-districts	Mixed land use strategy
SRS	A key strategy for sustainable urban development underlying the sustainability program for SRS is 'vibrant city.' The program for SRS aims at a mix of housing, offices, shops, amenities, and public services and facilities combined with well-designed, varied public spaces—streets, parks, and squares—as important meeting places that create conditions for a lively atmosphere between the buildings. Quayside walkways will be laid out along the port areas, with offices, restaurants, bars, and shops, conference centers, theaters, gyms, and hotel, helping to create a mixed urban development full of life and activity The dynamic of the city will be reflected in the diversity of living accommodation and the range of amenities, culture, and entertainment. Housing, amenities, and public spaces will be distinguished by accessibility and modernity.
Western Harbor	Western Harbor is a district with a mixture of housing, services, industries, workplaces, education, and recreation. The district has a unique, attractive location with urban and natural features; it is within walking distance of the inner city, has good transport links. By continuing to develop these qualities and building a mixed city, it will be possible to link Western Harbor to the central parts of Malmö.

regimes stabilize existing trajectories in various ways, including regulations and standards, sunk capital investments in technological infrastructures and competencies, adaptation of lifestyles to technical systems, and cognitive routines [110]. They shape technological innovation systems [115] and may host a range of innovative technological strategic niches, which generate innovations to challenge the status-quo. The concept of the niche is taken from socio-technical transitions studies, which analyze the processes through which innovations come about and are taken up in society more widely (e.g., [116, 117]). Transition governance emphasizes the role and contribution of these niches in the process of transitioning to ecological modernization. Innovative technological niches (e.g., [108, 111, 115]) constitute areas at which the space is provided for radical innovative experiments. Raven ([118], p. 48) defines a technological niche as "a loosely defined set of formal and informal rules for new technological practice, explored in societal experiments and protected by a relative small network of industries, users, researchers, policy, makers, and other involved actors." One strand of research within social studies of new technology centers on innovative experiments in alternative, sustainable technological niches, and draws lessons from the challenges these niches face in the context of a dominant, unsustainable socio-technological regime ([108], p. 128). A technological niche forms the micro-level where drastic novelties emerge and are initially unstable socio-technical configurations; niche-innovations are developed by small networks of dedicated actors, thereby their low performance [110].

Within smart eco-cities as experiments for transition, innovative techno-enviro-economic niches (related to green-tech innovation, green entrepreneurship, sustainable innovation, technological innovation, sectoral innovation, and so on) are increasingly seen as "nurturing socio-technical configurations, which grow and displace incumbent regime activities" ([109], p. 9), as well as providing lessons and insights to policymakers to manage ecological urban sustainability transitions. However, it remains to be seen if these transformative changes will be realized and sustained, and techno-enviro-economic niche activities will go mainstream. This depends on the extent to which the emerging models of smart eco-cities as a set of techno-enviro-economic innovations will solve the challenges of sustainability and provide concrete added value for sustainability. Many city government and municipal agencies within the ecologically advanced nations (e.g., Sweden, Denmark, Germany, the Netherlands, the UK, etc.) are increasing supporting new development projects as central demonstration sites for environmentally and economically sustainable urban development while capitalizing on advanced technologies. The hybridization of concerns over environmental and economic

Table 6 Some examples of three sustainability goals of SRS program

Ecological sustainability goals	Economic sustainability goals	Social sustainability goals
• Low use of energy, materials, water, and other natural resources. • Focus on sustainable energy use, eco-cycle solutions, environmentally efficient transport and buildings, and sustainable production and consumption patterns.	• Contributes to innovation, development, and marketing of Swedish environmental technology and knowledge within sustainable urban district development, and to the development of sustainable enterprises, products and services. • The principles of Life Cycle Costing shall be applied in the construction of the Stockholm Royal Seaport district.	• Promotion of social integration through mixed forms of housing ownership, housing in different sizes and integration with existing buildings. • Development of the ability and knowledge to live and work sustainably.

sustainability in the eco-city is a reflection of the economic-environmental nature of the problems and challenges that eco-cities are dealing with and designed to solve. Whiile adaptation to climate change may be one of the key driving logics behind the engineering of new eco-cities, economic transition policies and reforms enacted within eco-city projects are clearly concerned with economic sustainability. This is manifest in the confluence of urban entrepreneurialism and eco-city development, as they are both seen as pathways toward urban sustainability [119]. This is clearly seen in new-build smart eco-cities globally. This involves connecting the concept of urban entrepreneurialism with that of experimentation for transition.

Often marketing themselves as models for sustainable urban development or smart eco-cities, the recently built eco-cities or launched eco-city projects in Sweden (e.g., [13, 15, 20, 35]), Germany (e.g., [43]), China [44], the UK and the Netherlands [37], and France (Jolivet and Bond 2018) represent only sites of innovation, or are still under the banner of experimentation. In critically engaging with the notion of "urban experiment" and its articulation through the associated concepts of "living labs," "future labs," "urban labs," and the like, Caprotti and Cowley [120] introduce seven specific areas that need critical attention when considering urban experiments, namely normativity, crisis discourses, experimental subjects definition, boundaries and boundedness, historical precedents, "dark" experiments, and non-human experimental agency. However, eco-city initiatives tend to focus largely on integrating the environmental and economic goals of sustainability while embracing and leveraging what smart cities have to offer in terms of advanced technological solutions for sustainability. The idea of experimentation is associated particularly with the tendency for new technologies and ways of working to be trialed at a limited scale, often through cross-sectoral partnership approaches for learning purposes (e.g., [103, 121, 122]). Smart eco-cities can be viewed both as potential niches for introducing and testing new technologies, and where sustainable economic and environmental reforms can be rolled out in areas which are both spatially proximate and internationally oriented. The former concerns the surrounding region and the latter pertains to networks of knowledge, technology, and policy transfer and learning.

With reference to an example of the currently leading practical initiatives of smart eco-cities, one of the strengths of the smart eco-city district of SRS in terms of the environment, which gives it an advantage over other new-build eco-city projects, lies in its green-tech innovations. SRS is expected to contribute substantially to the economic growth of Stockholm's potential as an innovation hub. The two main economic growth sectors in SRS are the innovation sector and the service sector. With respect to the former, in particular the innovation center for sustainable technology, sustainability initiatives will become the focal point for the district to showcase sustainable development lifestyles. The innovation center is planned to feature the latest developments in clean technologies and show how the associated solutions are tested and applied. SRS will serve as platform for presenting the area to the public and interested parties and an important showcase to the outside world. It will also serve as an international meeting place where the city, the business community, and research institutions work together to profile and demonstrate Swedish know-how in urban sustainability. The formal organization in the SRS project works in parallel with the SRS Innovation Arena, which involves industry experts, businesses, and citizens, to build up practical knowledge [123]. The SRS project will provide opportunities to many development and construction companies and benefits to green-tech companies. Furthermore, SRS aims to take the lead in realizing the latest innovations within environmental technology and sustainable development, and affords particularly great opportunities for climate-adapted and future-oriented development, from pioneering energy-efficient technical solutions in building and infrastructure to the development of smart electricity networks that enable local production and distribution of electricity. However, drawing on a 10-year-long study of the digital footprint of SRS, Khan, Hildingsson and Garting (2020) show that ecological sustainability remains local in that it is situated in the specific spatial, temporal, and political context of the eco-city project. In other words, eco-city district projects are associated with particular places, initiatives, histories, technologies, values, and perspectives. Consequently, the authors suggest that the transition toward ecological sustainability always involves the transition of ecological sustainability in order for a transition to become ecologically sustainable. In particular, as revealed by Joss and Cowley [124] based on a comparative case study analysis, national policy is found to exercise a strong shaping role in what sustainable development for future cities is understood to be, which helps explain the considerable differences in priorities and approaches across countries.

However, the current model of the smart city is being promoted with significant investment of resources by numerous industrial actors [125], not least in relation to the model of the eco-city. The outcome is a very competitive market where the risk of the prevalence of stand-alone profit-making agendas becomes evident in smart cities [126] as well as smart eco-cities. The huge market of the smart city may well undermine economic development through the isolated ICT branding exercises of industrial actors [127]. This is most likely to have a bearing on the outcomes of environmental and socio-economic reforms taking place in emerging eco-cities. This risk becomes imminent when looking at the market growth of the smart city and the smart eco-city. It becomes evident why the ICT industry and the private sector view the idea of the smart city as an opportunity to promote digital transformation [128], including in relation to the smart eco-city. For example, China has made eco-city development its legislative priority and national strategy, investing a US$ 618 billion in a 5-year period from 2011 to 2015 that could reach as high as US$ 1, 124 billion in the period of 2016–2020 (Wu et al. 249). The smart city is increasingly advocated by governments as the primary means to deliver urban sustainability. However, while the smart city movement has created numerous initiatives globally, almost all of them have failed or lack adequate potential to generate sustainable urban futures [129]. The rationale behind this inadequacy is that the current practices of smart city portray technologically determined, reductionist, and techno-centric approaches to urban development.

It can be argued that the ability of smart eco-cities to achieve their utopian ambitions is limited by the realities of complex practices and the profit-driven, neoliberal approach to planning and development. The plans and publicity materials of eco-city projects, notably those promoted in Asia and the Middle East as ambitious, technologically driven projects led mainly by the state and private sector actors contain bold claims, attractive designs, ambitious targets, and innovative technologies to advertise their “eco-ness” [10]. Cugurullo [7] reveals that the eco-city developers capitalize on sustainability by building an urban platform to develop and commercialize clean-tech products, and concludes that the city is an example of a high-tech urban development informed by market analysis rather than ecological studies. The performance of eco-cities has long been heatedly debated and also criticized in terms of their profit-seeking and image-building projects simply capped with impressive names, although most of the eco-city projects are still under experimentation [63].

