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A framework for exploring futures of complex urban energy systems

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In order to address the climate crisis and provide citizens with clean, secure and affordable energy, urban energy systems need to transition. This is significant as urban energy systems are increasingly seen as complex systems for their close interactions with local urban society, while being interdependent with higher levels of governance. Decisions taken today will continue to influence the inhabitants of our cities for well over 50 years, locking in energy consumption patterns of the future. How, then, do we make decisions on the interventions needed to bring about a desirable future, and prepare for the probable and possible futures? In this paper, we consider the key characteristics of urban energy systems from a complexity science perspective in order to explore what methodologies in futures and foresight scholarship could be beneficial in supporting urban energy decision-making. To do this we have undertaken an integrative review—a method that allows review, synthesis, critique, and analysis of new and emerging topics across multiple disciplines and multiple literature types—and consider the findings in light of their usefulness in understanding complex systems, which are inherently uncertain. We consider how futures and foresight theories and methods can be applied in urban and energy studies, highlighting examples of where around the world these have been applied by organizations seeking to shape transitions. The many methods and approaches that exist under the futures' umbrella have not been applied to anywhere near their full potential in urban energy studies, despite the limitations of many of the planning and modeling exercises currently used. We use key learnings from existing futures and foresight scholarship, along with our understanding of urban energy systems as complex adaptive systems, to propose a theoretical and practical framework for exploring their futures. The framework encompasses concepts of futures, contextualization, mapping uncertainty, participatory processes, and futures governance. Although there is much further research work needed to test and operationalize this framework in an applied way with city stakeholders, we hope this charts a way forward in addressing the critical challenges faced by urban energy planners and their partners.

KEYWORDS

complexity, futures, foresight, urban energy, decision-making, local policy, scenarios, cities

1. Introduction

The way urban energy systems shape up, in the long run, will profoundly define urban societies for several generations to come—potentially perpetuating socio-economic structures, locking in resource needs, and creating new externalities. Therefore, examining and guiding the long-term future of the ongoing urban energy transition is of paramount significance. However, energy systems are complex systems in that they are multiscalar and multidimensional where many autonomous elements interact over time to emerge into a state that is *greater than the sum of its parts* (Bale et al., 2015). The complex systems paradigm is further underscored in the case of urban energy systems because of the place-specific characteristics that are closely tied to local societal complexities and historical context (Basu et al., 2019; IRENA, 2020a). This follows the urban studies scholarship that has long seen cities as complex systems, and has engaged in developing tools and frameworks to manage these complexities.

The complexity science scholarship propounds that complex adaptive systems, such as the urban energy systems, are a nested set of highly interactive and interdependent sub-systems but also simultaneously exhibit characteristics of self-organization, emergence, co-evolution, non-linear dynamics, positive and negative feedback that manifest over time, scales, and space (Basu et al., 2019). As a consequence, the future of such systems is continuously emergent, embodying the intersection of a wide spectrum of ideas, aspirations, and imaginaries (Jantsch, 1972; Floyd, 2012; Ravetz and Miles, 2016; Tõnurist and Hanson, 2021). Uncertainty and unpredictability then become features of such systems, and not only challenge any long-term static targets but also render incompatible notions of top-down *system architects*, linear evolution, centralized governance mechanisms, or optimization of system outputs (Ruth and Coelho, 2007; Samet, 2013; Heinonen et al., 2017a; Roelich and Giesekam, 2019). This can lead to policy paralysis and short-termism in public policies for complex systems and potentially obscure complex dimensions such as justice, equity, and fairness in energy systems transition (OECD, 2022). How then can policymakers think about the long-term future of urban energy systems from a complex systems perspective? What steps can policymakers take today to deal with such complexities and uncertainties? In this article, we undertake a multidisciplinary review of theories, approaches, and methods to answer these research questions.

The paper is set out as follows. In Section 2, we underline the relevance of this research by highlighting the limitations in current academic and policy initiatives related to urban energy systems planning. We also outline the approach and methodology followed for this review. Section 3 covers a detailed review of the futures and foresight literature to identify concepts, frameworks and methods that may be useful for conceptualizing futures for urban energy systems. It includes a specific discussion on the contributions of complexity systems framing on futures scholarship. In Section 4, we examine the conceptualization and practice of futures assessment in public policy studies, energy, and urban studies, and identify the gaps and learnings. We then summarize key learnings in Section 5, and propose a framework and a methodology for understanding the futures of complex urban energy systems. We conclude the paper in Section 6 and make suggestions for future research.

2. Urban energy systems and the need for futures thinking

In energy systems studies, futures hold special significance in light of multiple crises such as climate change, security of supply, and environmental degradation. With an urgent need for radical transformation, energy futures are mostly defined in terms of greenhouse gas and atmospheric pollutant emission reduction targets. Net zero is one such instance of an energy future that sets specific demands on the energy system and shapes the kind of technologies, scale, and sectors that an energy transition will prioritize today. Of late, there have been calls for energy systems to move beyond techno-economic objectives to capitalize on the inherent multidimensionality of new energy systems. This implies a practical recognition of energy systems' interlinkages with other sectors and delivering more than one objectives that cut across—material, societal, political, economic, and environmental aspects of the future. Urban energy systems have gained significant recognition as a distinct scale (municipal authorities, districts, city regions, local communities) because of their potential to deliver on these objectives (IPCC, 2022).

Despite energy planning being conventionally associated with national governments, urban governments across the world are setting climate targets or plans that hinge on the energy systems transitions in their cities. This more recent turn toward energy-futures thinking at the urban scale has been as a response to concerns about climate change, costs, and other environmental externalities at the local level (Britton et al., 2022). Driven largely by international city networks such as Covenant of Mayors, C40, RE100, a large number of city governments are setting targets on renewable energy, net-zero, or carbon neutrality (Mirakyan and De Guio, 2013; Leal and Azevedo, 2016; IRENA, 2020a; REN21, 2021).[1] Therefore, planning exercises for energy systems by city governments tend to be driven by normative policy ambitions often framed as a predetermined technical or quantitative target. There are two main interrelated ways in which these targets are approached. Firstly, through a methodological process of urban energy planning that lays down the actions that will deliver the emission targets. One of the most popular methodologies is Sustainable Energy Action Planning (SEAP) propagated by the Covenant of Mayors for inculcating a longer-term planning practice amongst signatory cities (Broersma and Fremouw, 2015; Croci et al., 2021).[2] While open to interpretations, SEAP like similar academic efforts such as Strategies Towards Energy Performance and Urban Planning (STEP UP) (2015) and Van Warmerdam (2016), focuses on short-term goals with little focus on interdependencies (Broersma and Fremouw, 2015).[3] Croci et al. (2021) show from an analysis of SEAPs across 124 European cities that there is significant room for integration of energy planning amongst different subsectors. The study also finds that most of these plans focus on limited public sectors (public buildings and transport) and plan for the next 10 years or shorter. Bernardo and Alessandro (2019) attempt to assess the impact of sustainable energy action plans on local development with the help of system dynamic modeling (Bernardo and Alessandro, 2019). They find that there is a need for a systemic understanding within such plans to avoid indirect feedback that can potentially jeopardize the intended emission reductions. Secondly, urban energy modeling techniques have been equally prevalent in urban energy planning

1 As of 2020, 653 cities had declared a target of 100% RE, 10,500 cities have passed CO2 emission targets, 800 cities have passed net-zero targets (REN21, 2021).

2 Targets set at achieving at least 20% emission reduction by 2020.

3 STEP-UP: Strategies Towards Energy Performance and Urban Planning; TRANSFORM: TRANSFORMation agenda for low carbon cities.

exercises for achieving these targets (Mirakyan and De Guio, 2013; Horak et al., 2022). These models, typically seeking resource flow assessment, optimization or simulation or all three, do not necessarily encourage a long-term assessment [see Moghadam et al. (2017) for a comparison of different models]. Like general energy models, urban energy models have been widely critiqued for their lack of (1) integration (Moghadam et al., 2017; Yazdanie and Orehounig, 2021; Horak et al., 2022)[4]; (2) uncertainty [for instance, the perfect market assumption (Abbasabadi and Mehdi Ashayeri, 2019; IRENA, 2020a; Yazdanie and Orehounig, 2021]; (3) embodied energy considerations (Abbasabadi and Mehdi Ashayeri, 2019; Horak et al., 2022); (4) participatory aspects in the prescribed energy planning exercises (Corsini et al., 2019). These gaps in urban energy planning also affirm the limited exploration of complexity thinking in urban energy planning for the future (Basu et al., 2019). Recent research projects such as City-zen and Local area energy planning (LAEP) have proposed new composite approaches to short-term energy planning in urban areas (Energy Systems Catapult, 2020).[5] Isolated urban energy studies have begun exploring tools of futures and foresight development within a limited scope (Dixon et al., 2014; Pereverza et al., 2019). While these are welcome academic and policy initiatives, there remains a need for a systematic exploration of developing urban energy futures from a complex system point of view that can be applied by city governments.

In this paper, we develop a multidisciplinary understanding of urban energy futures from a complex systems perspective as a means to embrace the uncertainties, interlinkages, and feedback intrinsic to such systems. To do this, we have undertaken a literature review of futures and foresight studies and its application in the disciplines of complexity theory, energy, public policy and urban studies. The review focusses on (a) the conceptualization of futures from a complex systems perspective, (b) analyzing the key approaches for operationalizing complexity in futures development (futures and foresight studies), and (c) identifying the best practices in real policy spaces (implemented policy frameworks). We argue that a systematic and scientific study of the futures, as has been attempted by particularly the futures and foresight studies (and other interlinked fields), may be able to respond to some of the gaps and concerns highlighted above in long-term urban energy systems planning. Futures thinking, as applied across multiple disciplines, foregrounds the complexities of the present world systems and unpredictability of the future by dovetailing theories of complex systems and deep uncertainty with practical tools for systematic future assessment by decision-makers in a multitude of contexts. In practice, this would imply not just a radical change in the way energy and climate planning is undertaken by cities today but also suggests a change in governing approach. We build on these findings to offer learnings, a methodological framework, and a methodology for developing a systematic way of thinking about the futures of complex urban energy systems.

To achieve this, we have adopted an integrative approach for the literature review that allows review, synthesis, critique, and analysis, of new and emerging topics across multiple disciplines and multiple literature types (Snyder, 2019; Cronin and George, 2020). Torraco (2005) suggests that an integrative review method is particularly suited to new and emerging topics where the synthesis can help in developing an initial or preliminary conceptualization (Snyder, 2019). The integrative review method allows researchers the discretion to choose between the balance of the different literature streams or "communities of practice" identified and the completeness of a review, depending on the objective of the study (Cronin and George, 2020; p. 2). The schematic above outlines the steps taken to develop the framework and methodology (Figure 1).

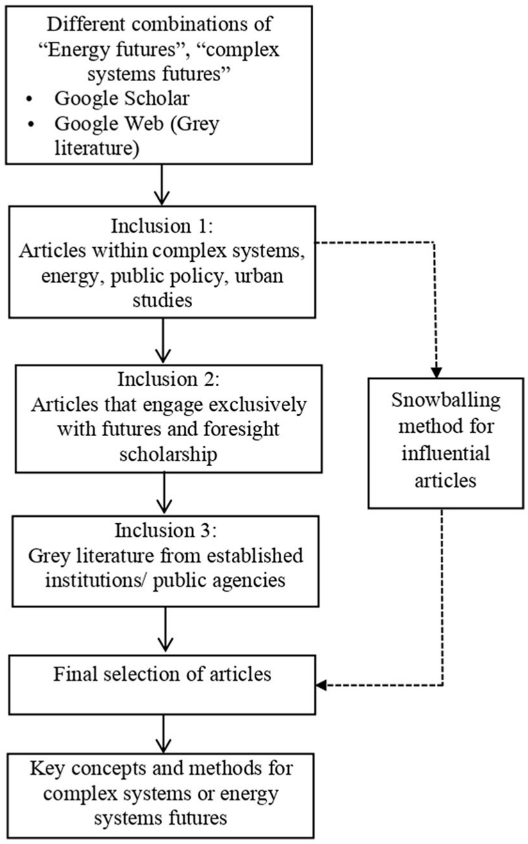

FIGURE 1
Integrated literature review method.

