



REVIEW

Transformative low-carbon urban innovations: Operationalizing transformative capacity for urban planning

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Abstract Cities can set in motion sustainability transitions through experimentation and innovation. To invest in and mainstream solutions that contribute to urban transformation agendas, urban planners need to understand which innovations have transformational potential as well as how these innovations can accelerate sustainability transitions. In order to explore this, existing frameworks of transformative capacity provide the guidance, but they are generic, abstract, and challenging to apply for urban planning. As part of our effort to develop a more operational version of the transformative capacity framework by Wolfram (2016), we conducted a systematic scoping review of the academic literature to determine the characteristics of people-based and nature-based low-carbon innovations that constitute their transformative capacity. After reviewing 65 records, we identified dimensions indicating each of the transformative capacity components through analysis and synthesis. Besides contributing to the science–policy interface through a knowledge synthesis on low-carbon people-based and nature-based innovations, this paper examines bridging frameworks to inform urban planners in developing practical solutions and actionable elements for low-carbon urban futures.

Keywords Cities · Low-carbon · Nature-based solutions · Social–ecological innovation · Transformative capacity · Urban planning

INTRODUCTION

Cities are trying to find ways to accelerate the transitions for strengthening urban resilience and achieving sustainability simultaneously (Holtz et al. 2018; Nagorny-Koring and Nochta 2018; Frantzeskaki et al. 2021). Particularly, in the last decades, a large abundance of research has been done to explore and unpack cities' social and ecological innovations (Cohen-Shacham et al. 2016; Keeler et al. 2019; Axon 2020; Eriksson et al. 2021; Tzoulas et al. 2021). The proliferation of research for these innovations demonstrates their transformative capacity, but also reveals a divide. There are few transdisciplinary efforts and research programs about cities that explore social–ecological aspects of innovative experiments (Frantzeskaki 2019; Lin et al. 2021; Mahmoud et al. 2021). Instead, innovative projects and experiments have been designed and assessed in the dichotomy of (social)people-based innovations and (ecological)nature-based solutions and innovations. Research confidently presents that both types of interventions have shown efficacy and the potential to contribute to urban transformations in cities (Bayulken et al. 2020; Almenar et al. 2021; Tzoulas et al. 2021). However, we identify three interlinked knowledge gaps that emerge from this divide. First, the evaluation and mapping of their transformative capacity remain fragmented and limited to place-based evaluations and assessments. Accordingly, the evidence is viewed through a 'social' or 'ecological' lens, without an integrative social–ecological perspective (Cohen-Shacham et al. 2019; Keeler et al. 2019; Avelino et al. 2020; Dignum et al. 2020). Second, these innovative projects and experiments are mostly designed and operated to deliver transformative impacts, without supporting transformative capacity in planning and community (Moore and Milkoreit 2020; Eriksson et al. 2021). Third, when these

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innovative projects/initiatives are evaluated from a social or ecological perspective, they often fail to integrate lessons and inform policy and planning (Pel et al. 2020; Wamsler et al. 2020). These knowledge gaps burden the ability to translate research results into policy and planning for better design, evaluation, and monitoring of such initiatives.

To respond to these interlinked knowledge gaps, we propose to examine the following research question: What are the transformative capacity dimensions of social–ecological innovations and experiments in cities? To address this critical question, we conducted a scoping review to explore the state-of-the-art research of social and ecological innovations for low-carbon urban transitions. Our focus on social and ecological innovations is to unpack the transformative capacity of people and nature-based solutions and innovations. We bring these two interconnected bodies of literature together and analyse them in light of Wolfram’s (2016) transformative capacity framework and its ten main components. Through these components, our analysis explores critical aspects of transformations such as how communities participate, experiment and are empowered, how knowledge is co-produced through social learning and other processes, and how innovation works across scales, agencies, and geographies. In this way, we are contributing threefold. Firstly, through a synthesis and review of the current state of the art and evaluation of transformative innovations in cities, we identify dimensions of the transformative capacity of social–ecological innovations in cities. Second, as a theoretical contribution, we identify dimensions that operationalize the transformative capacity framework to make it more applicable as a design and/or evaluation framework. The dimensions are programmatic interventions that urban planning/planners can employ to design social–ecological innovations which contribute to urban sustainability transitions. Third, we propose a bridging framework to connect the advanced transformative capacity framework (with the specific dimensions) with participatory and strategic urban planning.