Smart solutions for improving the social performance of the eco-city

Conventional paradigms of eco-urbanism require new responses under the current circumstances of urbanization and the complex challenges of sustainability in light of the rise of digitalization. The scales and rates of urbanization fundamentally disrupt the challenges that eco-urbanism research and practice must contend with. The eco-city is a quintessential example of a paradigm that is advocated just as much as it is criticized in the context of sustainability and technology. The critic pertains to, among others, the social performance of the eco-city in relation to technological solutions. Social proposals have long tended to be couched in speculative language in terms of investments and initiatives These issues reflect the challenge of incorporating the social dimension of sustainability into a design-oriented and technology-led approach characterizing the eco-city. In the existing literature on urban sustainability, the social factors are shadowed by the ecological aspects [130], as well as ignored in assessment methods [131]. Nevertheless, a set of new measures have recently been developed and implemented in emerging eco-city districts, which are expected to strengthen the influence of the social goals of sustainability over eco-city development practices. Among the strategies being adopted in this regard are:

- Citizen involvement and consultation
- Inclusiveness in terms of the level of participation in decision-making
- Security and safety of individuals and their living environment
- Efficiency in public services delivery
- Equity in terms of affordable housing for different income groups.

These strategies have recently become at the core of smart cities in response to the challenge of developing technologies that support equity and fairness and enhance the quality of life, as well as ensuring informed participation and creating shared knowledge for democratic city planning and governance. Concerning citizen involvement and consultation in regard to eco-city development and management, for example, it is deemed of crucial importance to improve social cohesion, among others. This is predicated on the assumption that sustainable urban districts can only be created by the cooperation between such stakeholders as residents, landowners, developers, energy companies, academics, and city administrators through dialogue in order to shape and manage eco-city development. Indeed, the planning of eco-city development involves complex socio–technical constellations of a variety of actors interacting with and influencing each other on multiple scales [95]. At the core of this dynamic interplay is the engagement of many stakeholders in continuous dialogue to determine the programs associated with the development and implementation of eco-cities. However, there seems to be a lack of structures for collaboration between the different stakeholders of eco-cities (see, e.g., [20, 123]), which is at the core of urban governance. The most serious obstacle for the effective transformation of cities into becoming ecological and/or smart is the lack of appropriate governance arrangements for the majority of cities. Researchers and practitioners have argued that many of the challenges for cities to become smart exceed the scope and capabilities of their current organizations, institutional arrangements, and governance structures (e.g., [132, 133]).

Furthermore, citizen participation in smart cities relate to planning, governance, innovation, and democratization (e.g., [3, 28, 134–139]). Seçkiner Bingöl (120) concludes that citizen participation in smart sustainable cities is only considered as a set of mechanisms aimed at supporting good governance, and recommends using these mechanisms to highlight other aspects of sustainability, such as securing comprehensiveness, promoting gender equality, and to focus on other aspects of citizen participation, such as real participation and democratic effectiveness. Moreover, Gebresselassie and Sanchez (2018) reveal that transport apps have the potential to address the equity and inclusion challenges of social sustainability by employing universal design in general-use apps, including cost-conscious features, providing language options, and specifically developing smartphone apps for persons with disabilities. In addition, Bibri and Krogstie [3] distill a number of solutions offered by smart cities to improve citizen participation in the context of sustainable cities and eco-cities, including, but are not limited to the following:

- Online platform which makes it easier for citizens to find out about planning issues and land use (i.e., local development plans, zoning regulations, building permits, planning applications, heritage sites, etc.), combining such data as street maps, aerial photography, historical maps, architectural heritage, areas of special protection, nature reserves, population census, and education services.
- Crowdsourcing platform which addresses important city issues related to different areas. The citizenry makes a difference as new forms of data and advice will be implemented using crowd-sourcing.
- Interactive platform which allows citizens to feedback, rate, and shape the type of experiences they want to have.
- Open government portal which improves the transparency of the city management, where a number of initiatives can be realized with respect to engaging citizens in various solutions.
- Online platform which engages citizens in dialogue so as to gather input on their needs and demands, evaluate all their suggestions, and identify and solve important urban issues.
- Platform where the citizens' complaints related to infrastructure, transport, healthcare, environment, and other issues are communicated to relevant agencies. Citizens can track the status of their application and control the execution of their filed complaints.
- Special portals which enables citizens to report the economic problems in the city.
- Geoinformation portals to involve citizens in the provision of urban amenities, to advise existing problems to executive bodies, and to manage urban systems more effectively.
- Classrooms where citizens can learn about the principles and applications of digital technologies, and gain access to tools that allow them to innovate and participate in urban projects.
- Space designed to attract startups and skilled innovators to develop new technologies leveraging the data produced by the extensive IoT infrastructure of the city.
- Co-innovation center which enables close collaboration among local technology customers, governmental agencies, startups, academics, and developers to create new business models, innovative ideas, and technological solutions.
- Participatory platform which connects companies, local authorities, universities, start-ups, citizens, associations, and so on to support decision-making processes, allowing the collection, processing, monitoring, and analysis of large amounts of data to generate deep insights pertaining to different uses and applications.
- Participatory democracy platform which allows citizens to see and discuss proposals put forward by the city government, and submit their own. Such platform is used to create the city's government agenda, with proposals coming directly from participating citizens.
- A city council which allows the provision of services by public agencies remotely and mobile kiosks, where one can receive various certificates, publish a complaint, get necessary information, and so on. This is to improve the convenience of public services received by citizens.
- Digital literacy programs and digital inclusion of minorities and vulnerable groups.

The social sustainability aspects in smart cities focus on the quality of life and the efficient use of human and social capital (e.g., Ahvenniemi et al. 2017 [101, 140–146];). Smart cities put data and digital technologies to work to make better decisions and enhance the quality of life based on deep insights generated through advanced data analytics. More comprehensive, integrated, real-time data give city agencies the ability to monitor various events as they unfold, understand how demand patterns are changing, and respond with faster and lower-cost solutions. So, the quality of life is much better as smart cities offer better safety and security, inclusiveness, ease of seeking and obtaining public services, cost efficient health care, quality education, and opportunities for participation in governance. Therefore, smart cities provide many new opportunities to enhance the social performance of eco-cities as a model of sustainable urbanism. The socially oriented aspects of sustainability are observed in smart cities [48] thanks to the symbiotic relationship between advanced ICT and urbanization. The human nature of urbanization and the social issues engendered by urban growth, such as social vulnerability, socio-spatial segregation, socio-economic disparity, social inequality, and public health decrease have underlined the importance of the social aspects of sustainability in emerging smart eco-cities. Smart cities provide great potential to enable eco-cities to move beyond their narrow environmental-economic goals to tackle the pressing social issues engendered by urbanization. The basic idea is to retain the best of what we already have that have been successfully enacted in real-world eco-cities, making use of the things that have been demonstrably better in the past in terms of environmental and economic sustainability, while being selective in adopting the best of what is emerging and promising in regard to advanced technological solutions, making use of the things that will add a whole new dimension to sustainability in terms of not only enhancing its social aspects and thus balancing its dimensions, but also harnessing its synergistic effects and thus boosting its benefits.

The second generation of smart cities is framed as a decentralized, people-centric approach where smart technologies are employed as tools to tackle social problems, foster collaborative participation, and address the needs of citizens [147]. Still the smart technology solutions catering to governmental agencies and civic society are currently unclear as to whether they improve the quality of life of all citizens, or whether they benefit a specific "elitist" part of society or prioritize a certain societal group over others that is digitally skilled or can financially afford these solutions [48]. Hatuka and Zur [148] argue that the initiatives that focus on social needs and address inequality in smart cities are still at the margins, and by way of conclusion, they call for shifting the focus from the city to society in developing digital initiatives and cultivating smart social urbanism. Trencher [147] argues that while scholars critique the first-generation, corporate-led model of smart cities for failing to tackle people-oriented agendas and to authentically respond to the needs of residents, many point to the potential to move beyond narrow environmental and economic objectives to address and overcome social issues. The author claims that the techno-economic and centralized approach rather pertains to the first generation model of smart cities, whose primary focus is on the diffusion of smart technologies for corporate interests. This however raises the question as to what trade-offs the so-called socially oriented smart cities are willing to make in order to contribute to the social aspect and quality of life over the economic benefits, including what the cost of these trade-offs will be.

Eco-city planning and development: key problems, issues, and challenges

Since the late1980s, eco-cities have been one of the leading global paradigms of sustainable urbanism and the most preferred response to the challenges of environmental sustainability. As a result, significant advances have been achieved in knowledge of green design and environmental technology, and a multitude of exemplary practical initiatives have been realized across the globe, thereby raising the profile of eco-cities and ecological urban sustainability. The change is still inspiring and the academic and practical endeavor continues to induce and motivate scholars, practitioners, and policymakers alike to enhance the existing models of the eco-city, or to propose integrated models of eco-city development in response to new major global trends or shifts. In particular, the rate and scale of urbanization will escalate over the coming years, and consequently, eco-cities will face new challenges, including creating cost-efficient environments, improving life quality for citizens, maintaining economic growth, and being able to handle dynamic and complex concepts that evolve over time. In the current climate of the unprecedented urbanization of the world, it has become even more challenging for eco-cities to reconfigure themselves more environmentally, economically, and socially sustainable without the use of advanced ICT. Therefore, policymakers, planners, and mangers within the ecologically advanced nations (e.g., Sweden, Denmark, the Netherlands, Germany, the UK, and France) need to promote, develop, and implement innovative solutions for operational management, development planning, and governance to address and overcome the negative effects of urbanization and the complex challenges of sustainability. In a nutshell, new circumstances require new responses.