The review explores multiple concepts across the above mentioned disciplines. Here we introduce the concepts that are central to the rest of the paper.

- *Futures* are the broader rubric of studies systematically examining the future, whether it is through extrapolating, forecasting, simulating, reflecting or qualitative deliberating context and emerging trends. It attempts to answer both "what the knowledge of the future may mean" and "how to acquire knowledge of the future" (Torraco, 2005: p. 178). The literature postulates that the future is plural at any given point in time (as signified by the ubiquitously used word *futures* in the literature). This is particularly true for complex systems where multiple dynamically interacting parts over time can deliver

4 Despite efforts for integrated modelling tools such as CitySim, HOMER Pro, LEAP.

5 http://www.cityzen-smartcity.eu/home/about-city-zen/objectives/

any version of the possible futures (or even those considered impossible today).

- Futures are typically differentiated on the basis of the chances of their occurrence. *Possible* ("might happen"), *plausible* ("could happen"), *probable* ("current trends"), *preferable or desirable* ("should happen"), and *projected* future (extrapolated from today) are some of the futures prevalent in the literature (Voros, 2003; p. 11). With long-term futures, uncertainty is a given. *Uncertainty* has been defined in multiple terms, such as indeterminacy of the components of a system, randomness in actions and unpredictability of the outcomes. With the involvement of social systems in technological systems such as energy, uncertainties get compounded. Within uncertainty, different types of uncertain events have been conceptualized: *Black Swan*—unanticipated, unpredictable events with large impacts; *Black Jellyfish*—anticipated but unpredictable with big impacts; *Grey Rhino*—highly likely, high impacts; *Black elephant*—anticipated but unknown levels of high impacts (Tõnurist and Hanson, 2021).
- *Foresight* is a specific sub-discipline of futures studies that focuses on the practice of future assessment in the fields of public policy, corporate management, and technological development. Foresight seeks to understand "what chances for developments and what options for action are open at present, and then follow up analytically to determine what alternative future outcomes the developments would lead" (Martin, 2010; p. 1441).
- *Anticipatory governance/innovation* is about thinking and acting upon the future, wherein evolution can be steered consciously. Additionally, Tõnurist and Hanson (2021; p. 31) posit that it also entails the aim "to shape people's perceptions about the future and develop their capacity to make sense of novelty." Governance and innovation are related to the wider set of activities that facilitate this steering.
- *Adaptive policies/governance/foresight*—Adaptive approaches are a response to the deterministic ways of forward-looking policies, limitations of influencing the future, and uncertainties that are inevitable in the long term. These approaches can be considered part of a broader policy position that encourages "adapting swiftly to changing circumstances" (Eriksson and Weber, 2008: p. 46).

3. Futures and foresight

The futures and foresight scholarship involves the systematic study of the possible, probable, and desirable futures, and how a certain vision might be reached in a world of uncertainty (Fergnani, 2019). Because of the focus on the temporal aspects of a sector or society, with an objective to change the present and concern about the unknown, futures studies have integrated concepts of complexity and uncertainty, and hence emergence, at the heart of its theories. As Kuosa (2011a; p. 331) argues, the study of futures requires a "unique epistemology" that differs from normal science in how it is to be inferred. H.G. Wells was one of the first scientists to initiate the systematic study of futures in 1932 (Sardar, 2010). A diverse range of approaches to futures evolved as a result of the frustrations associated with *prediction, forecasting and control* methods—particularly during the 1970s oil crisis (Slaughter, 1998; Cuhls, 2003; Cagnin and Keenan, 2008; Frau, 2019). Futures scholarship has evolved over several decades into this plural space with co-existing paradigms and related approaches such as anticipatory, adaptive, participatory, or integral (Frau, 2019). The prominent approaches, discussed in the sections below, originate from a complex-systems view of the world (Inayatullah, 2005; Kuosa, 2011a).

Organizational branches of futures studies (military studies, trade and business) can venture out to highly rational forms of assessment (particularly *anticipatory*), while other sub-branches, such as foresight, allow more eclectic, qualitative approaches to the study of futures (Kuosa, 2011a; Samet, 2011). Foresight-oriented approaches also encourage *participatory* methods of futures that draw on memories of the past, lived experiences of the present, and aspirations of the future (Martin, 2010). Another important paradigm of future studies is the *Integral Futures* theory that encourages a layered view of the future with the help of four distinct but interconnected lenses of intentional (individual's consciousness/motivation), objective (individual's behavior), cultural context, and social context (Slaughter, 1998, 2008; Collins and Hines, 2009). The approach posits that there are multiple ways, even multi-paradigmatic, of conceptualizing futures and encourages an inclusive, participatory approach to encompass a wide range of perspectives.

Foresight studies, in many ways, broaden the horizon of future studies. They shun prediction of the futures and instead focus on generating multiple futures in a more consultative and dialogic manner (OECD, 2016, 2019). They also provide a more long-term view than typical projections or forecasts allow (Jones, 2017). Ramos (2017: p. 4) describes how foresight studies have evolved to include more "predictive, systemic, critical, participatory and action-oriented" aspects. As a result, foresight exercises have gained currency in formal policy and decision-making circles. Since the 1980s, the governments of the Netherlands, European Union, Australia, Finland, and Canada, among others, have adopted foresight development in formal policymaking processes (Cuhls and Georghiou, 2004). Foresight studies have been adopted and adapted by the OECD as a mechanism to prepare countries for uncertainties and "governance of risks." The European Union (EU) defines foresight as "a systematic, participatory, future intelligence-gathering and medium-to-long-term vision-building process aimed at present-day decisions and mobilizing joint actions" (Kuosa, 2011a; OECD, 2022). Table 1 provides details of select well-known examples of foresight in practice in formal policymaking platforms. As is also evident in these methods, a key offering of foresight studies is that they offer integrated multi-method processes (both qualitative and quantitative) that go beyond traditional methods of scenario planning and trend analysis. Jones (2017: p. 663) elaborates this, "many foresight insights arise from imagining and reasoning about the future using and combining different forms of evidence. Foresight relies on interpretive and abductive reasoning from ambiguous and often provisional present data."

TABLE 1 Application of futures methods in policymaking in different institutions.

Institutions	Exercise	Approach	Key features	Addressing complexity	References
Finland	Energy and climate roadmap 2050	Extensive and recursive expert and citizen participatory process to develop scenarios	Methods such as Futures Wheel, Futures tables, and participatory processes such as World Café, "Me-We-Us," surveys used	Focus on expanding the base of participation to identify wide-ranging factors	IRENA, 2020b
Costa Rica	National decarbonization plan 2050 Cost and benefits of NDP	Extensive citizen engagement in the entire process Qualitative as well as quantitative analysis	Integrated models focusing on multisectoral interactions, used in combination with RDM to enhance robustness through stress tests	Interactions across sectors (though limited and quantitative) and uncertainties considered	World Bank, 2020; IRENA, UNELCAC, GET.transform, 2022
Newcastle City Council	Newcastle city futures to radically transform public services and infrastructure	Systems approach to smart city development	Each subsystem identified in detail Participatory efforts toward identification strategies Outcomes include funding leverage, demonstrator projects Cross-sector forum City policy cabinet	Systems of systems mapping (5-step including boundaries, architecture) Future actions graded along impact and deployment maturity matrix. Uncertainties only partially addressed	Government Office for Science, 2013; Ravetz and Miles, 2016
Singapore	National strategic foresight	Mainstreaming futures thinking in the national policymaking institutions Centrally coordinated drive for futures initiatives in individual sectors	Institutional structures: Center for Strategic Futures (CSF) part of PMO Risk Assessment and Horizon Scanning Programme (RAHS) Strategic foresight unit within Ministry of Finance	Cross-sectoral government capacity in futures thinking	Kuosa, 2011b; OECD, 2019
European Commission	Participatory foresight feeding into Horizon 2020 and Horizon Europe	Citizen-oriented workshops to contemplate, deliberate and envision preferred futures Key question: What should the future look like?	Step process for envisioning future; includes sending background information to citizens, workshops with citizens for visions, and needs, complimentary recommendations by experts	Extensive participation by citizens in developing vision	Rosa et al., 2021

3.1. Complex systems and futures

Complexity science has been considered a unifying element for the theory development of the futures studies (Samet, 2012). Complex systems have been defined as "an entity, coherent in some recognizable way but whose elements, interactions, and dynamics generate structures and admit surprise and novelty that cannot be defined apriori" (Batty and Torrens, 2005: p. 355). Socially-embedded systems such as urban systems or energy systems with heterogeneous, autonomous, hierarchical elements and deep, non-linear interlinkages fall under the definition of the complex system. Complexity stems from the intractability of all interactions and consequences, challenging the commonly understood causal nature of relationships between elements (SAPEA, 2019). Therefore, an important aspect of futures, particularly under the complexity lens, is the issue of the unpredictability of futures.

The inadequacy of linear causation models involving forecasting and prediction stems from the complexity of socio-technical or socio-ecological systems (Wright and Goodwin, 2009; Samet, 2011; Van Asselt et al., 2012; Jensen and Wu, 2016; Labanca, 2017). Johnson (2010: p. 167) argues, "What does it mean to make a prediction when the final state that characterizes the prediction will never be reached?" This is characterized by *emergence*—a concept synonymous with futures in complex-systems studies. It essentially implies that the aggregate behavior of multiple elements and their feedback mechanisms eventually delivers a system that may be fundamentally different from the input conditions or distinct from the constitutive elements (Batty and Torrens, 2005; Samet, 2010). This creates a "far-from-equilibrium" state and challenges the equilibrium-based notions within conventional modeling practices (Samet, 2011; p. 832). However, complex systems are also uniquely sensitive to their initial conditions (Gentili, 2021). Therefore, futures, under a complex systems lens are indeterministic but not completely malleable (McDowall, 2012). Samet (2012) also asserts that the emergence does not signify a complete lack of control, but critical intervention points can influence the trajectory of the evolution of a complex system. Batty and Torrens (2005) also support this view and argue that if an extensive understanding of the systems' interactions is captured and the ability of the system to respond in multitudinous ways can be accepted, complex systems can be manageable.

Li Vigni (2020) draws and contributes to a set of "future regimes" proposed by sociologists Chateauraynaud and Debaz (2017) that reflect different types of thinking about the future. Out of the several types identified, a few key future regimes are defined below (Li Vigni, 2020):

- *Urgency/emergency*—Limited time to act and back-up plan is needed.
- *Anticipation*—Future is uncertain but possible to imagine and assessed partially. Preparedness for different scenarios is followed.
- *Prediction*—Future is linear and hence, possible to quantify. Linear progression, and modeling are used.
- *Prospective*—Future is perceived to be non-linear, open and uncertain. Scenarios are used to deal with plurality.
- *High frequency*—Future is viewed as short units of time. Therefore, prediction and anticipation over the short term are combined.
- *Optimization*—relating to an open future and resorts to adaptive management and automatization.