THEORETICAL AND ANALYTICAL FRAMEWORKS

Low-carbon innovations as a mix of people-based and nature-based innovations

Becoming a low-carbon city remains a great policymaking challenge. There is a need for structural changes at various levels to move towards low-carbon transition cities (Holtz et al. 2018). Urban planners and policymakers progressively advocate low-carbon development and transition

processes to deliver innovative policies and practices in multi-level governance (Nagorny-Koring and Nochtta 2018; Moore and Milkoreit 2020). To challenge existing urban systems that are locked-in unsustainable practices, cities can demonstrate through experimentation how to set up as well as strengthen existing low-carbon initiatives (Nagorny-Koring and Nochtta 2018). Low-carbon behaviours and practices in the urban forms have evidenced the transformative capacity in social–ecological aspects, resulting in participatory strategies in transitional changes (Axon 2020). Low-carbon interventions can be driven by specific people-based and nature-based solutions through measures that have multiple benefits, for example, lowering air pollution levels, reducing heat island effects, along with building community engagement and delivering on social development and wellbeing activities (Nagorny-Koring and Nochtta 2018; Bayulken et al. 2020).

People-based and nature-based innovations have interlinked transformative (impact) characteristics (Holtz et al. 2018; Bayulken et al. 2020). As such, we propose conceptualizing social–ecological innovations as a continuum of people and nature-based innovations (inspired by Spijker and Parra (2018)). With this perspective, social–ecological innovations can facilitate transformative change that leads to improved social–ecological wellbeing, reduced carbon and ecological footprints, and positive sustainability outcomes. From a social–ecological systems perspective, these innovations are interconnected and interdependent, which enable truly unique new ways to learn, create, and interact (Frantzeskaki et al. 2021). However, these innovations are guided by different conceptual frameworks, tools and methods, and their knowledge remains disconnected.

On the one hand, people-based or social innovations are ‘institutionally and spatially embedded social struggles [...], to the reconfiguration of institutions, territories and urban governance arrangements’ (Wolfram 2016, p. 124). People-based (social) innovations create social impact by addressing basic human needs, social vulnerability, and disadvantage, as well as by empowering, including, and strengthening people’s capacity to enhance wellbeing and development (Moulaert et al. 2013, p. 16). From a sustainability perspective, social innovations are catalysts of sustainability transitions to low-carbon societies by shifting and transforming social practices, activities, and institutional logics (Avelino et al. 2020; Pel et al. 2020). Social innovations in the urban environment range from creating institutional spaces and new ways of thinking to supporting the shift to renewable sources of energy (Wittmayer et al. 2020), encouraging walking and cycling over other modes of mobility, and promoting environmental actions (Mehmood and Parra 2013, p. 64). People-based innovations are shaped by the place, peoples’ values, transformational

leaders, and a multiplicity of actors involved with experimental and experiential processes and activities (Wolfram 2016).

On the other hand, nature-based solutions (NBS) are proposed as resilience-building interventions that are inspired by nature to deal with interconnected social challenges and foster positive social, economic, and ecological change (Raymond et al. 2017; Frantzeskaki et al. 2019a, b). As solutions based on natural processes and structures, they offer cost-effective ways of decarbonizing the economy by reducing the urban heat island effect, and by increasing green canopy cover, green spaces, and living roofs and walls (Seddon et al. 2020). Nature-based innovations occur through experimentation, co-creation, co-production, flexible and adaptable governance mechanisms, and through multi-scale and multi-stakeholder long-term planning, implementation, and monitoring (Raymond et al. 2017; Frantzeskaki 2019; European Commission 2021). Recent research points to progressing the approaches and solutions-oriented character of nature-based solutions towards scaled-up innovations and conceptualizing them as nature-based innovation systems (van der Jagt et al. 2020), nature-based enterprises (Kooijman et al. 2021), nature-based urbanism (Pineda-Pinto and Frantzeskaki 2021), and nature-based approaches (Ignatieva and Hedblom 2018; Tzoulas et al. 2021). These new scaled-up innovations require urban planning's contributions to effectively design and implement nature-based solutions by enabling practical efforts and examining social–ecological trade-offs (Bush and Doyon 2019), by developing social–ecological models to assess spatial variations in land use changes (Pan et al. 2021), and by taking an ecosystem-based approach for landscape-scale structures and process (Albert et al. 2019).