Yet knowing if we are actually making any progress toward eco-cities as an approach to sustainable cities is problematic. There is a very contradictory, conflicting, and fragmented picture that arises of change on the ground. Given these complex conditions, it is sometimes hard to see where the common challenges of eco-cities may be identified. In addition, producing robust models of the eco-city has been one of the most significant intellectual and practical challenges since the late 1980s (e.g., [59, 102, 149]; Rapoport and Verney [24, 150]). Neither academics nor real-world cities have yet developed convincing models of the eco-city and have not yet gotten specific enough in terms of the design and technology components of the eco-city, despite the advances achieved in eco-urbanism. In other words, it has been very difficult to translate ecological sustainability into the built environment. Indeed, cities are generally characterized by "wicked problems" [151]. This implies that the physical, environmental, economic, and social problems of eco-cities are difficult to define, unfold in unpredictable ways, and defy the standard principles of science and rational decision-making. Wicked problems are difficult to grasp and impossible to solve—normally because of their complex and interconnected nature. They lack clarity in both their aims and solutions, and are subject to real-world constraints which hinder risk-free attempts to find and apply a solution. As a consequence, when tackling wicked problems, they become worse due to the unforeseen consequences which were overlooked because of treating the system under study in too immediate and simplistic terms, or failing to approach that system from a holistic perspective. Rittel and Webber [151] argue that the essential character of wicked problems is that they cannot be solved in practice by a central planner. Therefore, it is impossible to plan eco-cities as urban complexities due to the lack of a complete form of knowledge of the consequences of design and technology proposals or interventions, which is evidently impossible. In addition, realizing the status of the eco-city requires making countless decisions and complex negotiations about urban form, ecological design, urban design, environmental technologies, policy measures, and governance arrangements. Accordingly, the conflicts and contradictions associated with sustainable urban development thinking and practice will continue without conceptual anchor [150].

Research within eco-cities has, over the last two decades, produced contradictory, uncertain, weak, non-conclusive, and questionable results (e.g., [6, 19, 20, 129, 152]). The overall outcome of this research relates mostly to the actual effects or presumed benefits claimed to be delivered by the green design and environmental technology solutions adopted as part of the planning of eco-cities. This relates to the broader tradition within urban scholarship of critical analysis of utopian and "top-down" urban planning [153]. In short, the issue of eco-cities has, both in discourse and practice, been problematic. Besides, much of what we know about eco-cities to date has been gleaned from studies that are characterized by data scarcity and employ traditional data collection and analysis methods, especially case studies. These are associated with inherent limitations, biases, and constraints, often as a result of relying on selective samples. Also, case studies are by definition low in external validity as to how well the outcomes are applicable to real-world settings. Too often, the results obtained from research remain context-dependent and thus cannot be generalized to other districts or cities. In other words, a common limit of case studies is that they do not lend themselves to generalizability due to the issue of the representativeness of the subjects investigated—accessible population—with respect to the target population.

Critically interrogating eco-city projects without taking into account the question of scale renders the analysis of the operationalization of sustainable development quite difficult. A large body of work has addressed various scales and treated questions, such as urban design and planning, environmental governance, and sustainable technologies, from a single street to macro-scale, metropolitan city. There is a variety of notable studies on the implementation of eco-city ideas at various scales (see, e.g., [15, 154, 155]; Simon and Molella 2013 [8, 13]; Pow and Neo [69, 156]). Work on eco-cities should be explicitly aware of the scalar aspects of eco-city projects and of how the geographies of scale are in themselves interlinked with other scales, and with processes operating across scales. With respect to the latter, Bibri [83] concludes that conceiving scales as outcomes of processes and planning accordingly hold in fact great potential for attaining the goals of sustainability beyond a single scale. Sustainability outcomes are multi-scalar in nature, which justifies the need to integrate scales that have clear synergies in their management and planning and need to be coupled. This synergic integration produces combined effects that are greater than the sum of the separate effects of different scales with regard to sustainability benefits.

Scale relates to urban geography and architecture discourses [157–160]. In geography, scale classifies, with large approximation, the size of a land area. It is the extent of an area at which a phenomenon or a process occurs. In architecture, scale denotes "different level of complexity of the components internally arranged to construct a whole" ([161], p. 245). Moreover, some propose that scale could be defined by its functions [162] or by administration boundaries [163]. According to Bibri [83], scale is the geographical or physical structure that both shapes process and emerges from process. In this respect, the scales considered in eco-city projects need to be addressed as relationships between spaces of different dimensions, where the constructed whole of one scale can be a mere component among components at another. However, the scale of city district can enable a better understanding of the built environment as a complex entity and its sub-systems interconnections. It shows promise as an entity to start transforming the built environment in line with the dimensions of sustainability toward a more holistic view in terms of incorporating the full scope of sustainability. Still, it is important to analyze the different scales at which eco-city projects can be considered in order to be able to adequately examine their functioning and planning, and also place them into a more relevant context. Especially, the contradictions associated with sustainability go deeper, as the same effort might increase one aspect of sustainability on one scale (e.g., the city) while decreasing it on another (e.g., the neighborhood). Also, as concluded by Farreny et al. ([155], p. 1131), "the design of neighborhoods in different locations will lead to different results: there is no unique path to achieving urban sustainability or a uniform solution." Several studies have addressed these aspects at regional and city levels from different perspectives (e.g., [6, 152]).

Furthermore, as large-scale system transformation of an entire city at once can be associated with numerous challenges, finding ways for step-wise transitions could be more desirable. To date, much of these transitions have been addressed by aiming to improve individual structures within cities [164]. The scale of city district represents a promising entity as it is usually large enough to include required parameters and systems while retaining a holistic view [14, 165]. In addition, city district developments have become a common expansion route for growing cities and a common way to address and implement sustainability in the built environment (Joss 2015 [11, 14]). They have also become a form of urban innovation lab for testing new ideas and technologies, and could act to lower the threshold to engage essential stakeholders and drive development [15, 166]. However, it is vital to point out that some important challenges remain to be managed when working with the district scale, including the variation in how to define the borders of an urban district. Also, data and information collection can pose a great challenge because information is rarely collected with the correct resolution [13, 41, 42]. Therefore, there is a need to find more effective ways to address and implement the spatial scaling of eco-cities in an attempt to increase the outcomes of sustainability. This relates to the emerging model of sustainable cities, which is increasingly being enabled by urban computing and intelligence in terms of planning and design. Bibri [167] analyzes and discusses the emerging conceptions of and approaches to spatial scales that should be considered in the planning and design of data-driven smart eco-cities. The author highlights the innovative potential of urban computing and intelligence for enhancing and transforming the spatial scaling of eco-cities, and argues that data-driven technologies allow eco-cities to monitor, understand, and analyze the different aspects of their spatial scaling for generating the kind of designs that improve sustainability.

Visions of cities of the future highlight issues central to the analysis of the wider trend toward developing new eco-city projects as a form of experimentation. These concerns are mirrored in the literature on the confluence of interest in enacting sustainable urbanism [168]. However, other questions seem to be overlooked in recent research on eco-urbanism. This involves the need for eco-cities to be the focus of sustained critical engagement which focuses more clearly on the questions of scale and internal social resilience. With respect to the former, eco-city projects need to be considered in light of wider economic, political, and ideological contexts to make sense of new-build co-city projects over and beyond a limited focus on eco-cities as premium ecological enclaves [6, 68]. Regarding the latter, eco-cities should not be considered "only as empty containers into which a new, ecologically sensitive urban society can be inserted, but as potentially problematic spaces in that the social and political are often elided from, or glossed over in techno-rational plans for these new cities" ([6], p. 12). Eco-cities as social systems and communities should have the ability to withstand shocks and return to a state close to normal. Social resilience denotes the ability of a social system, not only to bounce back from events causing a shock through robust behavior, but also to adapt and learn from the past behaviors to surpass the previous state by extending its capacity. Moreover, Cugurullo [129] questions the sustainability of the eco-city by investigating the extent to which it is developed in a controlled and systematic manner. With reference to eco-city projects in China, Cai and Tang (120) point out that the eco-city construction has always been led by the central government and enacted by a top-down approach. Further, Cugurullo [129] counterclaims the mainstream view of eco-urbanism, arguing that what is promoted as cohesive settlements shaped by a homogeneous vision of the sustainable city are actually fragmented cities made of disconnected and often incongruous pieces of urban fabric. Eco-cities also lack social cohesion in terms of the willingness of residents to engage and cooperate with each other in order to prosper, despite the value of involving local communities in decision-making processes in regard to enabling residents to have a say in the development of eco-city projects. As noted by Caprotti [6], in new exemplars of eco-urbanism, few ties bind neighbors to one another, and there is little common or shared interest between residents as members of the urban polity. The author highlights the need to focus on the macro-scale aspects of social resilience at the systemic level, as well as on the micro-mechanisms through which communities and their resilience are built in terms of the appropriation of empty spaces as social spaces and the formation of identities in the eco-city, among others.

In addition, the focus in eco-urbanism has long been on long-term approaches to urban planning, the inability of simulation models to address the current conceptions of the eco-city as a complex system in terms of its optimal design, and the inefficient mechanisms used in city operational management, and traditional governance processes and institutional systems. It follows that most of the inadequacies, shortcomings, struggles, and bottlenecks related to eco-cities are due to how these forms of human settlements have been studied, understood, planned, designed, and managed for several decades. The problems and challenges facing eco-cities are increasingly more complex due to the flows and channels of information, the divergence of agents, the heterogeneity of actors, the dispersion of power, and the difficulty of decision-making (e.g., [2, 17, 20, 41, 42, 62, 123]; Verney and Rapoport 2011 [24]). Nevertheless, this is drastically changing thanks to the innovative potential role of big data technologies in this regard. The abundance of urban data, coupled with their analytical power, opens up for new opportunities for innovation in eco-cities, particularly in relation to linking their infrastructures to their operational functioning and planning through control, optimization, management, and improvements, and thus tightly interlinking and integrating their systems and domains (see [35] for practical initiatives). Indeed, it has been argued that eco-cities need to embrace and leverage what smart cities have to offer in terms of advanced technological solutions so as to achieve the desired outcomes of sustainability under what is labeled "data-driven smart eco-cities." Bibri (2021e [169]) proposes an applied theoretical framework for strategic sustainable urban development planning based on a case study analysis. The novelty of this framework lies in integrating notonly eco-city design strategies and technology solutions; data-driven smart city technologies, competences, and solutions for sustainability; and environmentally data-driven smart sustainable city solutions and strategies, but also compact urban design strategies. These combined hold great potential to improve and advance the contribution of sustainable cities to the goals of sustainability through harnessing its synergistic effects and balancing its dimensions. This is what the eco-city has long sought to achieve as a model for sustainable urban development.