Li Vigni (2020) further argues that complexity science literature, however, has been, at best, ambivalent about the development of futures. He identifies five different types of expert communities (ranging from computational physicists, and epidemiologists to economists, geographers and even social scientists) within the complexity science scholarship that are engaging with these future regimes. The approach to understanding futures spans from fine-grained computer simulations to broad narrative scenario development, to merely understanding futures through qualitative and discursive means rather than predicting futures (see Table 3 in Li Vigni, 2020).

In addition to the *system extensiveness* of the complexity lens, policymakers often find unpredictability associated with complexity paralyzing and deters them from taking long-term action, often opting instead for straitjacketed short-term solutions (Batty and Torrens, 2005; Tõnurist and Hanson, 2021). Accommodating uncertainty runs counter to the "traditional model of policy design and the overall 'evidence-based policy' movement" (Tõnurist and Hanson, 2021; p. 13). Scholars prescribe incremental and continuous learning, adaptive policymaking/planning, and anticipatory governance for practicing complexity instead of deterministic strategies toward a specific end goal (Cooney and Lang, 2007; Sanderson, 2009; Wilkinson et al., 2013; SAPEA, 2019; Cosens et al., 2021). These approaches, in turn, automatically depend on collective intelligence across sectors, disciplines, scales, evidence, and viewpoints—necessitating a participatory approach (Ziegler, 1991). Thus, exploring the futures of a complex system will not just need a new approach to understanding and conceptualizing futures, but also a different ontological and epistemological, as well as a new decision-making approach to governing them.

3.2. Uncertainty and complexity

Uncertainty surrounding the future and managing this uncertainty is a main concern of complexity science advocates, particularly to aid decision-making. Uncertainty has been theorized in policymaking as the nature and types of future events one cannot anticipate. Scholars have identified epistemological and ontological uncertainties where the former stems from the lack of knowledge of systems and the latter stems from the uncertainty around the make-up or existence of the system itself (Nanayakkara et al., 2020). Fox and Ulkumen (2011) also differentiate between aleatory and epistemic uncertainty wherein aleatory depicts the uncertainty in the outcome of a system in operation such as the outcome of a game (randomness). To assess futures, the uncertainty around the outcome of a complex system or the uncertainties that stem from the lack of knowledge of the interactions with other systems is most relevant. Walker et al. (2003) suggest that uncertainty can be thought of as a spectrum wherein uncertainty can span from being measurable to complete ignorance. These classifications are important to tackle uncertainty in any system for two reasons. Firstly, policymakers can direct suitable capacities toward mitigating these uncertainties (for instance knowing the system better or increasing understanding of the interrelationships further). Secondly, policymakers would also understand the limits of our knowledge and accept the unpredictability.

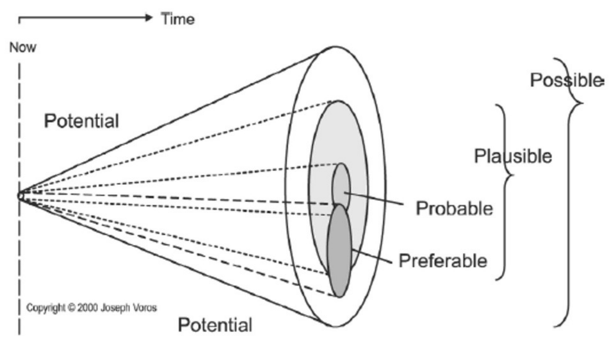

FIGURE 2
Futures cone (Voros, 2003).

A more well-established characterization of uncertainty in this field is the taxonomy inspired by erstwhile Secretary of Defense of the United States, Donald Rumsfeld that offers the allegories of animals for understanding different types of uncertainties—black swan (unknown unknown events), black elephant (known, unknown events), black jellyfish (unknown, known events), gray rhino events (well-known events) (Faulkner et al., 2017; Tõnurist and Hanson, 2021).[6]

Another helpful, as well as a common, way of conceptualizing the relationship between uncertainty and futures, is through the Futures Cone (Voros, 2003; Magruk, 2017; Fergnani, 2019). Figure 2 illustrates how with an increasing range of time; uncertainty increases primarily because of the increasing possibilities of the future. Uncertainties inherent in the complex systems then demand that futures are thought of as a range of possible, plausible, or probable futures (aspiring for preferable and desirable futures). Within this spectrum, scholars have argued for desirable futures that can serve as visions or "shared expectations" that is informed by "disparate human values and aspirations" (Eames et al., 2013; Bai et al., 2016: p. 352). This range of futures has special significance for complex systems governance. It signifies

6 The categorisation is generated from a Known and Unknown matrix.

that while attributes of unpredictability and emergence in complex systems can cause policy limbo, desired futures can offer direction and impetus to the policy process, mobilizing actor networks and galvanizing resources. Articulating plausible and possible futures can help in building capacities to deal with these other alternative trajectories. This too will need reforms in the current governing paradigms and strategies. To decrease uncertainties, policymakers will need to explore a significant range of futures before submitting to complete ambiguity or unknown unknowns. The Decision Making under Deep Uncertainty (DMDU) literature echoes the idea of multiple futures under different degrees of uncertainty and recommends modeling tools under each category (see Table 1.1 in Marchau et al., 2019).

Further, the identification of uncertainty in the future development of any arena becomes problematic, particularly for complex systems. Sardar and Sweeney (2016) suggest layers of uncertainty where at the *surface level*, the magnitude and probability of events and consequences are unknown; at a *shallow level, the* direction of change is unknown. Complexity, chaos and contradictions come together; at a *deep level* of uncertainty, nothing is known. In addition to the identification of surface-level uncertainties obvious from accessible sources such as economic data, political and societal trends, and environmental changes, complexity-related uncertainties also need to be analyzed more deeply and derived from wider knowledge sources. Multi-criteria, creative, diagnostic, and analytical methods are suggested for this level of uncertainty analysis (Courtney et al., 1997).

Lempert et al. (2003), one of the foremost experts in long-term policy analysis suggests that policymakers should account for a wide range of futures to counter uncertainties; devise robust instead of optimal strategies; leverage adaptivity, combine human and machine-based tools for managing the high level of scenarios related data. Havas et al. (2010) argue further that foresight exercises can help identify weak signals and thus can serve as a crucial part of an early warning system. Könnölä et al. (2006) find that diversity in ideas and viewpoints through open consultations can greatly reduce uncertainties in technological innovation fields.

Given these additional demands of a complex and uncertain world, it has been frequently argued that current methods to manage uncertainty in policymaking are inadequate as they fail to account for a wide range of uncertainties (Tõnurist and Hanson, 2021).

3.3. Futures approaches, methods, and tools

Futures studies have developed a wide range of approaches and methods over the years. These methods vary in their objectives and associated resource needs. There have been several attempts at categorizing the methods of futures and foresight (Inayatullah, 2011; Tõnurist and Hanson, 2021). A number of these methods have evolved into entire scholarships or sub-disciplines. A summary of some of the most common methods and tools is provided in Table 2. As this paper seeks to understand futures through the complex systems paradigm, the table includes methods that are related to complex systems and those that contribute to future or foresight development within this paradigm. We also indicate which methods have been applied in examining urban energy systems, if at all. The section below elaborates on some of the select approaches to futures development which have been applied independently or with other tools for a comprehensive futures analysis. The discussions highlight the key elements, significance, and debates associated with the approach.

3.3.1. Scenarios

Scenarios address uncertainty by articulating different possibilities of the future and are considered an important tool in multiple literature streams including modeling studies (Wulf et al., 2013). In future studies literature, that is particularly attuned to the complex systems paradigm, scenarios serve as both a tool and method particularly in contexts where quantitative prediction and forecasting-oriented scientific methods are inadequate or have little relevance (Quay, 2010; Kuosa, 2011a; Wilkinson et al., 2013). A key advantage that scenarios offer is a clear articulation of multiple possibilities of the future that can in turn aid in understanding the wider and temporal implications of the decisions made today. The Futures Cone (as discussed in Section 3.2) is a commonly followed framework in this scholarship for categorizing different types of futures based on their chance of occurrence. The Futures Cone imagines futures not as a single end state but as a spectrum of possibilities based on the current conditions. Within this spectrum are other types of scenarios that can arise in the future—preferable(envisioned), probable (based on trends), plausible (broader knowledge based), and possible (imaginable even without present evidence). Decisionmakers can then take advantage of scenarios across this futures spectrum to employ governing mechanisms that aim for the desired future, plan for the preferable scenarios, adapt according to probable scenarios, manage plausible scenarios, and prepare for (im)/possible scenarios.

Another approach to understanding scenarios is as per the nature of scenarios which can vary from normative (used widely in energy and climate studies as Net-Zero or carbon neutral targets) to exploratory (used in urban and other qualitative studies) while the mode of scenarios can range from a narrative (storylines), quantitative (statistical forecasts), to experiential (lived instead of abstract futures) (Jantsch, 1972; Candy and Dunagan, 2017; Venturini et al., 2019; Hanna and Gross, 2021).[7] Three schools of scenarios have been applied widely: Intuitive logic based (qualitative and participative); more systematic and probability-based (Trend-impact analysis (TIA) and cross-impact analysis (CIA) that takes cognizance of the interactions of events of the future), and the normative school in the form of *la prospective* school of scenarios (Wilkinson et al., 2013; Ernst et al., 2018).

Future studies studying uncertain futures have distinct insights on scenario approaches as compared to conventional usage in other literature streams (particularly modeling). A key criticism that emerges in the case of conventional scenario development methods is their entrapment in the present-day dynamics, failing

7 Scenarios have been used interchangeably as both end states and pathways (cf. National Grid ESO, 2022). Here it is considered to be an end state.

TABLE 2 Overview of key methods in futures studies and their application to complexity and urban energy futures development.

Method	Description	Relevance to complexity	Future development role	Stakeholders involved	References (Application based)	References (Urban Energy Application)
Horizon/environment scanning	Systematically examining the present context to understand trends and signs for the future	Limited: minimal focus on interactions	Context mapping	Experts and other linked actors	Habegger, 2010; Batisha, 2022	None found to date
Delphi analysis	Expert consultation process to reach a consensus about future trends. Divergent views can capture wide range of issues. Robustness likely to be high.	High: depends on survey design but can reveal detailed interactions	Scenarios development	Experts	Vidal et al., 2011; Kattirtzi and Winskel, 2020	None found to date
Causal layered analysis	Four layered analyses of the future. Challenges existing notions of the future	High: understanding of layered nature of present and future	Context mapping and scenarios development	Experts and other linked actors	Inayatullah, 2005; Heinonen et al., 2017b; Kim et al., 2021	None found to date
Visioning	Preferable future(s)/scenario development	Limited: unless open ended visioning process	Scenarios development	Experts and citizens	Nam and Taewoo, 2014; McPhearson et al., 2016	Dixon et al., 2018
Backcasting	Charting pathways from the vision/futures to present context	Limited: only in case multiple pathways and tracing interdependence and interactions	Pathways development	Experts	Soria-Lara and Banister, 2018	Phdungsilp, 2011; Dixon et al., 2014
Technology roadmapping	Mapping the technology development, innovation and scaling environment	High: can account for uncertainties and opportunities from the emerging technology landscape	Scenarios development	Experts	Amer and Daim, 2010	Dixon et al., 2014; Van Den Dobbelsteen et al., 2018
Megatrends/Trends analysis	Understand past and present context through trends and projections	High: understanding interconnections, interdependencies, self-organization tendencies, networks	Context mapping and short-term scenarios development	Experts	Wilkinson et al., 2013; Taylor et al., 2017	None found to date
Futures wheel	Visualize and organize consequences of trends, events, emerging issues, and future possible decisions	High: focus on first-order and second-order interactions	Short-term scenarios development	Experts and citizens	Benckendorff, 2008; Defila et al., 2018; Pereira et al., 2018	None found to date
Morphological analysis	Scientific methods rigorously structure and explore the total set of relationships in the non-quantifiable policy arena	High: focus on interrelationships between variables (visual models)	Scenario and pathways development	Experts to citizens	Coyle and McGlone, 1995; Ritchey, 2011	Da Silva, 2011; Pereverza et al., 2019
Wild cards and weak signals	Collaborative method to gauge low probability or low visibility events with high impact	High: focus on uncertainty and ambiguity	Scenario development	Experts	Saritas and Smith, 2011; Takala and Heino, 2017	None found to date
Relevance tree	Analytical technique to break down complex problems (both quantitative and qualitative)	High: hierarchical approach to understanding complex problems by dividing into subsystems	Context mapping and scenarios development	Experts	Benckendorff, 2008	None found to date

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to incorporate creative or *black swan* type events. Further, determinate or normative futures, apart from limiting the futures' possibilities, run the risk of dismissing the complexities and uncertainties jeopardizing the intended goals. Sardar and Sweeney (2016) contend that most scenario development practices, particularly for modeling purposes, are deeply influenced by the frames and notions of the present, essentially it is another form of prediction that extends the present. They suggest that given the multigenerational, multidimensional crises that the world faces today—captured by the term *postnormal times*—thinking of the future needs to go beyond a realm allowed by the present context and frames of thinking. Only then uncertainties that are unknown and unimagined can be taken into account in the best possible way (Montuori, 2011).