One of the greatest challenges for cities to achieve future sustainability, resilience, and liveability is to chart pathways for low-carbon urbanism (Newton et al. 2019). Understanding the strategies and interventions needed for incorporating social–ecological innovations with transformative potential is essential to these urban pathways. In this context, we need to examine which social–ecological innovations have the capacity for transformation, and analyse how they can be used by policy-makers, designers, planners, and other decision-makers to implement low-carbon innovations. In order to do this, we employ the transformative capacity framework (Wolfram 2016) as an analytical and organizing tool.

Transformative capacity framework

To explore low-carbon social–ecological innovations and their transformative capacity in cities, we use Wolfram's (2016) conceptual framework of urban transformative

capacity. We adopt the definition of transformative capacity from Wolfram in this review as the joint capacity of urban stakeholders to drive—through interactions across complex systems—divergent pathways or systemic change towards sustainability (2016). To examine how transformative capacity is elicited and manifests on the ground, Wolfram (2016) devised a diagnostic framework: the transformative capacity framework. The transformative capacity framework has ten interconnected and complementary components, which are considered important for identifying the conditions that enable innovative transformations (Wolfram 2016, 2019; Broto et al. 2019) (see Fig. 1).

An essential aspect in the transformative capacity literature is related to people and communities' capacities. The first component of the framework refers to **inclusive and multiform governance** as the participation of citizens and communities in decision-making processes through diverse governance networks that encourage collaboration and capacity building among stakeholders (Wolfram 2016; Borgström 2019; Ziervogel 2019). This component highlights the intermediary connections between the government and other stakeholders to guide different actors and processes (Wolfram 2016; Ziervogel 2019). Similar to intermediaries, the **transformative leadership** as the second component seeks to inspire communities and build collaboration across scales and actions by connecting shared values and visions (Wolfram 2016). Correspondingly, the third component highlights how **empowered communities of practice** plan and deploy interventions, which allows understanding people's motives and needs for pursuing social justice and wellbeing, which is directly linked to the social, technical, and material resources of communities (Wolfram 2016; Ziervogel 2019).

The governance dimension is fundamental for understanding transformative capacity. To analyse urban systems and governance structures that deal with sustainability challenges, creating a baseline through **systems awareness and memory** (component 4) helps in identifying systemic barriers (regulatory, physical, cultural) and path dependencies (Broto et al. 2019). Understanding this baseline enables other dimensions to emerge such as recognizing, reflecting, and evaluating systems' path dependencies to achieve **sustainability foresight** (component 5). This fifth component refers to the co-production of knowledge and formulation of innovative visions and multiple scenarios by the diverse groups of society (Wolfram 2016; Broto et al. 2019). In many cases, this leads to **community experimentation** (component 6), which involves challenging existing practices and policies through community-based experiments and ideas (Wolfram 2016).

Component seven, **effective sustainability innovations embedding** is useful to explore how groups access

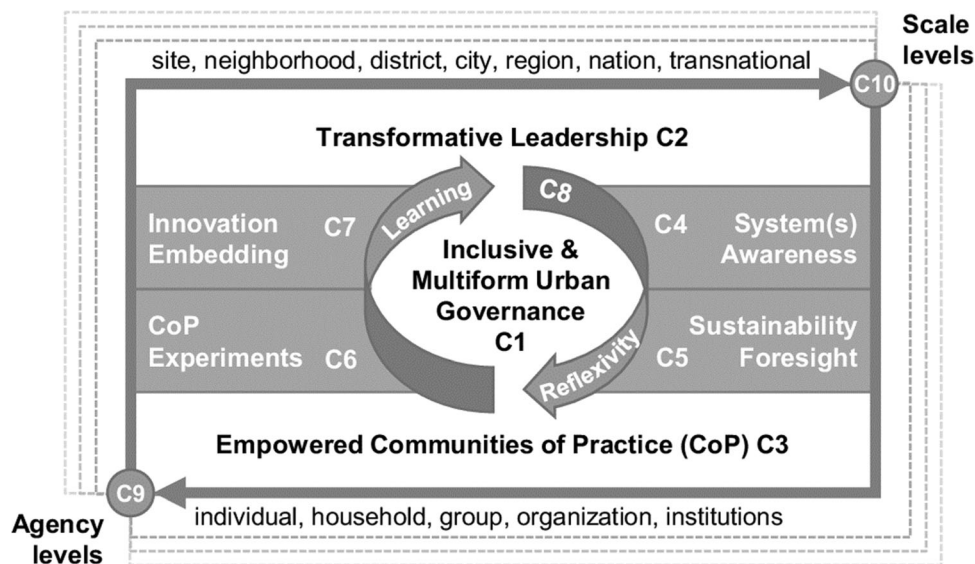


Fig. 1 Conceptual framework of urban transformative capacity (cf. Wolfram 2016)