The evolving model of the data-driven smart eco-city

Integrating the prevailing paradigm of sustainable urbanism and the emerging paradigm of smart urbanism

Data-driven smart eco-cities is an emerging global paradigm of urbanism that combines and integrates data-driven cities and eco-cities in terms of their dimensions, strategies, and solutions. This paradigm is increasingly justified by the need to monitor, understand, analyze, plan, design, and manage emerging eco-cities in more innovative ways to achieve the desired outcomes of sustainability, especially when engineering and constructing new-built eco-cities. This need is increased by the ongoing quest and growing motivation for achieving the SDG 11, as well as responding to the challenges of urbanization and its unintended negative consequences.

The phenomenon of the data-driven city has materialized as a result of the emergence of big data science and analytics and the wider adoption of the underlying technologies, the vast deployment of the IoT, the explosive growth of urban data, and the transformation of urban landscape in the light of urbanization [2]. These developments can be used in a range of proposals for a conceptual framework for the data-driven city. This emerging paradigm of urbanism is too often associated with "smarterness" under what is labeled "data-driven smart cities" (e.g., [31]; Dornhöfer et al. [169, 170]; Sutherland and Cook 2017 [171, 172]). This is due to the fact that big data technologies are seen as an advanced form of ICT that can bring more innovative solutions to a number of complex problems and challenges pertaining to sustainability and urbanization. There is no definite definition or a single conceptual unit of a data-driven city, nor is there an agreed industry or academic description thereof. In a broader sense, a data-driven city is a city that implements datafication for enhancing and optimizing its operations, functions, services, strategies, designs, and policies to some purpose. We currently experience intensive datafication of society, and we see the dawn of the datafied society in everyday life, manifested in the various forms of big data technologies permeating the very fabric of the contemporary city. Datafication (e.g., [173–175]) represents an urban trend which defines the key to the core functioning of the city through a reliance on big data analytics and its core enabling and driving technologies in terms of their use for enhancing decision-making processes pertaining to a wide range of practical uses and applications within various urban domains. In a sense, the data-driven city concept emphasizes big data technologies to bring about transformations or changes to city life, which are often claimed to be for the better. This entails embracing and bridging the gap between the basic elements used in the management of the city, including unobtrusive and ubiquitous sensing, intelligent computing, cooperative communication, and massive data management and analytics, as well as governmental and services agencies. Nikitin et al. [136] describe the data-driven city as a city that is characterized by the ability of city management agencies to use technologies for data generation, processing, and analysis aimed at the adoption of solutions for improving the living standards of citizens thanks to the development of social, economic and ecological areas of the urban environment. Bibri [2] conceives of the data-driven city as digitally instrumented, datafied, and networked for enabling large-scale computation to enhance decision making processes across various urban domains for the purpose of improving and optimizing operational management mechanisms and planning development approaches in line with the environmental, economic, and social goals of sustainability.

Drawing on examples from various cities, Caprotti [23] traces the convergence between eco-urbanism and smart urbanism in the past two decades by tracing the eco-city and smart city's conceptual trajectories and how these have become enmeshed into what has been termed "the smart eco-city" from the mid-2010s onwards. The author places the smart eco-city within a broader concern with harnessing the IoT, big data, digital lifestyles, and infrastructures to connect the urban to green economy visions, strategies, and pathways. In the context of this study, the data-driven smart eco-city as an integrated and holistic model of urbanism is approached from the perspective of combining and integrating the strengths of eco-cities and data-driven smart cities and harnessing the synergies of their strategies and solutions in ways that enable eco-cities to improve and advance their contribution to the goals of sustainability through green design and planning, renewable technologies, and environmental governance on the basis of the innovative data-driven applied technology solutions being offered by smart cities. Unlike the smart eco-city in regard to its focus, the data-driven smart eco-city is seen as an experimental city for testing and introducing environmental, economic, and social reforms and bringing about transformations to the built, sustainable, smart, social, and technological infrastructures of the urban landscape [3]. As such, it can be defined as a city that has the ability to use the IoT and big data technologies to generate, process, analyze, and harness urban data for the purpose of extracting deeper insights that can be used and leveraged to make well-informed decisions to address the existing and new problems, issues, and challenges related to sustainability and urbanization. These data-driven solutions can be adopted by city management agencies and city planning and policy offices to improve sustainability, efficiency, resilience, equity, and life quality. An integrated model for strategic sustainable urban development developed by Bibri (2021f [176) based on empirical research combines and integrates—eco-cities, data–driven smart cities, and environmentally data-driven smart sustainable cities—in terms of their strategies and solutions under a novel approach to urbanism: data-driven smart eco-cities. The main contribution of this work lies in providing innovative ways of building future models for sustainable urban development as well as practical insights into developing strategic planning processes of transformative change towards sustainability based on integrated approaches in the era of big data.

Data-based urban management

Urban management tackles the demands of cities which are expanding and redeveloping with policies for land use, structures, and service networks. As such, it should control urban growth and sprawl, change the development focus to the optimization of the urban structure and the renewal of inefficient land use in built-up areas, and encourage the polycentric urban fabric under the condition of sustainable (ecological and compact) development. Theory defines management as the process of designing and maintaining an environment in which individuals, working together in groups, efficiently accomplish selected aims [177]. In the urban sector, people form groups to accomplish aims that they could not achieve as individuals, so individuals have to work together in departments or on projects, while urban organizations must also integrate their activities.

Eco-cities across the globe are increasingly using data and technology to extract useful knowledge to perform critical urban processes and practices to achieve key environmental, economic, and social goals. They are gradually becoming dependent upon their data to operate properly—and even to function at all, and taking any possible quantifiable metric and squeezing value out of it to enhance decision-making pertaining to a wide variety of practical applications and uses in response to the complex challenges of sustainability and the negative effects of urbanization. In particular, urbanization creates enormous environmental, social, economic, and spatial changes, which provide great opportunities for sustainability, with the potential to apply advanced technologies to use resources more efficiently and control them more safely, to promote more sustainable land use, and to preserve the biodiversity of natural ecosystems and reduce pressure on the related services for the purpose of improving economic and societal outcomes. This is indeed at the core of emerging data-driven smart eco-cities, especially new build eco-city projects. In the near future, the performance of data-driven smart eco-cities will be measured, monitored, evaluated, and improved based on the ability of having control over the storage, management, processing, and analysis of the available data, as well as on the quality of the knowledge derived from these data in the form of applied intelligence within many spheres of city administration, such as transport, traffic, street lighting, energy, environment, mobility, waste, water, building, public safety, healthcare, education, and so forth.

The emerging city management mechanisms and approaches related to the administration, organization, and planning of eco-cities enable and support data-driven, model-driven, and evidence-based decisions. Generally, data-based city management involves a number of city management agencies and policy and planning offices that use technologies for generating, processing, and analyzing data to adopt solutions and strategies for improving and advancing sustainability. It is a basic driver for the transformation of urban operations, functions, services, designs, and policies. Therefore, it is expected to dramatically change the principles of eco-city development, to bring cohesion and congruence to urban strategies, and to unify the expectations of different urban actors in ways that render plans feasible and adequate to the reality of urban places and facilitate a shared vision of sustainable urban development.

In eco-urbanism, big data technologies and their novel applications are increasingly seen as the key driver for sustainable development, especially in relation to integrating the three dimensions of sustainability. This involves harnessing the synergies between green design, renewable energy, smart energy, environmental governance, citizen-centered service innovation, intelligent city infrastructure, digitalized water production and distribution, citizen behavior change, and climate change mitigation and adaptation. Therefore, there has been a conscious push for eco-cities across the globe to be smarter and thus more sustainable by developing and implementing data-driven technology solutions so as to optimize operational efficiency, enhance functions, strengthen infrastructure resilience, and improve social equity and life quality. This trend is evinced by many topical studies conducted recently on eco-cities or low-carbon cities (e.g., [23, 35, 37, 39–44, 62, 63, 178–181]). This is owing to the core enabling and driving technologies of the IoT and big data analytics offered by smart cities in relation to sustainability (e.g., [2, 30, 31, 45, 47, 136, 147, 182–189]). With recent developments in big data computing, smart cities offer the opportunity for establishing different urban centers and platforms as hubs of innovation (e.g., [31, 136, 137, 190]) for adopting data strategies for a common good-oriented urban development. Underlying the functioning of data-driven smart eco-cities is a set of platforms and centers associated with data-oriented competences and practices, including (see [95] for a descriptive account):

- Horizontal information systems
- Operations centers and dashboards
- Research and innovation centers
- Educational centers and training programs
- Strategic planning and policy centers

These competences relate to the degree of the readiness of the eco-city to introduce data-driven technology as well as to the degree of the implementation of applied technology solutions with respect to city management. The degree of readiness is characterized by the availability and development level of the technological infrastructure and competencies needed to generate, transmit, analyze, and visualize data. The degree of implementation demonstrates the extensive use of the applied technology solutions in city operational management and development planning in regard to the different areas of sustainability.