Further, given the complexity, non-causal dynamic interactions (through non-predictive scenarios) will have to be given equal weight in developing future scenarios as compared to causal interactions in a system (Miller, 2007; Booth et al., 2009). Batty (2008) has argued in favor of including non-testable hypotheses in scenario development in line with complexity thinking. There is also a case of imagining worst possible outcomes or even outlier scenarios when considering futures (Tõnurist and Hanson, 2021). Futures' scholars also encourage—"impossible scenarios" or "undesirable scenarios" beyond the imagined possible scenarios (Voros, 2017; p. 11; Tõnurist and Hanson, 2021; p. 99). Derbyshire and Wright (2014) argue that this method could reduce dependence on causation based scenario approaches, help in addressing deep uncertainties of the future stemming from unknown interrelationships, and aid societies in preparing for unforeseen circumstances. However, exercises that seek to develop scenarios from data, experts, or citizens tend to extrapolate the present without necessarily delving into unforeseen circumstances or imagining emergencies, or unpleasant, accidental situations. Heinonen et al. (2017b) argue that even methods like *horizon scanning* are only able to develop scenarios that are predictable with certain degrees of possible uncertainties. There is an increasing inclination amongst governments, pushed by justice-oriented organizations, to formulate only consensual vision-oriented scenarios in public policy, if at all (Jones, 2017; Dixon et al., 2018). However, Jones (2017) cautions that adopting only consensus and evidence-based scenarios can overlook the *black swan* events—unpredictable and improbable but with potentially high impacts. To counter this, specific measures in the form of targeted workshops, the inclusion of dissident voices, and allowing radical views, need to be taken to ensure the development of these scenarios in future development exercises.

These insights have significant implications for complex systems such as energy and cities as socio-political circumstances are often dynamic and reactionary events emerge quickly. Not only a wide range of futures will need to be assessed, going against the standard practice, but also a combination of methods that include both participatory (qualitative)as well as quantitative scenario building, will need to be employed. A particularly common approach is the Story and Simulation Approach which involves developing qualitative storylines through interviews and participatory approaches and using these for inputs in quantitative modeling (Alcamo, 2008). Story and Simulation Approaches have been prevalent for socio-ecological or socio-technical systems for their methodological robustness through an iterative process between scenario developers and experts (Kok and van Vliet, 2011; Weimer-Jehle et al., 2016).[8] Several practitioners have shown that scenario-building processes can be made more robust, particularly for managing complex systems, when combined with other assessment or evaluation methods such as participatory multi-criteria analysis (Montibeller et al., 2006; Kowalski et al., 2009; Ribeiro et al., 2013) or Multi-objective Evolutionary Algorithm with Robust Decision Making (MORDM) framework (Kasprzyk et al., 2013; Hassani et al., 2023) or causal loop diagrams (Haraldsson and Bonin, 2021). Other commonly applied methods of scenario development are listed in Table 2.

Finally, Floyd et al. (2020), argue that despite the robustness of methods, scenarios only manage to capture some degree of uncertainty and complexity. Researchers, then, need to exercise discretion in understanding the limits to what can be measured and modeled when analyzing and interpreting modeling outputs as in the case of energy studies.

3.3.2. Envisioning

Envisioning represents a different way of thinking about futures and has been considered one of the strategies for developing alternative scenarios or selecting preferred futures (Nikolova, 2013). It represents a process of articulating the future in terms of one's preferences, desires, and cultural context; in that it is more subjective in nature than other futures development processes (Ziegler, 1991). Envisioning is often thought to serve as a recourse out of the highly technocratic and esoteric organizations, toward a more democratic and creative process of thinking about futures. As a result, visions of future encourage scenarios fall within the desirable futures typology; imaginable beyond the restrictive clutches of the present (Ziegler, 1991; Magruk, 2012). Masini (2002) frames visions as a "humanistic future" that are achievable by humans if they strive for it. Here, creativity does not imply that visions lose any linkages to the present, become a wish list, or border on being fantastical. Instead, Ziegler (1991) describes the process of envisioning to be "hard inner work—deep imaging, deep questioning, deep listening, and deep learning, each of which has its practicum" (Magruk, 2012: p. 521). McDowall (2012) cautions that visions need to strike the balance between plausibility and desirability.

Some scholars have also offered an alternative idea of future visions, particularly keeping in mind the emergent nature of complex systems. Instead of thinking of visions as an end state due to uncertainty, vision should be thought about as a direction of change that then comprises a plurality of pathways (Jørgensen and Grosu, 2007). Within the Transitions Management scholarship (sub-discipline of futures), Smith et al. (2005) propose a different

8 IPCC's SRES exercise is one of the well-known examples of this approach in climate change but bends heavily on the side of quantitative analysis. However, not only has this approach been critiqued for its lack of consistency across storylines, challenges on its translation of qualitative storylines in quantitative parameters, but also how they manage complexity of these areas has not been widely addressed (Weimer-Jehle et al., 2016).

ontological approach "*Guiding Visions*"—that is essentially a possibility space, helps frame a problem, and bring together actors and resources to work in the present (Smith et al., 2005; p. 1506). A second approach is that of *systemic vision* that does not involve listing a set of goals but involves imagining the interlinkages of different elements that will shape the future—drivers, impacts, indirect, and hidden connections, and feedback (Wiek and Iwaniec, 2014). In practice, this means imagining a future system.

Ziegler (1991) argues that visions for futures thinking need to be fundamentally participatory in nature. But beyond the normative rationale, Ziegler's argument arises out of a common understanding underlying complexity thinking that knowledge will always be incomplete in a complex system. Therefore, developing knowledge will need a wider set of participants, their views, and their experience. Visions also tend to be amenable to participatory methods as it does not require specialized vocabulary, mitigating epistemic hegemony. One of the earliest proponents of envisioning futures was Robert Jungk whose workshops for desirable futures sought to "liberate the intuitive and emotional in these workshops as well as using the rational and analytical" (Hicks, 1996: p. 105). Trutnevyte et al. (2011) from extensive community energy modeling exercises share that, to counter uncertainty, a large number of visions should be generated that can be then filtered based on both "intuitive and analytical perspective" (Trutnevyte et al., 2011; p. 7884). Trutnevyte et al. (2011) suggest that complex system tools such as system dynamics and participatory visioning can be further suitable in this approach. Repo and Matschoss (2018) point out, here, that analyzing a shared vision from stakeholder input can be arduous, but a widely accepted method of analyzing and synthesizing these visions has not yet emerged (Repo and Matschoss, 2018). Most research endeavors have developed individual methods to analyze this. Setting a vision and building public consensus around these targets can be one way to develop the same legitimacy as a shared vision. However, Stirling (2006) warns, like in the case of normative scenarios, that this may restrict socio-technical choices for pathways. Shared vision projects have been critiqued by McDowall (2012) and Dixon et al. (2014) who argue that over-emphasis on consensus based approaches can further marginalize radical views and perceptions of the underrepresented or politically weak communities (McDowall, 2012). Mitigating approaches such as ensuring wide participation, accountability and plausibility of the visions can address some of these gaps (McDowall, 2012). Visions, then, will also need to be combined with other scenarios for ensuring the robustness of pathways addressing issues of uncertainty and non-predictive futures.

3.3.3. Participatory futures

Participatory methods in developing foresight and futures have been less frequently used until recently (Nikolova, 2013). This has been particularly true in the case of technological foresight fields (Cagnin and Keenan, 2008). Nikolova (2013) writes a participatory approach requires the "inclusion of agents," which have traditionally been considered "external" for the foresight endeavor. She propounds the concept of Participatory Foresight. Widening the base of inputs for futures thinking is an attempt to take back control of what is essentially a public good from experts and policy elites (Gidley et al., 2009). Therefore, participatory futures is about democratizing future development exercises (Ramos et al., 2019). Participatory futures draw on the methods of futures and foresight development with a focus on involving a wider set of related audiences. Because of the involvement of non-experts and non-technical audiences with varied interests, approaches veer toward exploratory and innovative methods of engaging and communicating like storytelling, gamification, design, art, and deliberation (Gidley et al., 2009; Miller et al., 2015; Ramos et al., 2019). There can be a wide divergence between the citizens' and experts' foresight. For instance, Rosa et al. (2021) show a common finding that citizens tend to amplify concerns in their futures narratives, while experts tend to highlight opportunities (Rosa et al., 2021). Situations like these can sow the seeds of discontent in the larger public about the present day policies being undertaken for their future. Many authors consequently argue that citizen foresight should be produced alongside those of experts. Beyond the normative stance like in case of vision building and conflict avoidance objectives, the related activities entailed in foresight or future development including systems mapping and understanding short-term major trends can benefit from public perspectives and a wide knowledge base to account for the complex system characteristics of any society. While vision building is a case of convergence of ideas and ethos, building worst-case scenarios, wild cards, imagining implications and interactions also need participation and a wide range of divergent views.

As discussed earlier, uncertainty associated with complex systems, in particular, demands wide range of inputs and participation from a broad base of actors. However, uncertainty praxis is also a two-way street. In addition to contributing to uncertainty assessment during futures development, citizens will need to be involved in futures capacity building simultaneously. Therefore, participatory futures exercises are not just for an end but also serve as means in that it contributes to building the capacity of the stakeholders and citizens at large for developing a shared understanding of unforeseen yet inescapable uncertainties. Rosa et al. (2021: p. 3) argue that participatory approaches in foresight studies need "to strengthen peoples capacity to recognize and embrace uncertainty while collectively shaping a preferable vision of the future." Through both processes and products of the participatory futures exercise, collective or individual action can be galvanized for a contribution toward future making (Foran et al., 2013). Participatory foresight approach is being increasingly applied across formal policymaking circles like that of European Commissions Mission development (Repo and Matschoss, 2018; Rosa et al., 2021).

3.3.4. Adaptive foresight

Adaptive foresight, combined with adaptive planning, has been suggested to be one of the more specific approaches to foresight development that accounts for complexity thinking. Eriksson and Weber (2008) offer the concept of *adaptive foresight* as a response to what they saw as an oversimplified and over-optimistic treatment of foresight practices in public policy. The authors understand adaptive foresight as a "continuous monitoring, exploration and adaptation process and to move beyond collective and participatory foresight processes by also considering targeted and "closed" process elements in order to bring foresight fully to bear on decision-making" (Gidley et al., 2009: p. 472). They argue that the stress on participatory processes in foresight development needs to be supported with adaptive practices in the future that in turn shape specific strategies of scenario building, uncertainty hedging practices such as *best possible variant*, and individual-level strategies. An assessment of most foresight practices in the public policy domain by the authors shows that while most practices secure the participatory inputs, they fail to bookend the endeavor with adaptive strategies.