knowledge, learn, share lessons, and find support to potentially mainstream innovative efforts and generalize to different contexts and locations (Wolfram 2016; Borgström 2019; Broto et al. 2019). This can influence local and national policies by modifying regulatory frameworks. Access to knowledge also requires **social learning** as a crucial component (8) to critically reflect on the project's procedures, development, and outcomes, allowing progressive actions to monitor and continuous learning. Finally, the last two components bring the other components together through an understanding of how innovations and actors **work across human agency levels** (building capacity within individuals, networks, and organizations) and **across the political-administrative level and geographical scales** (capacity building across different government levels and geographical scales) (Wolfram 2016; Borgström 2019; Broto et al. 2019).

METHODOLOGY

To examine the transformative capacity of low-carbon urban innovations reported in the academic literature, we conducted a scoping literature review. This is a useful method for improving policymaking processes by identifying key subjects, spotting knowledge gaps, and offering recommendations (Arksey and O'Malley 2005; Daudt et al. 2013; Tricco et al. 2016). In this study, the scoping review was implemented according to PRISMA guidelines (Fig. 2) to follow a systematic process, which consists of four reviewing steps: identifying, screening, eligibility, and inclusion (Arksey and O'Malley 2005). A detailed

methodology is presented in Supplementary Material within a complete list of all reviewed papers against the theoretical components of transformative capacity framework.

Eligibility and screening

Scopus and Web of Science were chosen as databases for searching academic articles. The first coding keywords to search for articles used the string “low carbon” AND “innovation” AND “urban* OR city”. After collecting this set of articles, two new search strings were conducted. The first one filtered people-based articles—(*people* OR social**) AND (*wellbeing* OR “social cohesion”**)—and the second search filtered nature-based articles (*forestry* OR forest* OR nature-based* OR “nature-based solution”* OR “green infrastructure”* OR nature**). Only published peer-reviewed articles in English were included and exported to Mendeley reference management software. After duplicates were eliminated, two reviewers (FS and MPP) independently screened articles, and disagreements between the two reviewers were resolved with the assistance of the third reviewer (NF). The reviewers screened the full-text articles for study selection and included 65 records for qualitative analysis (See Supplementary Material—Figures S1 and S2 and Tables S1 and S3 for details).

Data synthesis

We operationalized Wolfram's (2016, p. 122) Transformative Capacity Framework in order to identify the transformative capacity of low-carbon innovative urban