The processes and practices of eco-urbanism are becoming highly responsive to a form of data-driven urbanism. One of the consequences of data-driven urbanism is that the systems and domains of eco-cities are becoming much more tightly interlinked and coordinated respectively. And also, vast troves of data are being generated, analyzed, and exploited to understand the multiple complexities and wicked problems inherently embodied in eco-cities so as to make them cleaner, safer, more efficient, liveable, more equitable, more resilient, and, above all, more organized. Indeed, most of the problems, issues, and challenges related to eco-cities largely relate to how these human settlements should be monitored, understood, analyzed, planned, and managed in order to improve their sustainability performance. It is argued that more innovative solutions and sophisticated methods are needed to address and overcome these concerns. Especially, it has become increasingly feasible to attain important improvements of environmental and economic sustainability by integrating eco-cities and smart cities (see, e.g., [37, 43, 44]) as prevalent models of urbanism thanks to the proven role and untapped potential of data-driven technologies as an advanced form of ICT. Bibri and Krgostie (120) develop a novel model for data-driven smart sustainable cities of the future based on the outcomes of four case studies, performed on six of the ecologically and technologically leading cities in Europe. This empirically grounded model combines and integrates the leading global paradigms of urbanism—smart eco-cities, compact cities, data-driven smart cities, environmentally data-driven smart sustainable cities—in terms of their dimensions, strategies, and solutions. This research work revolves around the enabling role and innovative potential of advanced ICT, especially the IoT and big data technologies, in meeting the United Nations' Sustainable Development Goal (SDG) 11. It is also motivated by a number of intertwined factors, which have had a clear bearing on the performance of sustainable cities (specifically, eco-cities, and compact cities) with respect to their contribution to the three goals of sustainability. These factors include, but are not limited to, the following:

- There is an increased need to tackle the problematicity surrounding sustainable cities in terms of their development planning approaches, operational management mechanisms, and fragmentary design strategies and environmental technology solutions pertaining to compact cities and eco-cities, respectively.

- Sustainable cities are quintessential complex systems in the sense that they are:
  - Dynamically changing urban environments,
  - Self-organizing social network embedded in space and enabled by various infrastructures and activities, and
  - Developed through a multitude of individual and collective decisions from the bottom up to the top down.
- The escalating trend of urbanization and its unintended negative consequences.
- Sustainable cities are full of contestations, conflicts, and contingencies that are not easily captured, steered, and predicted respectively. In a nutshell, they are characterized by wicked problems.
- Sustainable cities and smart cities are weakly connected as approaches and extremely fragmented as landscapes, both at the technical and policy levels.
- The real challenge for the future lies in moving genuinely past the assumption that there are only two contrasting, mutually exclusive realities.
- An "either/or" approach will hamper progress toward urban sustainability.

In consideration of the above, the authors construct a vision of a sustainable future based on the theoretical and practical knowledge gained from conducting case study research:

A form of human settlements that secures and upholds environmentally sound, economically viable, and socially beneficial development through the synergistic integration of the more established strategies of sustainable cities and the more innovative solutions of data-driven smart cities toward achieving the long-term goals of sustainability ([191], p. 13).

This vision is a future state where most of the aforementioned problems, issues, and challenges related to sustainable cities have been solved by means of the data-driven technologies and solutions offered by smart cities of the future.

Applied data-driven approaches and solutions for city management: the case of Stockholm City

Therefore, recent research has started to give more attention to what has been called data-driven smart eco-cities, revolving around integrating eco-cities and smart cities in a variety of ways in the hopes of reaching the optimal level of environmental and economic sustainability. As a corollary of this, there is a host of unexplored opportunities toward new approaches to data-driven smart eco-cities. Within the framework of smart cities, many topical studies have addressed a number of areas of environmental sustainability in relation to operational management and development planning using the IoT and big data technologies (e.g., [83, 192–194]; Rathore et al. 2016 [184, 195]). The data-driven technology solutions offered in this regard are increasingly being utilized and implemented in emerging data-driven smart eco-cities with respect to their processes and practices. One of the cases often used as the best practice example in the literature on ecological urban sustainability is Stockholm City. And the success of the city makes it a good sample to highlight in regard to environmental solutions in the context of the emerging model of the data-driven smart eco-city.

Shahrokni et al. [40] identify the inefficiency of waste management and transportation using big data analytics and GIS, and suggest potential improvements. As an outcome of an extensive data curation process, the authors develop a series of new waste generation maps based on a large data set consisting of half a million entries of waste fractions, weights, and locations. These maps serve to describe what waste fraction comes from where and the way it is collected. Moreover, the authors analyze the route efficiency and construct the maps of selected vehicle routes in detail, as well as assess the efficiencies of the routes using the efficiency index (kg waste/km). As a conclusion, substantial inefficiencies are revealed and a shared waste collection vehicle fleet is suggested among other intervention measures to increase the efficiency of waste management.

Pasichnyi et al. [179] present a novel data-driven smart approach to strategic planning of building energy retrofitting, using data about actual building heat energy consumption, energy performance certificates (EPCs), and reference databases. This approach allows a holistic city-level analysis of retrofitting strategies thanks to the aggregated projections of the energy performance of each building, such as energy saving, emissions reduction, and required social investment. The case investigated demonstrates the potential of rich urban energy datasets and data science techniques for better decision making and strategic planning. The proposed approach allows change in total energy demand from large-scale retrofitting to be assessed, and explores its impact on the supply side, thereby enabling more precisely targeted and better coordinated energy efficiency programs. In addition, Pasichnyi et al. [179] review the existing applications of the data of EPCs and propose a new method for assessing their quality using data analytics. The authors identify 13 application domains from a systematic mapping of the analyzed material, revealing increases in the number and complexity of studies as well as advances in applied data analytics techniques. Prior to these two related studies, Shahrokni et al. [39, 40] evaluated the energy efficiency potential of different building vintages, and found that the retrofitting potential of the building stock to current building codes can reduce heating energy use by 1/3.

Bibri and Krogstie [35] investigate the innovative potential and enabling role of data-driven smart solutions in improving and advancing environmental sustainability in the context of smart cites and eco-cities under what can be labeled "environmentally data-driven smart sustainable cities." The results show that smart grids, smart meters, smart buildings, smart environmental monitoring, and smart urban metabolism are the main data-driven smart solutions applied in eco-cities and smart cities in regard to environmental strategies and practices. There is a clear synergy between these solutions in terms of their interaction to produce combined effects greater than the sum of their separate effects—with respect to the environment. This involves energy efficiency improvement, environmental pollution reduction, renewable energy adoption, and real-time feedback on energy flows, with high temporal and spatial resolutions. The authors conclude that data-driven decisions are unique to each city, so are environmental challenges, and that big data are the answer, but each city sets its own questions based on what characterize it in terms of visions, policies, strategies, pathways, and priorities.

Shahrokni et al. [41] present the first implementation of smart urban metabolism (SUM) in a Smart Eco-City R&D project, and further analyze some challenges and barriers to this implementation and discuss the potential long-term implications of the findings. Four key performance indicators (KPIs) are generated in real time based on the integration of heterogeneous, real-time data sources, namely kilowatt-hours per square meter, carbon dioxide equivalents per capita, kilowatt-hours of primary energy per capita, and share of renewables percentage. These KPIs are fed back on three levels (household, building, and district) on four interfaces developed for different audiences. Speaking of performance indicators at the building and household levels, advanced ICT has made it easier to collect performance parameters from the built environment so to be able to carry out a detailed evaluation of energy consumption. Holmstedt et al. [196] examine the potential of using dynamic and high resolution meter data for the evaluation of energy consumption in buildings and households. The novelty identified with this approach is that it can increase the level of detail in the evaluation results and ease the detection of deviations in the structures performance. The authors found that the commonly used indicator energy use per heated floor area remains an inadequate tool for communication when taking a holistic approach to building energy evaluation. Further, as with all ICT-based solutions, there are several challenges, barriers, and issues that need to be addressed and overcome, just as there are opportunities that need to be embraced and explored. One of the challenging barriers identified by Shahrokni et al. [41] lies in accessing and integrating siloed data from the different data owners. Moreover, there are some instances when some residents choose simply not to be involved in, or opt out of, providing data due to privacy concerns. Adding to this is the technical issues related to emission factors, system boundaries, data structure, ontology, heterogeneous data, and multiple sensors tracking the same flow. Also, Holmstedt et al. [196] identify several limitations associated with using dynamic and high resolution meter data for the evaluation of energy consumption in buildings and households, namely data collection and management, preservation of personal integrity, and incentives to react to the given evaluation information. Nevertheless, the SUM framework involves a number of long-term opportunities, which include:

- Allowing citizens, city officials, and other stakeholders to receive real-time feedback on the consequences of their choices in a systematic way
- Enabling a new understanding of the causalities that govern urbanism
- Understanding the GHG emissions resulting from the consumption of electricity, heat, and the generation of waste
- Allowing the follow-up and evaluation of the evolution of urban metabolism, and facilitating the identification of the cause-and-effect relationships of metabolic flows
- Providing rich datasets on energy and material flows at the city level in terms of both production- and consumption-based approaches

In particular, integrating and analyzing data from different city systems and domains to provide real-time feedback to different stakeholders can support intelligent decision making, generate new insights, and make these stakeholders aware of the effects of their actions. This is important to meet the vision of the real-time feedback as outlined in the city's sustainability program for SRS, which represents the joint collaboration effort of utilities, developers, citizens, as well as the departments of the city administration [123].

To sum up, like Stockholm City, many eco-cities across the globe are making substantial efforts for improving their environmental sustainability performance and meeting their sustainability commitments by utilizing the IoT and big data technologies in urban development. They are increasingly relying on the applied technology solutions offered by smart cities in their endeavor to become data-driven smart eco-cities. However, they still tend to focus largely on the environmental dimension of sustainability. Therefore, emerging eco-cities need to balance the three dimensions of sustainability as they evolve by leveraging what urban computing and intelligence have to offer in terms of planning and design. Bibri [83] analyzes and discusses the enabling role and innovative potential of urban computing and intelligence in the long-term, short-term, and joined-up planning of data-driven smart eco-cities, as well as devises a novel framework for urban intelligence and planning functions as an advanced form of decision support. The author argues that the fast-flowing torrent of urban data, coupled with its analytical power, is of crucial importance to the effective planning and efficient design of this integrated model of urbanism. This is enabled by the kind of data-driven and model-driven decision support systems associated with urban computing and intelligence. The novelty of the proposed framework lies in its essential technological and scientific components and the way in which these are coordinated and integrated given their clear synergies to enable urban intelligence and planning functions. These utilize, integrate, and harness complexity science, urban complexity theories, sustainability science, urban sustainability theories, urban science, data science, and data-intensive science in order to fashion powerful new forms of simulation models and optimization methods. These in turn generate optimal designs and solutions that improve sustainability, efficiency, resilience, equity, and life quality.