3.3.5. Integrated methodologies

Futures methods and tools are increasingly used in combination to form systematic integrated composite methodologies. Prominent examples of such integrated approaches/methodologies have been presented in Figure 3 highlighting the key steps involved in each. These integrated mixed methods' approaches for future assessments mitigate the limitations of one directional approach. A detailed background on these processes can be found in Supplementary material. The frameworks/methodologies presented are a mix of theoretical output and action research related outputs. The key objective of these composite methodologies is to aid decision-making and policymakers in taking step-wise action for futures development. Despite different origins and objectives, the simplified analysis of these approaches reveals a consensus on a broad sequences of actions. All the methodologies recommend scanning or mapping the current context with the help of experts or broader stakeholder participation. Some even stress the need for some degree of historical analysis that can help in understanding the interrelationships from the past. Identifying drivers of change and interdependencies, interrelations run common through all the methodologies, in some cases delivering short-term modeling or futures assessment. Based on the developed understanding, a large number of scenarios are generated. Worst-case situations, uncertain events and further scrutiny of the generated scenarios result in a smaller number of selected scenarios on which consensus is forged. These selected scenarios become the foundation on which pathways and futures governance strategies are formulated.

4. Futures in policymaking, energy and urban studies

Having delved in detail into the theories and methods that have been prominent in the futures and foresight scholarship, we now turn to review the conceptualization and application of futures thinking in the field of policymaking, energy, and urban studies. Gaps identified and lessons learnt from these interlinked disciplines also shape the framework and methodology proposed in the next section of the paper.

4.1. Futures in policymaking

Policymaking is inherently linked to futures wherein decisions and strategies are often taken with the intention to shape the future. This could be related to a current problem that would have implications for the future or anticipated adverse turn of events in the future. When not addressing specific problems, policymaking tends to steer societal evolution toward a particular goal. These processes are not mutually exclusive. However, almost antithetically, long-term futures policymaking is considered to bound to fail due to the inevitable change in initial conditions, resulting in short-termism or risk-averse attitudes amongst policymakers (Nair and Howlett, 2014). This is particularly pronounced for complex adaptive systems characterized by uncertainty, ambivalence, and incomplete understanding. Policymaking studies also define futures of complex systems as a range of possibilities and a spectrum of uncertainties and ambiguities involved (Nair and Howlett, 2014; Tõnurist and Hanson, 2021). In this sense, one tends to agree with Sanderson's (2009; p.699) contention that "policy making is more a "craft" than a science; the "art of the possible" rather than the "art of the optimum."'

As discussed earlier, current policymaking capacities have been considered to be inadequate to address complex global and local systems challenges (Burrows and Gnad, 2018; Minkkinen, 2019). One of the main barriers is the overreliance on ideas and frames in the present that prevents actors from imagining future states beyond what is known (Hanna and Gross, 2021). Jensen and Wu (2016) argue that even current modeling methods that support policymaking in some ways fall short of capturing the complex present and future that we occupy. They posit, "many of the methods used to address uncertainty such as sensitivity analysis, decision-tree analysis, system dynamics modeling and Monte Carlo simulation, etc. rarely fulfill the conditions in real life and also require specification in probability distributions, which disregard the possibility of multiple and unknown futures" (Frau, 2019: p. 116).

Instead, a completely different framework of governance and policymaking needs to be adopted. Intelligent policymaking, adaptive policymaking, and anticipatory governance are some of the recommendations for long-term policymaking in the literature (Sanderson, 2009; Nair and Howlett, 2014; Tõnurist and Hanson, 2021). These approaches are underpinned in the conceptualization of the long-term futures, involving wide-ranging scenarios including a vision, worst case and plausible scenarios as well as uncertainties ranging from probabilistic risk to complete ignorance of uncertainties, constructed through public participation. The policy response broadly comprises short-term goals, signposts, and tipping points with continuous learning, evaluation, and reformative actions (Quay, 2010; Haasnoot et al., 2013; Bhave et al., 2016). Roelich and Giesekam (2019), for instance, highlight the critical importance of alignment of the motivations, interactions, and momentum of different actors and actions in a dynamic adaptive policymaking process.

Tools of different kinds have been proposed to deal with complex futures and uncertainty in policy spaces. The OECD (2022) has called for *strategic foresight* development and states

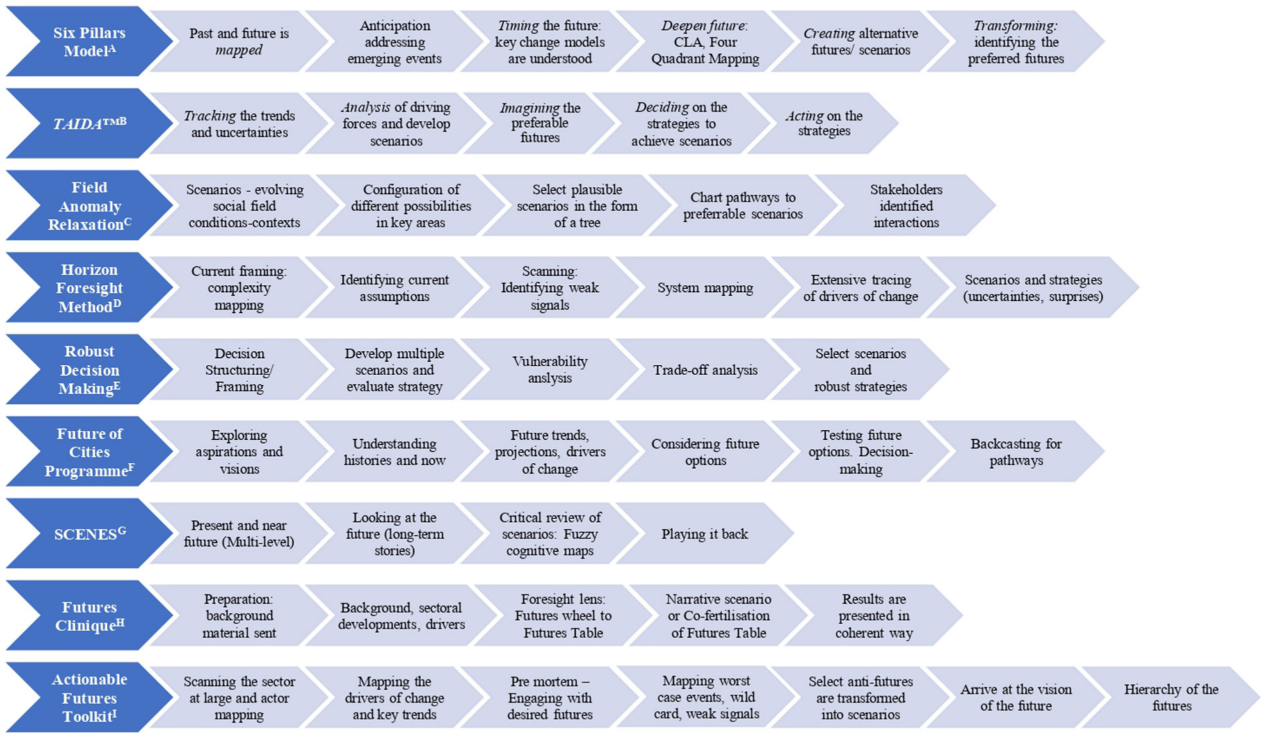

FIGURE 3
Key integrated frameworks applied to futures Ref: **(A)** (Inayatullah, 2008); **(B)** (Karlsson and Leander, 2007); **(C)** (Rhyne, 1995); **(D)** (Padbury, 2020); **(E)** (Lempert, 2019); **(F)** (Government Office for Science, 2013); **(G)** (94); **(H)** (Heinonen and Ruotsalainen, 2013); **(I)** (Nordkapp, 2022).

that future assessment is a *critical driver* of anticipatory and adaptive governance today. This will involve revisiting the way capacity needs are envisaged, partnerships and collaborations are forged, data collection and evaluation processes are established, and long-term and day-to-day decision-making systems are put in place. Strategic foresight and related offshoots have been widely applied by a number of national governments including Europe, Canada, and Singapore (see Table 1 for examples).

Swanson et al. (2010) offer a seven-step tool for adaptive policies that span both anticipations of the future through (1) Integrated and forward-looking analysis; (2) Multi-stakeholder deliberation; (3) Policy adjustments through *signposts*; and adapting to the unknown uncertainties through (4) Enabling self-organization; (5) Decentralizing decision-making; (6) Promoting variation; and (7) Policy review and learning.

Another approach of anticipatory (innovation) governance emerges out of futures and uncertainty studies that differs from the adaptive approaches to governance. Anticipatory governance suggests proactive interventions to emerging conditions and potentially shaping the direction of futures instead of just adapting to emerging conditions (Quay, 2010; Guston, 2014). Similar to reflexive governance models, anticipatory governance scholars recommend a modular format of governance that implement reflexive and flexible actions taking view of the circumstances that are unfolding but also allowing space for the unknowns (Tõnurist and Hanson, 2021). Gaining more acceptance in policy circles, *anticipatory governance* is being piloted in several initiatives (OECD, 2022). The UNDP describes anticipatory governance as "collaborative and participatory processes and systems for exploring, envisioning, direction setting, developing strategy and experimentation for a region."[9] The OECD has initiated studies on *anticipatory innovation governance* as a sub-concept that underlines the actionable areas of this field such as purposeful experimentation, setting a research agenda, and establishing collaboration and partnerships (see model in Tõnurist and Hanson, 2021; OECD, 2022).

4.2. Energy studies and futures

As recent global events have been well-demonstrated, energy systems have profound implications for energy security, economic and political stability, and social wellbeing. Therefore, modeling and planning how global and national energy systems should develop in the future has been a significant preoccupation in energy studies. The 1970s oil crises underlined this; changing the trajectory of future studies that had failed in cautioning and preparing the world for impending crises. Today, Shell's energy scenarios are widely used by organizations across sectors and are considered an example of risk management by an organization for its future—which infamously included obscuring risks of climate change (Waldman, 2018; Scoblic, 2020). Shell's methodology has

9 https://www.undp.org/vietnam/blog/anticipatory-governance-primer

evolved over the years shifting from trend analysis based on past data, to engaging widely with energy sector experts to reach their future assessments in the form of multiple scenarios that then shape their current actions (see Weimer-Jehle et al., 2016, Table 1 for an overview of the different energy scenarios).

The need for managing energy futures has intensified in the last few decades due to the critical need to decarbonize energy systems, requiring micro to macro changes at different levels, amidst multitudinous uncertainties. Projections linked to climate change with a normative global temperature target of 1.5°C have led to commitments to net-zero emissions or carbon neutrality by multiple national and local governments.[10] These targets are backed by modeled medium-term strategies that are expected to deliver the selected energy pathways.