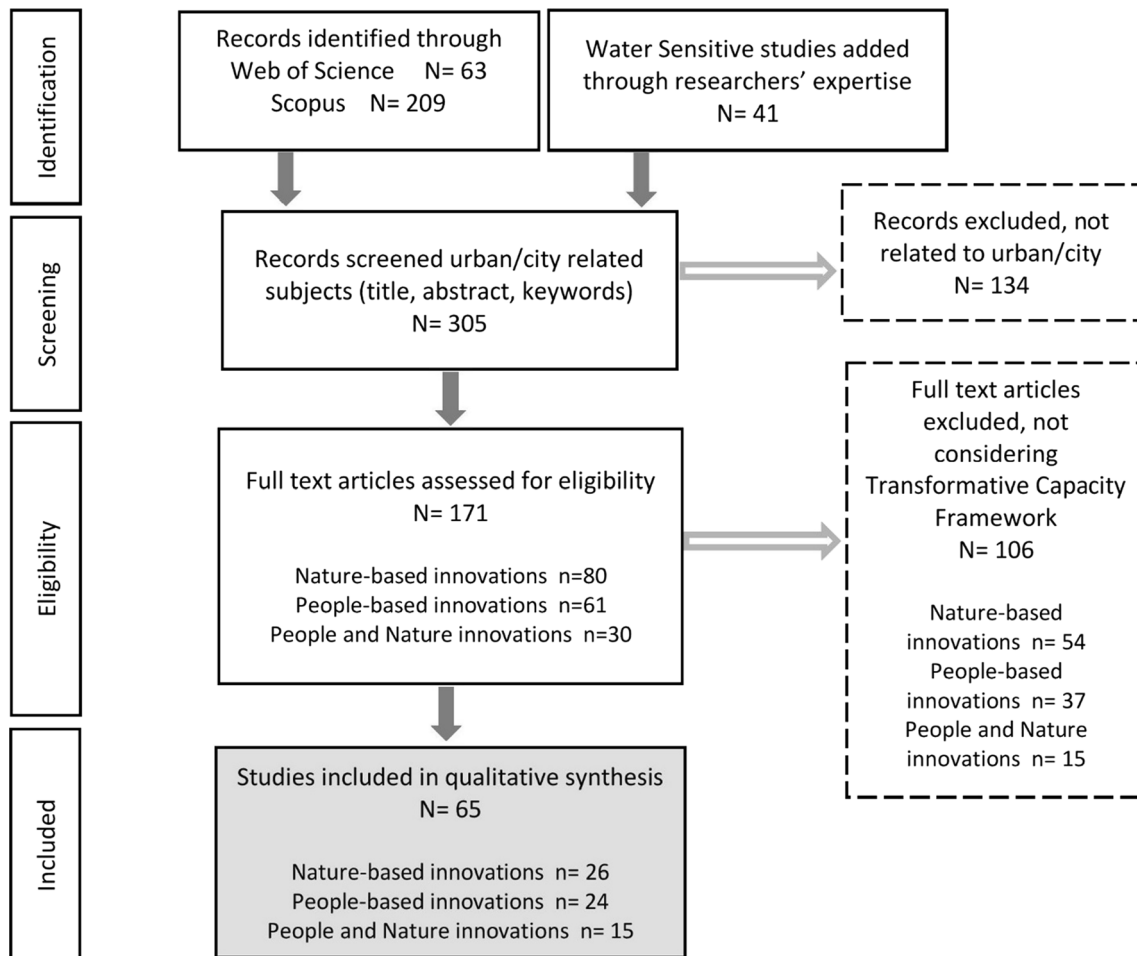


Fig. 2 PRISMA Diagram presenting the systematic scoping review

strategies. To enable a practical use of the framework as an analytical framework, we applied Broto et al. (2019) operationalization of the subcomponents (See Supplementary Material—Table S2 and Figure S3 for details). Based on this operationalization, we identified keywords and defined questions to evaluate the ten components, which we used to interrogate the studies included in the review. By identifying the keywords and examining the questions within this framework, we synthesized each article's content against and across each of the components criteria (See Supplementary Material—Table S7 for details).

RESULTS

Based on the analysis of the records screened for the final review, we identified the key capacities, conditions, and processes across diverse innovative interventions (including for example, urban planning and governance approaches, new infrastructures and ways of urban living)

designed for transforming cities towards sustainable futures. Based on the review and analysis of papers on people-based and nature-based innovations, Table 1 provides an overview of the synthesis from the reviewed literature in the form of the *characteristics* that contribute and constitute their transformative capacity (within each transformative capacity component). The following sections summarize the findings for each of the ten transformative capacity components.

Inclusive and multiform governance

Inclusive governance according to Wolfram (2016) is emphasizing the role of citizens and communities in decision-making processes to promote collaboration and capacity building among them. The synthesis of the reviewed papers points to three ways of ensuring inclusive and multiform governance. First, it is important to curate and organize participation to ensure trust-building, diversity, inclusivity, and activation of urban actors. Our review

Table 1 Dimensions of low-carbon urban innovations that contribute and constitute their transformative capacity (for every transformative capacity component (C1–C10) (Wolfram 2016), we identify specific dimensions from a synthesis of the reviewed literature cited against them)