The relationship between the planning and governance of data-driven smart eco-cities

Ecological planning is, as stated by Ndubisi [197], "a way of mediating the dialogue between human actions and natural processes based on the knowledge of the reciprocal relationship between people and the land" [198]. This knowledge is derived from ecology as opportunities and constraints for decision-making in the management of the natural environment and ecosystems based on strategies and methods for creating green, safe, vibrant, and healthy urban environments. In general, planning involves the application of scientific and technical processes to build consensus among a group of choices for decision-making purposes. Smart ecological planning relies on urban computing and intelligence in terms of enabling enhanced decision-making processes pertaining to the built environment and land use with respect to both their development, design, and regulation as well as the infrastructure connecting urban areas at multiple levels, including transportation system, communication system, and distribution network. Urban computing refers to the process of generating, integrating, processing, analyzing, and synthesizing colossal amount of data from heterogeneous sources for some purpose, ways of improving sustainability, efficiency, resilience, equity, and life quality. Urban intelligence involves the use of big data analytics and the underlying core enabling technologies to devise more effective solutions in the form of designs and responses using advanced simulation models, optimization methods, and intelligent decision support systems. As an integrated approach, urban computing and intelligence (e.g., [199–201]) represents a holistic approach to exploiting the vast troves of data generated in cities to improve urban forms, urban infrastructure, urban environment, and urban services, as well as urban operational management and development planning systems [83]. As such, urban computing and intelligence helps make well-informed decisions, and can also create feedback loops between human activities and the urban environment.

One can think of many examples in the context of the eco-city. As a first example related to a bus network, buses should carry passengers who wait a few minutes to be transported over a few kilometers. Measuring the time in between buses at each stop, possibly together with the number of passengers waiting, gives the planner the basis for a feedback control solution. This entails communicate with buses to enforce desired standards of service, quickly place more or fewer units in service where these parameters start to deviate from the ideal metrics. Consequently, the quality of service as measured by per person waiting time will improve. This type of strategy can be operated automatically by an algorithm with access to the necessary measurements and actions. As a second example, by analyzing data on urban domains (e.g., traffic, environment, and healthcare) public authorities can quickly identify underperforming domains, evaluating improvement and cost-saving potentials, and prioritizing actions for performance efficiency interventions. As a third example, by analyzing the energy consumption of the previous years, public authorities can predict the demand for the next year and take the necessary actions to fulfill that demand, and can also make energy plans for various periods of the year. Overall, the efforts "dedicated to connecting unobtrusive and ubiquitous sensing technologies, advanced data management and analytics models, and novel visualization methods to structure intelligent urban computing systems for smart cities" ([199], p. 675) are increasingly being utilized to develop innovative solutions and sophisticated methods for eco-city development planning and operational management.

Advanced data analytics techniques have become of crucial importance to policy and governance processes due to their role in enabling and enhancing evidence-based decisions, cooperative communication channels, learning and sharing mechanisms, and collective intelligence tools. These are seen as the key driver of accelerating eco-city transitions. The outcome of big data analytics can be used as the evidence base for formulating policies and tracking their effectiveness and impact. Using a data-driven approach to investigate all available evidence from research can generate well-informed decisions based on accurate and meaningful information. The outcome can also enhance stakeholders' collaboration capabilities, increase the capacity to handle challenges, and improve technologies' usefulness, all aimed at achieving the objectives of smart eco-city development in terms of sustainability. This depends on the potential of the interaction and synergy of smart governance components within a specific context. Collective intelligence emerges from the collaboration and collective efforts of many actors and appears in consensus decision making.

The term "governance" has been widely used to describe the relationships between civil society, the state, and private sector with various interpretations. UNDP [202] defines governance as "the system of values, policies and institutions by which a society manages its economic, political, and social affairs through interactions within and among the state, civil society, and private sector." Urban governance refers to how government and stakeholders decide to plan, manage, and finance urban areas. That is, how different actors and institutions are engaged in the planning and steering of the city. These actors and institutions influence urban planning outcomes, including agencies of government, non-governmental organizations (NGOs), community-based organizations (CBOs), trade unions, political parties, businesses, and industries. Urban governance involves a continuous process of negotiation and contestation over the allocation of social and material resources and political power. It is, therefore, profoundly political, influenced by the creation and operation of political institutions, i.e., government capacity to make and implement decisions and the extent to which these decisions recognize and respond to the interests and needs of citizens. This relates to the concept of "good governance," which is widely promoted and considered essential to the effective planning of eco-city development. There are a number of principles for a good governance performance, including:

- Sustainability: balancing social, economic, and environmental needs for present and future generations
- Subsidiarity: taking decisions at the lowest appropriate level of government
- Equity or inclusiveness: level of participation in decision-making and access to basic services
- Transparency and accountability: of decisions
- Civic engagement: of citizens
- Security: of individuals and their living environment
- Efficiency: in services delivery and locally sustainable economic development promotion.

Regarding efficiency, for instance, urban governance should be efficient in such a way as to not use more of societal resources than is necessary to achieve the desired outcomes, as well as fair in that it should not in a structural way prioritize certain social groups over others. However, as regards eco-city development, a good governance performance by local authorities entails providing citizens with a quick and flexible response, allowing them to know and understand the various challenges facing the city and to meet their daily needs. For example, based on the data generated and analyzed on residents' expectations and use of urban space, new streets, parking lots, service facilities, public spaces, public transport routes, and waste sorting stations can be planned in response to new demands. Another aspect of good governance is to have a continuous and creative interaction with civil society. This can stimulate a cultural cooperation between local authorities and citizens, which helps reduce the impact of negative externalities, promoting a greater inclusiveness and efficiency thanks to smart city governance [135]. Gil-Garcia ([203], pp. 274) states that smart city governance is expected to "use sophisticated information technologies to interconnect and integrate information, processes, institutions, and physical infrastructure to better serve citizens and communities." As argued by Sarker et al. (120), smart city governance is a combined function of public, private, and community stakeholders that seek to adapt data-driven technologies in their practices for ensuring urban sustainability.

Smart city governance is a new paradigm of urban policy, planning, and management that is able to solve emerging challenges of urban areas while ensuring urban sustainability. Data-driven technologies provide an opportunity to transform the conventional practices into smart practices at all levels of urban actors in terms of city management. Smart city governance has emerged as a result of the innovative potential and growing role of advanced ICT in the functioning of smart cities and smart eco-cities (e.g., [123, 127, 204–208]). This has made local, regional, and national governmental agencies rethink their functions in regard to the use of new technologies in upgrading administrative systems as part of e-government by streamlining city operations, enhancing decision making processes, and improving the different aspects of sustainability. Smart city governance denotes the capacity of employing technology and innovation as a set of intelligent and adaptive acts and activities for facilitating and supporting enhanced decision making and planning through better collaboration among different stakeholders. From a socio-technical perspective, and based on an extensive literature review, smart city governance means [135]:

- Making the right policy choices or decisions;
- Developing innovative governance structures via ICT; and
- Governing with a focus on the outcome, i.e., dealing with substantive urban challenges.

A systematic literature review conducted by Ruhlandt [209] indicates that various smart city governance definitions exist, and also reveals substantial variances in contextual factors, measurement techniques, and outcomes among the concepts of smart city governance. However, the planning of smart eco-city development is linked to governance in that it is largely government-led and its effectiveness depends on the capacity of local administrations and the acceptance by the majority of urban actors, a function of different stakeholder groups, based on regulatory capacities and framework, and a core mechanism for delivering wider social and environmental goals. Similarly, the governance of smart eco-city development relates to planning in that it plays a critical role in shaping the physical and social character of urban areas; determines the sharing of costs and distribution of resources among different stakeholder groups; affects residents' ability to engage in decision-making, influencing local government accountability and responsiveness to citizen demands; and influences the quantity and quality of local services and enhances their delivery.

In light of the above, the most evident relationship between planning and governance in the context of the smart eco-city lies in that the latter manages a range of actors and institutions and their relationships. This determines and influences how eco-city development can be planned through forging partnerships with and among key stakeholders. Therefore, building smart eco-cities involves complex socio-technical constellations of a variety of actors interacting with and influencing each other on multiple scales. Tu put it differently, smart eco-cities represents a socio-technical assemblage of technologies, services, business models, organizations, regulations, users, norms, visions, and challenges. In this context, smart city governance is seen as a way of supporting the decision-making process and the implementation of policies toward a common good-oriented urban development. It requires the engagement of the administration authorities and governmental agencies at all levels, the socio-economic agents, and the civil society. Here, advanced ICT, particularly big data technologies, plays an important role by contributing to facilitating the exchange of information and the sharing of knowledge, streamlining the operations of urban systems; improving the management of information flows and communication channels; enhancing the mechanisms of learning and coordination; and supporting the development of networks while promoting the cohesion of social, territorial, and spatial components of the city. The socio-technical system of the eco-city is where ICT is embedded and interacts with a social context, comprising formal institutions (e.g., laws, regulations, and standards) and informal institutions (e.g., norms, practices, and values), as well as the built environment and the physical infrastructure and the associated processes. The importance of ICT in governing smart eco-cities lies in that it supports innovative models of urban planning and management, such as appropriate tools, technological resources, procedures, and forms of action, to create conditions conducive to assisting the decision-making agents in dealing with different challenges. Indeed, maintaining the process of eco-city development is an enormous challenge in terms of planning and management, and thus requires an effective collective approach to coordinating actions and decision-making processes, thereby the necessity of advanced forms of smart city governance. These are particularly intended to facilitate more effective city government capacity with respect to the ability of institutions to deliver public services and design and implement development strategies, the adaptability to changing needs or shifting priorities, and the stability achieved through institutionalizing and disseminating good practices.