Between these two broad approaches in thinking about energy futures, a few characteristics of energy futures studies become evident; (1) Energy futures have been predominantly approached through quantitative energy modeling studies for typically short to medium-term periods (Ernst et al., 2018; Hanna and Gross, 2021; Fodstad et al., 2022); (2) These efforts have also been shaped by technology-defined or normatively-defined futures. Reviews of these approaches have pointed to gaps such as limited integrations with socio-political aspects, lack of appropriate accounting of uncertainties as well as wider cross-sectoral interdependencies, and not enough focus on the human agency (Kowalski et al., 2009; Ernst et al., 2018; Fodstad et al., 2022). Recent studies have attempted to incorporate participatory approaches to scenario development, in particular, to account for the diverse visions of the futures in an energy system. However, these approaches have been critiqued for not undertaking meaningful participation (Trutnevyte, 2014; Trutnevyte et al., 2016a). In almost all cases, these studies do not adopt a comprehensive complex systems framework to understand energy systems and therefore do not necessarily undertake a more complete understanding of the uncertainties involved (McGookin et al., 2021).

Scenario planning or development exercises are among the most commonly followed methodologies in energy studies. Both climate change and energy policy studies depend on scenario development typically from quantitative modeling as a key method for planning solutions or pathways development (Dixon et al., 2014; Schubert et al., 2015; Guivarch et al., 2017). These indicate possible or plausible future states/or pathways of the energy systems but do not necessarily encompasses ideas of a future (Schubert et al., 2015). Energy modeling efforts have started developing integrated energy scenarios that combine qualitative and quantitative methods of scenario development with the help of approaches such as Story and Simulation or Context scenarios (Mahony, 2014; Fortes et al., 2015; Weimer-Jehle et al., 2016).

Scenario development in energy systems has been widely critiqued from a complexity perspective. While multiple scenarios illustrate an acceptance of the unreliability of a single pre-determined future and sophisticated models such as the Integrated Assessment Models (IAMs) model the potential cross-sectoral interactions, the attempt to embrace complex systems theoretically as well as practically remains partial or inadequate. Hanna and Gross (2021) in their review of reviews find that complex systems characteristics such as discontinuity and disruption are addressed primarily in qualitative and exploratory scenario development in energy studies. This is significant as multiple studies have highlighted the challenges of firstly, consistency of storylines across participants in qualitative scenario studies and secondly, translating complex qualitative storylines to quantitative parameters, particularly in current energy modeling frameworks (Fortes et al., 2015; Weimer-Jehle et al., 2016; Guivarch et al., 2017; Chaudry et al., 2022). A review of past UK energy scenarios shows that they were shaped by contemporary debates in the energy sector (Trutnevyte et al., 2016b). The study finds that policymakers were eventually faced with the same uncertain events in the sector's trajectory that were dismissed as unlikely in the scenario development phase (Trutnevyte et al., 2016b). Chaudry et al. (2022) demonstrate that the quantitative basis of developing scenarios can fail to absorb the complexities of socio-political context; long-ranging energy scenario planning through such models is highly challenging and often does not take into account whole systems (also see Li and Pye, 2018; McGookin et al., 2021). Li and Pye (2018) find that even energy policy scholars think that the current approach to incorporating uncertainties in energy modeling for developing future scenarios needs reassessment and will have to incorporate better integrated qualitative and quantitative assessment as well as meaningful public participation (also argued by Weimer-Jehle et al., 2016; McGookin et al., 2021). Hanna and Gross (2021) call for the incorporation of techniques and approaches of futures studies and foresight exercises to augment the capacities of current energy modeling studies while Trutnevyte et al. (2016b) call for widening the base of insights on the future through multi-organizational, multi-method, and multi-scenario approaches. Guivarch et al. (2017) summarize the contribution of 13 energy and environmental research papers to suggest that the diversity of scenario approaches, addressing the vulnerability of these scenarios (particularly pathways), multi-objective, and multiple–scale approaches can address some of the challenges related to complex systems.

An alternative paradigm or idea of energy futures is also developed by the social science enquiries of energy systems that centers on the socio-technical nature of energy technologies. Here energy futures are expressed in the form of visions, framing, imaginaries, and values (Sovacool et al., 2020). Inspired by the socio-technical imaginaries field, social science energy scholars argue that these imaginaries tend to define today's pathways, policies, and politics of energy. However, the articulation of these imaginaries varies widely. While sometimes they are made obvious through visual images or vision statements, in others, expression of energy futures can remain latent through storylines, narratives, and science fiction outputs (see for instance Venturini et al., 2019; Britton et al., 2022). Often, communities tend to embed their idea of clean energy futures in the hope of reduced costs, energy independence, or green jobs. Of late, there have been calls to leverage the ongoing energy transitions to capitalize on the inherent multidimensionality of particularly the new energy systems. This implies delivering on more than one objective and a vision that cuts across material, societal, political, economic, and environmental aspects of the future. However, a comprehensive conceptualization

10 Net-zero targets have typical timeframe ranging from 2040 to 2050.

or assessment of an energy future or energy visions in these qualitative studies has been rare in this part of the scholarship. Less attention is paid to the increasing complexity of energy systems with accelerated demand for energy transition, and consequently, no solutions are offered to the uncertainties associated with long-term futures (Sovacool et al., 2020). Participatory modeling methods attempt to bring some of these disciplines together with qualitative data gathering and quantitative modeling. However, this discipline still faces challenges with adopting traditional complexity thinking and addressing deep uncertainties of the energy system (OECD, 2022).

4.3. Urban studies and futures

Planning for the future has been an integral part of urban studies as demonstrated by the evolution of urban planning as an independent discipline. Planning is important for urban areas as a large part of the physical infrastructure, once built today, has particularly enduring characteristics and engenders path dependence or *lock-in* reducing the opportunity for change at a later point. A classic example of how urban planning binds societies in a particular pathway of living is the development of suburbs in the USA that gave rise to dependence on cars that has shaped the scale, pace and pathways of energy transition plans in the USA (Filion, 2018). Futures exercises in cities have been taking place in either planning documents with a 10–15 year timeline or through vision documents with a similar timeframe.

The envisioning of cities' futures started around the 1980s (Dixon et al., 2018). Around this time some cities started experimenting with futures studies. Thinking around urban futures was greatly influenced by the call of "the right to city," first by Lefebvre (1996), then developed further by Harvey (2003, 2008), dos Santos (2014). Dixon et al. (2018) opine that this shift was also driven by the breakdown in past futures thinking practices and worsening socio-economic, and environmental conditions in today's cities. The main contention here is that urban spaces and planning have been dominated by capitalist paradigms of governance that design urban futures for capital accumulation leading to citizen alienation. Therefore, scholars and activists alike stress that more democratic and citizen-led imaginaries are needed to claim back urban governance (Inayatullah, 2011; dos Santos, 2014; Dan Hill, 2016). The idea of breaking down the technocratic silos of urban futures thinking has ushered multiple exploratory, experiential, participatory and even radical approaches to city planning and visioning for the future. An offshoot from this paradigm has been the Quadruple Helix framework that advocates synergy between all key domains of stakeholders—government, business, university, civil society and citizens—and for envisioning city futures (van Waart et al., 2015; Ferraris et al., 2018).

Urban sustainability studies have contributed toward futures thinking of urban areas with a predefined normative target of achieving sustainability. Dixon (2022), however, demonstrates that while cities are increasingly setting up initiatives to organize the development of long-term or long-ranging futures envisioning, most of these endeavors cannot be considered to be based on a systematic futures methodology or principles, even when referring to futures studies methods. Further, while some recent projects show that there is an increasing acknowledgment of systems thinking in urban futures in both academia and practice, the actual complexity of the systems and related implications are yet to be fully incorporated (Dixon, 2022).[11]

The turn toward the sub-discipline of complexity in urban studies offers more novel frameworks for conceptualizing urban futures. Urban complexity scholars focus less on the final future and more on the societal capacity needed to change and adapt—futures as processes and pathways (Karakiewicz, 2019). The roots of this lie in the far-from-equilibrium nature of complex systems (Batty, 2008). Here, the future can be conceptualized as a set of broad values and characteristics toward which the system needs to steer. The steering happens through small-scale, contextual interventions, often articulated as innovation, that bring about large-scale societal changes (Batty and Torrens, 2005; Dan Hill, 2016; Pollastri et al., 2016; Batty et al., 2019; Karakiewicz, 2019). This echoes well with the conceptualization of the democratic and radical futures turn in urban planning as discussed earlier and has been often used in relation to each other.

Other urban complexity science scholars make use of specific models to understand futures better, albeit they take different approaches. It demonstrates a shift from "aggregate to disaggregate modeling, from the focus on equilibrium to dynamics, and on processes and behaviors rather than simply outcomes" (Ferraris et al., 2018: p. 56). Models linked to complex systems, and particularly catering to urban planning—agent-based modeling (individual behavior), system dynamics (interactions and feedback), network analysis (relationship between elements)—simulate disaggregated components of the city complex system without aiming for equilibrium (Batty, 2008). Batty (2008) argues that the complex systems modeling paradigm departs from conventional urban modeling techniques in that it allows non-causal hypotheses to be incorporated into the model. In practice, this would imply a number of things. Firstly, complex systems paradigms and modeling techniques are particularly suited for the urban scale where contextual, localized, and even agent-level modeling is more relevant. Secondly, models incorporate the non-finality of the future or the unpredictability of the system that then, in turn, reduces the dependence on the output of the models; instead, the attempt is to understand the local context deeply as non-deterministic indicators of a future. Lastly, there is also space for the uncertain and the unknown in complexity modeling.

Therefore, complexity modeling can be a helpful complementary tool in urban studies, navigating the evolution of the dynamic and heterogeneous elements of urban systems. However, most modeling attempts are a result of current urban planning exercises (either policy or academic) which are by default short-term. With increasing timeframe, the reliability of modeling exercises reduces, and hence other techniques and strategies need to be adopted in parallel. As Batty and Torrens (2005: p. 765) submit "where we are dealing with systems that are intrinsically

11 See Future of Cities project below in Table 1.

uncertain and infinitely complex, then the only way forward is to learn the limits to such systems and in this way, to fashion our models to account for such limits."

5. A complex systems framework for urban energy futures

The disciplines discussed previously while offering disparate insights, also validate the need for a new integrated framework (encompassing relevant approaches and methods) for developing urban energy futures from a complex system perspective. We first consider the paradigm and dimensions for conceptualizing futures for complex urban energy systems, and then we propose key aspects which together form a framework and a methodology for exploring futures in complex urban energy systems.

5.1. Key learnings for complex urban energy futures

The discussions in the previous sections lead us to several key messages and definitions.

5.1.1. Definition of the future

Complexity thinking compels us to think about futures as a spectrum rather than a simplified projection from the present conditions. The futures studies literature offers a solution in a typology of futures comprising possible, probable, plausible, preferred, and desirable futures (visions), each embodying varying degrees of uncertainty (see Figure 1). Therefore, futures in any public policy arena will need to be a plural space where different ideas are expressed and considered. An important discussion that scholars of complexity need to engage with is what is *future* and what should it entail. As identified earlier, there is a range of ontological positions in futures studies. Some have conceptualized futures as a hard-end, delivering an ideal world or society, while others have conceptualized futures in the form of specific situations or events in the future. In other words, these scenarios, reflect certain points, turns, and eventualities in the evolution of society (like in case the of military foresight strategies). Still others define scenarios or futures as a single dimensional goal that the future needs to achieve (e.g., 1.5°C, a certain percentage of renewable energy generation) or pathways that will deliver these goals. Studies have also taken an alternate route where they have veered toward epistemological approaches to future, that is, through indicators of the future. One example, here, is the values that futures should come to represent (*guiding visions*) based on the economic and technological choices made today that, in turn, can shape public acceptance (Butler et al., 2015; de Wildt et al., 2021). Futures exercise then will need to begin with an understanding of the ontological or epistemological basis for the future.