Transformative capacity components	Dimensions for low-carbon urban innovations	Supporting references
C1—Inclusive and multiform governance	Participation requires curation and organization to ensure diversity, inclusivity, and activation of urban actors	Bos et al. (2013), Buijs et al. (2019), Caprotti et al. (2015), Carlet et al. (2017), Frantzeskaki (2019), Haase et al. (2017), Huxley et al. (2019), Landholm et al. (2019), Macke et al. (2018, 2019), Tonks and Lockie (2020), van der Jagt et al. (2019), and Yan and Roggema (2019)
	Self-governance arrangements of urban projects as well as bottom-up sustainability initiatives contribute to inclusive governance of urban transitions	Chatterton (2013), Ehnert et al. (2018), Gorissen et al. (2018), Hausknost et al. (2018), Lopes et al. (2018), and Nicolosi et al. (2018)
	Urban experiments are settings of inclusive governance of urban transitions	Chatterton (2013), Chelleri et al. (2016), Christie and Waller (2019), Druckman and Gatersleben (2019), Foster (2020), Landholm et al. (2019), Macke et al. (2018, 2019), and Meira et al. (2020)
C2—Transformative Leadership	Shift to bottom-up or local leadership in uprooting new ideas, technologies, and approaches	Affolderbach et al. (2019), Borgström (2019), Bos et al. (2013), Christie and Waller (2019), Frantzeskaki (2019), Lopes et al. (2018), Macke et al. (2019), Meira et al. (2020), Onubi (2019), and Tonks and Lockie (2020)
	Thematically focussed initiatives with a determined and identifiable focus and vision	Affolderbach et al. (2019), Christie and Waller (2019), Lopes et al. (2018), and Meira et al. (2020)
	Transformative leadership needs to connect initiatives and opportunities across (multi-level) governance scales	Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Chatterton (2013), Guillen-Royo et al. (2017), and Nicolosi et al. (2018)
C3—Empowered communities of practice	Social needs and motives need to be addressed through inclusive urban design and thereafter, urban projects need to strive to be inclusive by design	Arsenio et al. (2018), Bian et al. (2020), Buijs et al. (2019), Caprotti et al. (2015), Chapman et al. (2016), Chelleri et al. (2016), Christie and Waller (2019), Cuthill et al. (2019), Druckman and Gatersleben (2019), Fink (2016), Haase et al. (2017), Hasanzadeh et al. (2019), Hausknost et al. (2018), Joffe and Smith (2016), Kilkiş (2016); Landholm et al. (2019), Leporelli and Santi (2019), Macke et al. (2019), Mindell et al. (2011), Stevenson et al. (2016), and van der Jagt et al. (2019)
	Recognize equity as a value and a guiding principle when formulating urban plans as well as programs and initiatives	Adabre et al. (2020), Bartesaghi-Koc et al. (2019b), Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Chatterton (2013), Chelleri et al. (2016), Christie and Waller (2019), Du and Zhang (2020), Guillen-Royo et al. (2017), Kaae et al. (2019), Kullman (2013), Mindell et al. (2011), Nicolosi and Feola (2016), Nicolosi et al. (2018), and Zhu et al. (2019)
	Social learning is a vehicle for empowering communities	Arsenio et al. (2018), Bos et al. (2013), Buijs et al. (2019), Burgin (2018), Butler et al. (2014), Chelleri et al. (2016), Christie and Waller (2019), Crowe et al. (2016), Fink (2016), Ghanem et al. (2016), Gorissen et al. (2018), Guillen-Royo et al. (2017), Hausknost et al. (2018), Huxley et al. (2019), Landholm et al. (2019), Macke et al. (2018), Mindell et al. (2011), Schäfer et al. (2018), and Stevenson et al. (2016)
	Equip communities so as to sustain empowerment over time and ensure their autonomy with altering systemic conditions and lifting barriers	Bos et al. (2013), Buijs et al. (2019), Gorissen et al. (2018), Kaae et al. (2019), and Scott et al. (2014)