The smart eco-city depicts a great picture where big data technology can be applied to all aspects of urban development and governance. Based on case study research, Kramers et al. [123] provide insights on how the city administration integrates ICT solutions for urban sustainability into processes of planning in terms of governing the smart eco-city. The authors track how ICT becomes an integral part of the environmental program for the SRS district, how this type of technology is conceived in terms of relation to the planning and implementation of other urban technologies, as well as what expected effects are highlighted. The main conclusion drawn by the authors concerns how ICT and sustainability can be merged in the planning phase of new eco-city developments, and ultimately, how a city administration can govern a city toward a smart eco-city. Smart governance "is about crafting use of new forms of human collaboration through the use of ICT to obtain better outcomes and more open governance processes" [132]. By leveraging the power of big data through advanced analytics, technically derived knowledge can be gained to understand the urban issue and enhance decision-making [204]. Jiang et al. [135] propose a framework for smart urban governance on the basis of three intertwined key components, namely spatial, institutional, and technological components. The authors found that smart urban governance varies remarkably depending on the context in which the environmental, economic, and social challenges facing the city are embedded, which in turn affects and influences the governance modes and ICT functionalities applied in that context. They also indicate that a focus on substantive urban challenges helps to define appropriate modes of governance and develop dedicated technologies that can contribute to solving specific smart urban challenges. It can be concluded that smart urban governance should promote a context-based, socio-technical approach to governing smart eco-cities by understanding their problems, issues, and challenges within their own socio-cultural context. It is important to acknowledge the decisive role of context in analyzing alternative approaches to smart urban governance (e.g., [210, 211]) in terms of its development, application, and effects with respect to sustainability (e.g., [212]).

The negative implications and potential risks of smart urbanism and smart governance

Urbanism is concerned with the study of urban phenomena in terms of the urbanization and organization of cities, as well as the practice of urban planning and development. As an emerging academic field, smart urbanism analyzes and reflects on the varieties and outcomes of smart city development. This involves a large body of mainly applied studies that highlight the opportunities, potentials, benefits, and risks of the solutions of the smart city. Smart urbanism provides a flexible and responsive means of addressing the challenges of urban growth and renewal, tackling environmental problems and building a more socially inclusive society. According to Marvin et al. [34], smart urbanism, "the rebuilding of cities through the integration of digital technologies with buildings, neighborhoods, networked infrastructures and people" is being socially constructed as a unique emerging "solution" to the majority of problems facing contemporary cities, or as "the response to almost every facet of the contemporary urban question." Big data science and analytics as an instance of science and technology embodies an unprecedentedly transformative power—manifested not only in the form of transforming the knowledge of sustainable urbanism, but also in enhancing its practices and fostering its progress under what can be labeled "data-driven smart sustainable urbanism" [213, 214]. Some downsides remain unavoidable though.

The discourse of smart urbanism is deeply originated in normative visions of the future where the salient driving factor for transformation is technology and its constant advancement. However, not only is our current understanding of the opportunities and risks of smart urbanism limited, but we should also expect some pitfalls that are yet to be seen, as new advancements in big data analytics and artificial intelligence will emerge together with unanticipated changing directions of their use for other purposes than what people wish. This is predicated on the assumption that all technological developments come with their dark side. Indeed, future models for smart cities have been extensively criticized in the literature for reflecting techno-utopian, neoliberal approaches to urban development. There is a lack of the theoretical basis and empirical evidence required to holistically evaluate the potential effects and hidden agenda of the transformative processes within smart urbanism in connection with the practices, operations, and institutions of modern society [2]. Yigitcanlar (120) highlights some of the fundamental shortfalls around smart city conceptualization and practice.

While smart urbanism offers seemingly seductive visions of the future in relation to eco-cities, it raises a number of concerns. In recent years, numerous studies have addressed the negative implications of smart urbanism and the ramifications of the infiltration of the associated socially disruptive technologies (e.g., the IoT) into urban life (e.g., [34, 46, 125, 211, 215–217]), including technocratic reductionism, technocentricity, city governance corporatization, dataveillance and geo-surveillance, privacy encroachment, and mind control and manipulation. In addition, smart urbanism has been criticized due to the fact that it:

- Ignores social, political, cultural, economic, and historical contexts shaping urban life;
- Curtails the opportunities for wider perspectives beyond technical systems and scientific processes;
- Breaks city systems into pieces and reduces urban life to logic, calculative, and algorithmic rules and procedures to make the city measurable, tractable, and controllable;
- Lacks the acknowledgement that the urban is not confined to the administrative boundaries of the city;
- Misses on the importance of local social-economic, cultural-political, and environmental contingencies in analyzing the development, implementation, and effects of urban policies;
- Marginalizes certain groups and create multiple divides between those who have access to smart applications and those who do not, especially in relation to public or social services;

- Reinforces neoliberal economic growth, focuses on more affluent populations, and disempowers citizens;
- Distorts the individuality of neighborhoods and strips off the particularities of urban fabrics and localities, such as the history, feelings, concerns, knowledge, and trajectories of urban communities; and
- Risks to psychologically disconnect inhabitants from the environment and disrupts their relationship with nature as a result of their overexposure to technology.

While there is a pervasive belief that new technologies will prevent social, economic, and environmental collapse, data-driven technological fixes show that the negative unintended consequences of science and technology are inherently unpredictable; sustainability improvements do not offer lasting solutions; and advanced technologies, considering the current paradigm of economic growth, do not promote sustainability but instead hasten collapse. Some authors dispute the net contribution of smart urbanism to sustainable urbanism [218, 219]. The failure and inadequacy of smart city initiatives to generate sustainable urban futures is justified by the fact that the current practice of smart urbanism portrays technologically determined, reductionist, and techno-centric approaches to the eco-city, to reiterate. These approaches overlook urban, human, and social complexities, and create conditions for new forms of social control, increased social inequality, and marginalization [220], to reiterate.

Similarly, smart city governance has been criticized due to the fact that it is strongly driven by government policies and the interests and agenda of high-tech companies and corporations (e.g., [221, 222]). Many studies have focused on the potential risks and negative implications of the technocratic, corporate-led approach to smart city governance (e.g., [135, 190, 220–230]), including:

- Concealing those urban issues, conflicts, and controversies that cannot be represented by digital models and embedded in data analytics techniques;
- Emphasizing either the government as the prime initiator of innovative solutions, or the private sector as the provider of ICT-based solutions;
- Treating city governance merely as a management problem that can be dealt with by making use of the power of big data and related analytics techniques;
- Perceiving important urban problems as being solvable primarily through the application of technologically derived knowledge, or reframing urban problems into technological problems and solutions;
- Neglecting the role of contextualization and place-based knowledge in shaping the process of governance;
- Ignoring citizen's involvement in policymaking and public service design, especially in relation to marginalized people who lack digital capabilities and power to engage in the policy making process
- Focusing too much on the technical, engineering, and economic dimensions of urban governance while missing on the role of social processes in configuring its meaning in practice;
- Leaving the smart to the powerful (government and corporate elites) rather than foregrounding it in the lifeworld of different stakeholders, especially citizens and civil society;
- Developing policies that are largely featured with the corporatization and neo-liberalization of urban governance; and
- Leading to highly unequal urban societies, characterized by unequal power relations, social exclusion, and unbalanced distributions of costs and benefits.

The technocratic governance challenges may prevent data-driven smart eco-cities from achieving the desired outcomes of sustainability. What smart urbanism entails and the way it functions raises several critical questions, including whether the governance of data-driven smart eco-cities will become too technocratic as well. Addressing this contemporary concern is of equal importance in achieving the desired outcomes of sustainability by means of advanced technologies. The ideals of eco-urbanism in seeking to take advantage from the emerging data-driven applied solutions being offered by smart urbanism require a "reinvention of governance" Barns ([204], p. 6). To put it differently, there is a need for transformative approaches to smart governance (e.g., [135, 138, 139, 231, 232]). Meijer and Bolívar (2016 [233) argue for new forms of human collaboration in smart governance to attain the desired outcomes, as well as open and transparent processes. Jiang (120) argue for the urgency and need for a transformative perspective on ICT-enabled urban governance as a context-based, socio-technical way of governing cities in response to the problems associated with the technocratic, corporate-led approach to smart governance. Regardless, smart eco-cities need to be framed as complex, dynamic, poly-centric, open, contingent, and relational systems that are full of contingencies, conflicts, contestations, cultural specificities, political tensions, competing interests, and wicked problems, instead of being cast as bounded, measurable, knowable, controllable, and manageable systems that can be steered mechanical ways and predicted based on computational models. This is predicated on the assumption that computational and scientific approaches to cities have been perceived as inadequate to solve urban problems. These are often best solved through social-political solutions, citizen participation, and deliberative democracy, instead of technocratic and top-down modes of governance [234]. All in all, policy frameworks, community approaches, and technology intelligences and their implementation and management to govern smart eco-cities should be interconnected and balanced to drive and secure sustainable urban futures for all.

Knowledge gaps in the area of data-driven smart eco-cities

The area of data-driven smart eco-cities is still in the early stages of its development. Therefore, there are many problems and questions that need to be addressed, which in turn offers a large number and wide range of research opportunities. Accordingly, the numerous knowledge gaps that need to be filled in this regard can be approached from a variety of perspectives, including theoretical, empirical, evaluative, discursive, and futuristic. These involve technical, scientific, socio-political, socio-economic, socio-technical, environmental, and institutional aspects. The knowledge gaps are identified to be critically important for the functioning, dissemination, success, and expansion of the evolving model of the data-driven smart eco-city. They relate to various topics, of which the most relevant to this study are listed in Table 7. Addressing these gaps means supporting and advancing the integration of eco-urbanism and smart urbanism on the basis of the IoT and big data technologies in a bid to integrate and balance the three goals of sustainability.