5.1.2. Methodologies

As the literature shows, futures exercises typically involve phased, multi-level, multi-stakeholder, iterative activities that can be both resource and knowledge intensive. The framework we propose is necessarily resource intensive. To acknowledge that, these methodologies need to be contextual in nature to take into account the aims, as well as the capacities and resources available; there will be no "cookie cutter" solution (Ramos et al., 2019; p. 8). These methodologies must also encompass the broader ways of governing the outcome of the futures exercise and will need to be adjustable and adaptable to the governance capacities of urban and national policymakers and long-term uncertainties.

5.1.3. Timeframe

A futures or a foresight exercise needs to be organized in a way that is distinct from a planning exercise or 10-year vision-setting exercise. These exercises envisage a societal transformation involving multiple generations. A formal futures development exercise will need to be carried out over a sufficiently long-term timeframe while keeping short-term goals as signposts. Government foresight activities vary in the range of 20–50 years' timeline (Kuosa, 2011b; OECD, 2019); a length of the period not typically attempted in technical spheres like urban energy futures (Lempert et al., 2003). Some have even suggested a 100 years' timeline (Government Office for Science, 2021). Most climate change or energy planning exercises with a timeline of 2030 or even 2050 fall short of this measure. The timeframe considerations hold special significance in the case of complex systems that have sensitivity to initial conditions. For instance, hard infrastructure and a broader built environment built today for new technologies are likely to lock in energy consumption patterns for at least the next 100 years. Europe's energy challenges with its old building stock are one of the most well-known examples.

5.1.4. Sensitivity to initial conditions

In a similar vein as above, initial mapping of present and historical trends and patterns of the past can be important harbingers of the future. While this is intuitive in regular future-setting exercises, complex systems can have a tricky relationship with the past and present. Historical and short-term future trends can be an important input for modeling exercises that, as discussed earlier, can serve as important inputs for futures exercises. For instance, mapping the latest technological advancements in the short term can deliver important insights for the longer term, especially in view of technological lock-in possibilities in the energy sector as discussed above. Tracking past events to the extent possible can relay important information on the relationships between different aspects of geography and help open our current ideas of interdependencies and interlinkages.

5.1.5. Communicating uncertainties

Visualization and mapping have been considered effective ways of communicating uncertainties and conflicts in visioning or future exercises (Shaw et al., 2009). Visualization (including the use of experiential tools) also helps in articulating desirable futures that may not have a direct resonance in the present circumstances, thereby exploring uncharted avenues.

5.1.6. Participatory methods

The recursive and reflexive practice of participatory methods can help mitigate the critical concerns of uncertainty and the unknown in complex systems. Targeted consultations with relevant stakeholders can help gather a large spectrum of intelligence on interactions, interdependencies, conflicts, and potential uncertainties. Further, assigning probabilities to these uncertainties can help prioritize strategies. When combined with anticipatory or adaptive governance mechanisms that advocate regular temporal review of these uncertainties with new participants (over multiple generations), it ensures that evolving uncertainties are taken into account. A more salient significance for participatory methods also emerges out of the need to include marginalized voices in foresight and futures exercises. In energy and climate modeling exercises, scenario development is often the domain of select experts. As discussed above, the concerns of experts (often belonging to a privileged social class) contrast with the concerns of the general public. Therefore, participatory methods in futures thinking can help in gaining political and public legitimacy.

5.2. Proposed framework and methodology

Learnings highlighted in Section 5.1 signal a need for change in the current framings and approaches to thinking about futures for complex energy systems, particularly at the urban scale. We propose a framework for developing urban energy futures and the change in approach needed for urban energy planning research and policy practice. The framework is diagrammatically presented in Figure 4. Figure 4 is adapted from the Futures Cone diagram (Figure 2) wherein key elements of the framework have been superimposed. Table 3 highlights how this framework is different from the existing approaches to urban energy system futures or planning.

5.2.1. Futures

A wide range of desired (visions), preferable, probable, possible and undesired futures or scenarios for futures should be at the heart of an energy futures exercise, generated through wide and inclusive participation. We suggest that the question of what entails futures (values, expectations, or particular landscape of the city) should be shaped by the inputs from the participants engaged in the futures exercise. However, participants will need to be informed transparently about the options and encouraged to freely express their way of envisioning the future. Visualization of these scenarios, possibly linked to the initial complex urban energy systems map created in the contextualization phase, can further help in teasing out the details of the scenarios This will also ensure that futures are grounded, drawing from past experiences and current conditions. Energy plans or system modeling studies often generate scenarios in restrictive or normative ways, without engaging with exploratory approaches. This risks disengagement from the wider public aspirations for the city. Exploratory approaches can encourage wider participation while helping in tiding over the *present bias* and generating unreserved imaginaries/visions of the future. At the same time, the limitations of participatory approaches need to be recognized. Influence on the futures of the non-represented communities should form part of the futures exercise. Quantitative modeling in combination with the help of expert inputs through methods like Delphi can contribute to the generation of a wide range of probable and possible scenarios (including worst-case scenarios) as well as inform the robustness of the desirable scenarios. Simultaneously, the futures process should explicitly venture into the generation of undesirable futures or scenarios (Hughes and Strachan, 2010; Tõnurist and Hanson, 2021). These serve as the boundary condition for the futures spectrum or ambit and is the first step toward identifying actions that will aid in avoiding these scenarios. While pathways will focus on delivering the desirable futures, accounting for the feedback from the actions proposed in the pathways can ensure that undesirable repercussions in the long term are avoided.

A particularly important aspect to consider from the nested (hierarchical) nature of complex systems is that urban energy futures should be embedded within the general futures exercise of the urban government that, in turn, should be linked to the national (or regional) government level futures exercise (energy or otherwise). The interconnectedness of the different elements in a complex system creates both interdependencies as well as synergies. Urban governance studies in the UK, for instance, show that local city energy visions are often not taken into account by national programs (Britton et al., 2022). An additional aspect of interconnectedness is defined by the impacts that future energy systems can have on other systems and geographies (pollution climate change, resources). Here, evaluating the generated or selected futures from exploratory or normative dimensions (like in the case of multi-criteria analysis) would ensure robustness and fairness.

5.2.2. Pathways

Pathways follow futures. As a planning tool, they are widely used in energy futures analysis. Often taking the form of roadmaps, these plans comprise the steps that need to be taken—including the technologies, institutions, new actor networks, laws and policy reforms, and innovations—to realize the desirable futures. From a complexity lens, however, pathways are neither likely to be singular nor likely to experience a linear progression as planned. Therefore, in the case of a complex urban energy system, the steps that will eventually comprise the chosen pathways will need to comprehensively take into account the interdependencies and interactions of the system to understand the consequences, and long-term feasibility, including public acceptance in the future with the help of tools such as Future wheels, Delphi and Morphological analysis Uncertainty analysis of pathways will need to include both qualitative (wild cards, surprises, thresholds/tipping points) as well quantitative techniques (e.g., Monte Carlo technique/RBM). With the possibility of unthinkable eventualities or immeasurable uncertainties, pathways development will need to actively consider the steps that will be needed to avoid undesirable futures or failure of planned

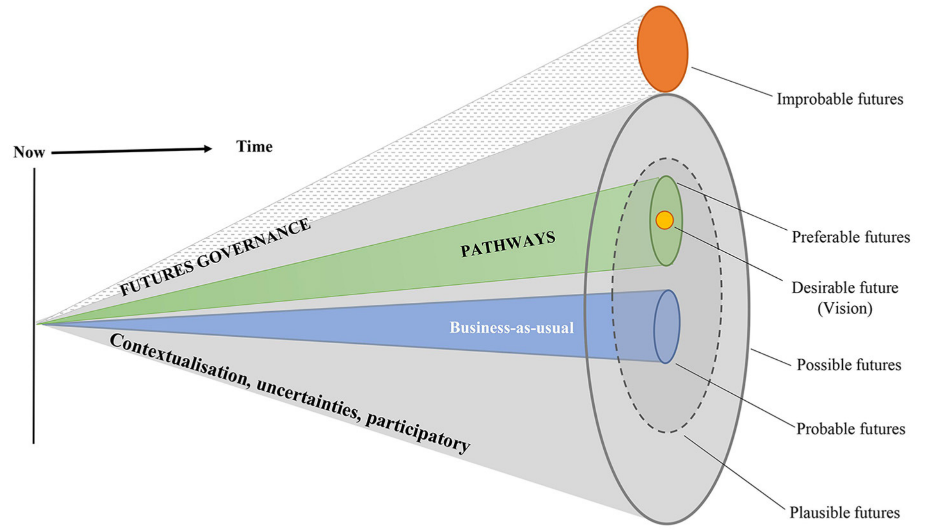

FIGURE 4
Methodological framework for complex urban energy systems futures.

TABLE 3 Framework components.

	Current approach in urban energy plans	Proposed new approach
Futures	Set typically as single-point normative targets by local authorities (For instance, LAEP) Scenarios based on optimization modeling techniques Length of futures development vary widely	Futures viewed as an ambit instead of an end point A wide variety of scenarios generated with the help of participatory scenario development tools Scenarios could include categorization of probable, possible, worst-case scenarios identified Future range of 50–100 years Scenarios linked to or fed into cross-city level scenario development or visioning efforts and other normative criteria
Contextualization(/mapping context)	Understanding of the main system actors and cross-sectoral interlinkages within the city to some extent	Complex systems mapping of the urban energy system Trends analysis/horizon scanning/Delphi analysis based in-depth understanding of the interdependencies and interactions of multiple, multisectoral, and multilevel elements. Methodologies such as Futures Wheels, system dynamics can highlight some of these interactions
Mapping and managing uncertainty	No established methodology or acknowledged except in the form of limited scenarios in energy modeling or sensitivity analysis	Based on the understanding of extensive interactions and trends, key uncertainties are identified for different scenarios through tools such as Delphi Analysis, RDM Uncertainties will also draw from the historical patterns of self-organization, co-evolution, surprise events that do not feature in the identified interactions
Participation and data gathering	Limited participation allowed in most projects in the form of validation of modeling results or in the framework of social acceptance (even in case of contemporary framework such as City-Zen)	Participation sought in all stages of futures development for knowledge inputs, validation, and capturing citizen imaginaries Participation can be in the form of workshops, citizen assemblies, surveys, and interviews Participation from wide interest groups should be sought including representatives of other sectors and societal segments
Pathways and futures governance	Techno-economic pathways with limited outlook for governance strategies	Multiple/plurality of pathways for the different scenarios Uncertainties, interdependence, and consequences (up to third order) of steps involved traced Actions prioritized and categorized as what needs to be avoided Institutional arrangements for scenario development (panel of experts), review committee Equity and justice related provisions established Review procedure, signposts, tipping points determined (Futures Panel/committee/budgetary provision)

pathways. A key tool here may be to produce multiple iterations of the visual urban energy map produced in futures and context exercises.

5.2.3. Futures governance

Complex system thinking also necessitates that governance strategies are dovetailed with pathways and the development of futures. Careful application of anticipatory, incremental, and adaptive governing strategies such as frequent review of context, multiple futures and scenarios, and pathways; regular exploration and experimentation; learning and reflexive practices; participatory and plural methods; dedicated institutional arrangements (see Singapore and Finland cases for national institutions); signposts and tipping points are as important as the futures and pathways themselves. While this may be axiomatic, in the case of complex systems these steps hold special significance in that the imminent uncertainty around the future makes the incremental strategies and adaptive pathways much more central to the idea of futures. These different segments of energy planning at the urban level will also need to be in constant conversation with each other as proactive feedback on institutional capacities, course correction, and review of goals and contingencies with changing circumstances will be a constant feature, Lastly, governance of complex systems futures will need "humility" for the *black swan* events that are inevitable in a long-term time frame and make provisions for responding suitably (Jasanoff, 2003; p. 223; Tõnurist and Hanson, 2021).