Table 1 continued

Transformative capacity components	Dimensions for low-carbon urban innovations	Supporting references
C4—System awareness and memory	Strategic urban planning takes a system's perspective that accounts for desirable and undesirable effects of plans and programs	Adabre et al. (2020), Affolderbach et al. (2019), Bartesaghi-Koc et al. (2019a, 2019b), Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Chapman et al. (2016), Du and Zhang (2020), Fink (2016), Foster (2020), Guillen-Royo et al. (2017), Hasanzadeh et al. (2019), Hausknost et al. (2018), He et al. (2019), Huxley et al. (2019), Mindell et al. (2011), Schäfer et al. (2018), and Zhang et al. (2019)
	Showcasing, advocating and gathering evidence on the performance of low-carbon solutions to assist them to gain traction	Adabre et al. (2020), Borgström (2019), Butler et al. (2014), Caprotti et al. (2015), Christie and Waller (2019), Foster (2020), Frantzeskaki et al. (2019a, b), Mindell et al. (2011), Hagbert and Bradley (2017), Hausknost et al. (2018), Joffe and Smith (2016), Lopes et al. (2018), Scott et al. (2014), van der Jagt et al. (2019), and Zhu et al. (2019)
C5—Sustainability foresight	Knowledge co-production is organized with expertise and with the expectation or prospect of scale out participation over time	Buijs et al. (2019), Ehnert et al. (2018), Frantzeskaki (2019), Frantzeskaki et al. (2019a, b, 2019a), Gorissen et al. (2018), Haase et al. (2017), Nicolosi and Feola (2016), Tonks and Lockie (2020), van der Jagt et al. (2019), and Yan and Roggema (2019)
	Inter- and transdisciplinary knowledge is required to support the different low-carbon innovations for mapping out their forecasted benefits across sectors	Affolderbach et al. (2019), Arsenio et al. (2018), Burgin (2018), Butler et al. (2014), Chatterton (2013), Chelleri et al. (2016), Ghanem et al. (2016), Guillen-Royo et al. (2017), Hagbert and Bradley (2017), Hasanzadeh et al. (2019), Joffe and Smith (2016), Lopes et al. (2018), Macke et al. (2019), Meira et al. (2020), Onubi (2019), Plazier et al. (2017), and Schäfer et al. (2018)
	Alternative pathways include a mix of disruptive and conforming/incremental low-carbon innovations that co-shape the route to radically alternative futures	Adabre et al. (2020), Arsenio et al. (2018), Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Burgin (2018), Caprotti et al. (2015), Chapman et al. (2016), Chatterton (2013; Christie and Waller (2019), Crowe et al. (2016), Cuthill et al. (2019), Druckman and Gatersleben (2019), Fink (2016), Foster (2020), Frantzeskaki (2019), Ghanem et al. (2016), Hagbert and Bradley (2017), Hasanzadeh et al. (2019), Hausknost et al. (2018), Huxley et al. (2019), Joffe and Smith (2016), Kilkiş (2016), Leporelli and Santi (2019), Liu et al. (2016), Lopes et al. (2018), Macke et al. (2018), Meira et al. (2020), Mindell et al. (2011), Nicolosi and Feola (2016), Plazier et al. (2017), Sandberg (2018), Schäfer et al. (2018), Stevenson et al. (2016), and Yan and Roggema (2019)
C6—Community experimentation	Experiments need to be developed through a co-production/co-design process centring on social learning and coordination of activities across different actors and scales	Bartesaghi-Koc et al. (2019a), Borgström (2019), Buijs et al. (2019), Carlet et al. (2017), Frantzeskaki et al. (2019a, b), Kullman (2013), and Tonks and Lockie (2020)
C7—Effective sustainability innovations embedding	Enabling resources and knowledge to be shared from different levels and factors	Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Gorissen et al. (2018), Onubi (2019), Tonks and Lockie (2020), and van der Jagt et al. (2019)
	Generalizing the process and methods and providing a holistic perspective	Adabre et al. (2020), Bartesaghi-Koc et al. (2019a), Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Chelleri et al. (2016), Du and Zhang (2020), Frantzeskaki (2019), Frantzeskaki et al. (2019a, b), Frantzeskaki et al. (2019a, b), Guillen-Royo et al. (2017), Hagbert and Bradley (2017), Huxley et al. (2019), Kilkiş (2016), Kullman (2013), Lopes et al. (2018), Macke et al. (2019), Meira et al. (2020), and Nicolosi and Feola (2016)
	Changing the policies and regulations through community initiatives and active citizenships	Adabre et al. (2020), Affolderbach et al. (2019), Bartesaghi-Koc et al. (2019b), Borgström (2019), Bos et al. (2013), Buijs et al. (2019), Caprotti et al. (2015), Chapman et al. (2016), Chatterton (2013), Chelleri et al. (2016), Hausknost et al. (2018), He et al. (2019), Huxley et al. (2019), Kaae et al. (2019), Landholm et al. (2019), Onubi (2019), Sandberg (2018), Schäfer et al. (2018), and van der Jagt et al. (2019)