Conclusions

The underlying idea of SIDs is to combine the strategies of urban sustainability, or to follow the principles of urban ecology, to achieve more sustainable cities in terms of increasing and balancing their environmental,

Table 7 Topics related to the knowledge gaps in the area of data-driven smart eco-cities

- Conceptual and theoretical models for data-driven smart eco-cities
- Analytical frameworks for data-driven smart eco-cities as to three sustainability dimensions
- Assessment methods for evaluating data-driven smart eco-city development at different spatial scales
- Eco-cities and science fiction and utopian discourses
- Socially responsible urban intelligence for eco-urbanism
- Data-driven smart solutions for environmental sustainability
- The economic, social, cultural, political, institutional, and ethical dimensions shaping data-driven smart eco-cities
- Opportunities and challenges for engineering and developing new build data-driven smart eco-cities
- Socio-technical and transformative approaches to data-driven smart eco-city governance
- Balancing techno-centric and human-centric policies in data-driven smart eco-city development
- Eco-social policy integration in the practice of emerging data-driven smart eco-cities
- Political ecology of data-driven smart eco-cities
- Comprehensive models for integrating eco-city design strategies and smart city technology solutions
- Urban intelligence functions for monitoring and developing data-driven smart eco-cities
- Horizontal information platforms and operations centers for data-driven smart eco-cities
- Big data-enabled frameworks and architectures for data-driven smart eco-cities
- The risks and implications of sensorization, hyper-connectivity, and algorithmization on residents
- The negative implications of digitally instrumenting the built environment of eco-cities
- Advanced simulation models for dealing with new conceptions of data-driven smart eco-cities as dynamically changing urban environments and self-organizing social networks
- Simulation models and optimization methods based on the integration of complexity science and sustainability science for optimal designs for improving ecological sustainability
- Models of data-driven smart eco-cities functioning in real-time
- New smart eco-urbanism theories based on data-intensive science
- Data-driven long-term, short-term, and joined-up planning for eco-city projects
- Integrating passive solar, low-energy, and net-zero houses/buildings with smart energy technologies
- Data-driven smart approaches to strategic planning of building energy retrofitting
- Modeling and simulation of SIDs
- Data-driven smart climate change mitigation and adaptation strategies
- Digital ecosystems for smart eco-cities (smart environments, intelligent systems, distributed systems, data management)
- Data-sharing in smart eco-cities (data markets, data governance, privacy and security preserving technologies, data engineering, distributed ledger technologies, ontologies/taxonomies)
- Data-driven citizen-centered service innovation in smart eco-cities (public services, mobility, sharing economy)
- Resilient data-driven smart eco-cities (cyber security, situation awareness, emergency preparedness, intelligent city infrastructure)
- Accelerating renewable energy transitions in data-driven smart eco-cities
- The pace of the diffusion of zero-emission innovations in data-driven smart eco-cities
- Influence of policy discourse networks on local renewable energy transitions in smart eco-cities
- Challenges and barriers to the upscaling and diffusion of environmental innovations in data-driven smart eco-cities
- The impact of data-driven smart technologies on the pace of renewable energy transitions in eco-cities
- The impacts of evidence-based policy decisions on the pace of environmental innovations in eco-cities
- Best practices for the rapid diffusion of environmental innovations in data-driven smart eco-cities

economic, and social benefits and dimensions, respectively. The basic idea of data-driven smart eco-cities is to explicitly bring together eco-cities and smart cities as practical urban endeavors to address and overcome the key problems, issues, and challenges facing eco-cities in ways that continuously optimize, evaluate, and enhance their performance with respect to sustainability as to its tripartite composition. As a strategic sustainable urban development approach, data-driven smart eco-cities are being represented as a flexible and responsive means of rising up to the challenges of sustainability in the face of the escalating trend of urbanization. They are also socially constructed as a unique emerging solution to the majority of environmental, economic, and social problems faced by eco-cities today. Modern eco-cities holding unparalleled potential to address and overcome these challenges and problems largely depends on how and the extent to which they can be planned, designed, and governed in response to emerging societal trends, scientific discoveries, and technological advances. Appropriately engineering and building or redesigning and restructuring urban places as eco-cities/districts and adopting innovative solutions to make urban living more ecologically sustainable is a continuous endeavor toward achieving the three goals of sustainability.

This paper provided a comprehensive state-of-the-art literature review on SIDs and data-driven smart eco-cities. Specifically, it endeavored to deliver a detailed analysis, critical evaluation, compelling synthesis, and well-worked discussion of the available research covering the topic of eco-cities, sustainable urban districts, and smart cities in terms of their integration—with new insights and perspectives as a result of combining the narrative and best-evidence synthesis approaches to the literature review. In doing so, it identified, described, and discussed the conceptual, theoretical, discursive, and practical underpinnings of eco-urbanism. This is meant to facilitate the integration and fusion of the different disciplinary fields underlying the field of eco-urbanism for the sheer purpose of generating the kind of interactional and unified knowledge needed to gain a broader understanding of and readily explore the topic on focus. Afterwards, this paper shed light on the ideals, benefits, and guiding principles of eco-cities with respect to urban sustainability and urban ecology. Then, it delved into sustainable integrated cities in terms of shortcomings and deficiencies, emerging planning practices and development strategies, and evaluation of sustainable urban districts, with a focus on the integration of eco-urbanism and compact urbanism. Next, it addressed eco-cities as techno-enviro-economic experiments for transition, discussing several issues from various perspectives, including ecological modernization, transition studies, innovation studies, and social studies of technology. This is followed by the role of the solutions being offered by the smart city in improving the social performance of the eco-city, with an emphasis on citizen participation and the quality of life, together with some critical perspectives. Subsequently, this paper discussed eco-city planning and development with regard to current deficiencies, shortcomings, difficulties, and uncertainties, focusing on the key problems, issues, and challenges pertaining to eco-cities from a variety of perspectives. Following that, it detailed and documented the evolving model of the data-driven smart eco-city in terms of integrating the emerging paradigm of smart urbanism and the prevailing paradigm of sustainable urbanism, data-based urban management and the potential role of the applied data-driven technology solutions for operational management and development planning in boosting the performance of eco-cities, and applied data-driven approaches and solutions for city management using the case of Stockholm City. This is followed by elucidating the relationship between the planning and governance of data-driven smart eco-cities, supported by a detailed conceptual and analytical discussion. Lastly, this paper attempted to develop a critical understanding of smart urbanism and smart governance, focusing on their potential risks and negative implications from different perspectives and how and to what extent the emerging data-driven smart eco-cities can be consequently affected by these drawbacks.

This study revealed that eco-city district developments are increasingly embracing compact city strategies and becoming a common expansion route for growing cities to achieve urban ecology or urban sustainability. It also showed that new eco-city projects are increasingly capitalizing on data-driven smart technologies to implement environmental, economic, and social reforms. This is being accomplished by combining the strengths of eco-cities and smart cities and harnessing the synergies of their strategies and solutions in ways that enable eco-cities to improve their performance with respect to the three dimensions of sustainability. This in turn means that big data technologies will change eco-urbanism in fundamental and irreversible ways in terms of how eco-cities will be understood, analyzed, planned, designed, and governed. However, smart urbanism poses significant risks and drawbacks that need to be addressed and overcome in order to achieve the desired outcomes of ecological sustainability in its broader sense. One of the key critical questions raised in this regard pertains to the potentiality of the technocratic governance of emerging data-driven smart eco-cities and the associated negative implications and hidden pitfalls.

The contribution of this review lies in providing a valuable reference for scholars, practitioners, and policymakers, and the necessary material to inform them of the latest developments in the area of SIDs and data-driven smart eco-cities. This review enables scholars to focus their work on the identified real–world opportunities and challenges pertaining to these integrated models for urban development. Practitioners and policy-makers can make use of the outcome of this review to identify the weaknesses of eco-cities and to find more effective ways to address these weaknesses based on the emerging applied data-driven technology solutions offered by smart cities. However, while advanced technologies can bring numerous advantages to eco-urbanism, it is important to acknowledge the fact that they can be problematic, and therefore, policy-makers and planners should be careful when employing them.

It is hoped that this study will provide the grounding for further in-depth research particularly in the emerging area of data-driven smart eco-cities. Especially, a large part of the problems in this area is still not addressed, with many diverse critical aspects being fleshed out as part of the research endeavors being undertaken within different disciplines or fields. There are also many problems that have not been addressed well or appropriately by any of the existing research in the areas of both SIDs as well as data-driven smart eco-cities. This pertains particularly to how to integrate and balance the dimensions of urban sustainability using advanced technologies, as well as to the multiple forms of integrating eco-cities or districts and smart cities at the technical and policy levels so as to make actual progress toward urban sustainability. There is a host of unexplored opportunities toward new approaches to data-driven smart eco-urbanism. This is key to mitigating the extreme fragmentation and the weak connection pertaining to eco-cities and smart cities through developing multiple visions of sustainable futures. Data-driven smart eco-cities are a fertile area of interdisciplinary, transdisciplinary, and cross-disciplinary research involving numerous intriguing and multifaceted questions awaiting scholars and practitioners from across many city-related academic or scientific disciplines.

Abbreviations

CCI: Clinton Climate Initiative; IEFS: International Economics and Finance Society; GHG: Greenhouse gases; ICT: Information and communication technology; IoT: Internet of things; KPIs: Key performance indicators; NGOs: Non-governmental organizations; SDG: Sustainable development goal; SIDs: Sustainable integrated districts; SRS: Stockholm Royal Seaport; SUM: Smart urban metabolism; CBOs: Community-based organizations

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