5.2.4. Complexity principles-in-practice

5.2.4.1. Contextualization: Mapping multiscalar—past and present context and trends

Contextualization will serve as the bedrock for a futures exercise in the case of urban energy systems. As both complex systems and energy studies literature point out, urban energy systems are markedly different from general energy systems because of their close relationship with the local context, material, and society. Therefore, the contextualization of urban energy futures, in practice, will have to be approached differently from the quantitative baseline development exercises in typical energy plans. To address the complexity of a deeply interconnected complex system, understanding the context needs to happen in multiple phases spanning firstly, mapping the present and tracing historical context; secondly, assessing the short-term trends; and thirdly, identifying the key drivers and other interactions. This approach does not signify that a projection of these parameters would deliver knowledge about the future. Instead, it helps in focusing on understanding the myriad components of a complex system and the interactions; understanding what is quantifiable, linear, and predictable in the short term but also what is immeasurable, unknown, and non-linear; what are the negative and positive feedbacks; where are the strong and distant influencing networks and interdependencies; where and how has past self-organization or co-evolution occurred. This detailed understanding is often ignored in regular energy modeling increasing the uncertainty in any system's futures. These insights generate both measurable and non-measurable inputs for thinking about futures as well as for designing and prioritizing pathways and governing strategies. A schematic model for urban energy systems interdependencies has been proposed previously by us (Basu et al., 2019). A similar shared visualization approach could be used to undertake the contextualization exercise. We also propose that any methodology for a futures exercise itself should be contextualized. The desire for a robust complex futures exercise should also match the practical context of resource and capacity availability.

5.2.4.2. Mapping uncertainty—interactions, worst-case scenarios, and weak signals

Mapping uncertainty, distinct from other similar exercises such as risk assessment or SWOT (Strengths, Weaknesses, Opportunities, and Weaknesses) Analysis, aims for an extensive assessment of the aspects that may change non-linearly and therefore difficult to predict or simulate. We propose that futures exercise of complex systems such as urban energy systems should embrace the assessment of short-term risks, uncertainty, and completely unknown elements along the entire process. This is because complex systems not only can evolve in unpredictable ways but when not habitually seen as complex systems, there can be many unknown elements. Foresight methods offer a number of tools to map or acknowledge different types of uncertainties under different categories. This can vary from understanding the multigenerational and multidimensional implications of a particular scenario (causal layered analysis, for instance) to exploring *what if* scenarios (see in Liveable Cities project— Leach et al., 2020); exploring different dynamics of the future scenarios or identification of weak signals—low probability, high impact events—that can throw surprises for policymakers; assessment of threshold and tipping points in designing pathways; or simply building an understanding of what is completely unknown (Taylor et al., 2015; SAPEA, 2019). Lastly, the uncertainty identified should aid decision-makers in undertaking suitable adaptive measures or managing governing strategies.

5.2.4.3. Participatory processes

Given the interconnected nature and vastness of complex systems, rich data, and broader intelligence, plural perspectives become critical for making informed choices about the future. As we make the case earlier, this critical input is likely to be possible only by ensuring a wide base of participation beyond traditional policymaking circles. In understanding the critical micro- and macro-interactions and interdependencies, as well as in imagining the myriad uncertainties, and signals that may jeopardize desirable/preferable futures, a wide net needs to be cast for participation. There is also the normative issue linked to public participation to make futures democratic, as well as inclusive. Urban energy system initiatives dealing with futures will need to remedy the current criticism of superficial public engagement to conceptualize participation more deeply and move beyond the impression of conflict avoidance.

Equally important here is the process of participation. As most of the comprehensive futures approaches showcase, we suggest a recursive approach to participation (from mapping to pathways and governance planning) is essential in the development of plurality and robustness. Experiences from

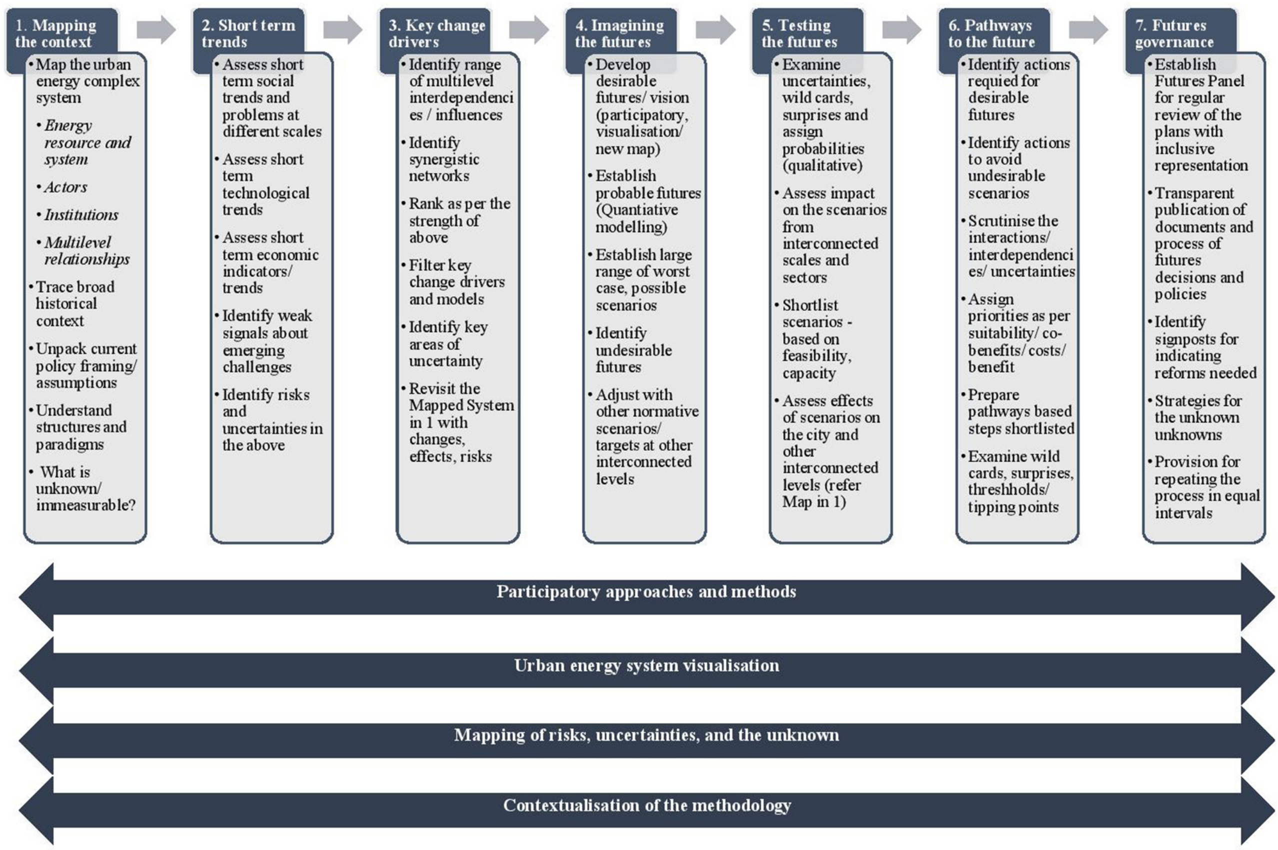

FIGURE 5
Proposed methodology for complex urban energy systems futures.

urban futures exercise also highlight that often futures are not always articulated clearly and can be derived from secondary sources. Implicit ideas of a city's future, values associated with long-term and inter-generation wellbeing, and ecological sustainability need to be carefully curated to be part of visions of the future.

Building on this framework (Figure 4) and drawing from the processes of the existing futures methodologies highlighted in Figure 3 we propose a methodology identifying the key steps needed for a comprehensive futures development for urban energy systems. The methodology identifies seven key steps needed for futures development. Each step is further detailed with the actions needed to fulfill the objectives in the framework. Complex systems dimensions such as participatory methods, mapping the uncertainties, and contextualization efforts need to be followed through these seven steps. Visualization of the urban energy system can serve as a critical tool across all steps listed. The proposed integrated methodology, presented in Figure 5, is a preliminary attempt toward operationalizing the framework above. The methodology can be further teased out by putting focus on the development of the pathways and governance aspects of the framework.

6. Conclusion and future research directions for urban energy futures

This study highlights that current city-level climate or sustainable energy action plans are only simplified endeavors for what are essentially complex and uncertain systems. Developing long-range futures of urban energy systems, of the order of 50–100 years, can have many advantages including an intergenerational view of our actions today, increased future democratic acceptability as well as enhanced adaptive and innovation potential at the local level. In addressing this, we offer a new framework for enriching these initiatives from a complex-system perspective. While forecasting and modeling exercises have always been used to plan for the future of energy systems, there has been limited exploration of the theory as well as application of energy futures, particularly from a complex-systems point of view. We have undertaken an integrated review of complex systems literature, futures and foresight studies, and urban studies, and interrogated their treatment of complexity and uncertainty in decision-making. Future and foresight studies build upon complex systems theory to offer practical methods to develop foresight for governance institutions and support the management of uncertainties. It is difficult to establish the best practices within futures literature as it is fundamentally untestable for current researchers. Nevertheless, a few prominent examples from futures exercises in formal policy circles have been highlighted in a tabular format. A key strategy offered in the theory and practice of the futures is the conceptualization of multiple long-term futures ranging from worst-case scenarios to desirable futures based on extensive mapping of the system's past and present. Considering futures as a spectrum allows pathways to be malleable instead of a set plan while absorbing and adapting to uncertainties that are inevitable in complex systems. The literature also offers additional tools and methods to manage uncertainties that in particular embed the practice of extensive understanding of interactions (both qualitative and quantitative) and wide-ranging participation within any futures exercise. On the other hand, urban studies, particularly planning and design scholars, have offered new ideas related to futures of a complex system, limitations of modeling efforts, and alternative strategies for embracing complexity. The theme of participation is resounding even in this literature, and bottom-up, local interventions of innovation form a key part of the strategy. We suggest that complex systems such as energy systems can benefit from these theoretical as well as practical offerings. Based on the findings from the review, a framework and a proposed methodology are put forward with the objective of supporting decision-making for the complexities and uncertainties involved in long-term urban energy planning.

One of the main conclusions from this review is that there is much scope for further research, particularly in the application of futures ideas to the urban energy domain. There are precious few examples of cities where real futures thinking and methods have been applied to the critical challenges of providing low-carbon, affordable, secure, and clear energy. As much of this methodology is untested in the energy systems domain, new studies are certainly needed to trial methods with city stakeholders. This is something we are aiming to undertake using the complexity framework we have already proposed as a way to undertake the mapping in the contextualization phase (Component *d* of the framework). A second important area of research should be learning from actual experiences of the governments that have gone through a foresight preparation in the past years; how does a national foresight exercise get translated to the subnational levels or sub-sectoral levels, and vice versa? And what aspects of the foresight exercises could city-level governments undertake themselves, given the capacity and resource limits? At the very least, the framework offered in this paper reaffirms that sound urban sustainability actions need further support in the form of commensurate resources and technical capacities. Further, very little has been discussed on justice and fairness in futures studies beyond the notion of increased participation. It is an area that needs further contemplation in both conceptualization and practice.

Lastly, for futures thinking to translate into the urban energy planning practice, political appetite for long-term thinking, policy acknowledgment for uncertain futures, and scientific humility for incomplete knowledge will have to be some of the critical first steps.

Author contributions

SB conducted the primary research, the integrative review, led the writing of the article, and the development of the framework and methodology with significant contribution from CSEB. CSEB mentored SB in the choice of literature and direction of the paper, contributed to the development of the framework and methods based on the review results, and led the editing of the paper including drafting the abstract and conclusions. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2023.1145277/full#supplementary-material

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