Table 1 continued

Transformative capacity components	Dimensions for low-carbon urban innovations	Supporting references
C 8—Social learning	Critical discussions of the project development	Adabre et al. (2020), Affolderbach et al. (2019), Bartesaghi-Koc et al. (2019b), Caprotti et al. (2015), Chapman et al. (2016), Druckman and Gatersleben (2019), Hasanzadeh et al. (2019), Joffe and Smith (2016), Leporelli and Santi (2019), Liu et al. (2016), and Sandberg (2018)
	Analysing and reporting the outcome of the projects	Adabre et al. (2020), Arsenio et al. (2018), Buijs et al. (2019), Chatterton (2013), Kullman (2013), Landholm et al. (2019), Mindell et al. (2011), and Wolfram (2019)
	Evaluating and accessing the applied methods and tools	Bos et al. (2013), Chelleri et al. (2016), Crowe et al. (2016), Ghanem et al. (2016), Borgström (2019), Burgin (2018), Christie and Waller (2019), Joffe and Smith (2016), Macke et al. (2019), Onubi (2019), and Plazier et al. (2017)
C 9—Working across human agency levels	Engaging citizens, communities, marginalized groups, and NGOs	Bos et al. (2013), Buijs et al. (2019), Burgin (2018), Christie and Waller (2019), Crowe et al. (2016), Cuthill et al. (2019), Foster (2020), Gorissen et al. (2018), Guillen-Royo et al. (2017), Hausknost et al. (2018), Lopes et al. (2018), Macke et al. (2018, 2019), and Stevenson et al. (2016)
	Collaborating between governments and civic society	Buijs et al. (2019), Frantzeskaki (2019), Gorissen et al. (2018), and Tonks and Lockie (2020)
	Involving policymakers, planners, and politicians	Caprotti et al. (2015), Chapman et al. (2016), He et al. (2019), and Schäfer et al. (2018)
C 10—Working across political and administrative level and geographical access	Building networks across global and regional scales (a set of countries)	Adabre et al. (2020), Affolderbach et al. (2019), Bockarjova et al. (2020), Buijs et al. (2019), Burgin (2018), Chelleri et al. (2016), Ghanem et al. (2016), Hausknost et al. (2018), Kilkış (2016), Landholm et al. (2019), Meira et al. (2020), Nicolosi and Feola (2016), and Sandberg (2018)
	Developing the capacity across national and state levels	Bos et al. (2013), Caprotti et al. (2015), Fink (2016), Kaae et al. (2019), and Macke et al. (2018, 2019)
	Inspiring the capacity of the local governments	Aiken (2017), Frantzeskaki (2019), Frantzeskaki, et al. (2019a, b), Gorissen et al. (2018), and Tonks and Lockie (2020)

suggests the importance of urban experiments for inclusive and multiform governance, which is defined by broad stakeholder participation, diverse interactions, and valuable intermediaries (Wolfram 2019). In this way, experiments enable diverse actors and modes of governance to be mobilized and creatively engaged through co-creation mechanisms for urban transitions (Landholm et al. 2019; Macke et al. 2019; Meira et al. 2020). Inclusive governance requires an understanding of how to build trust, legitimacy, and empowerment across stakeholders (Frantzeskaki 2019; van der Jagt et al. 2019) and considering social–ecological trade-offs while ensuring diverse actor representation (Haase et al. 2017). According to the reviewed literature, it is important to develop and use analytical tools to design and guide participation and collaboration, including the identification of key stakeholders, raising awareness, and facilitating collaboration (Scott et al. 2014; van der Jagt et al. 2019; Yan & Roggema 2019). The current literature investigates how to create inclusive institutional spaces and how active citizens can contribute to these spaces (Buijs et al. 2019), based on their local social–technological–ecological environment (Kaae et al. 2019).

Second, self-governance arrangements and bottom-up sustainability initiatives contribute to inclusive governance of urban transitions by ensuring a diverse range of formal and informal interactions (Wolfram 2019). Inclusive governance can be achieved through a set of initiatives that take into account the varying scales, capacities, and knowledge of various groups (Bos et al. 2013; Borgström 2019; Wolfram 2019; Tonks and Lockie 2020), including their needs, demands, and opinions. These also include supporting local initiatives that incorporate community knowledge (Haase et al. 2017; Ehnert et al. 2018; Gorissen et al. 2018; Frantzeskaki, et al. 2019a, b), creating partnerships as well as providing urban change agents with resources to advance sustainability agendas (Ehnert et al. 2018; Gorissen et al. 2018). Review of the literature demonstrates the need for (multiple) intermediaries to facilitate knowledge transfer between stakeholders and build trust at various stages (Frantzeskaki 2019; van der Jagt et al. 2019; Tonks and Lockie 2020), with a long-term vision embedded in the socio-political landscape (Bos et al. 2013).

Third, urban experiments are settings of inclusive governance of urban transitions. A number of low-carbon

leisure activities can be done at the grassroots level by involving more people, such as cultural heritage and adaptive reuse programs, compost trials projects (Christie and Waller 2019; Druckman and Gatersleben 2019; Foster 2020), guiding co-design programs (Chatterton 2013; Lopes et al. 2018), and community self-governance of co-housing and eco-city projects (Caprotti et al. 2015; Huxley et al. 2019). In the literature, diverse governance modes have been presented as means to translate low-impact urban living from an idea/concept into a reality (Chatterton 2013; Chelleri et al. 2016; Macke et al. 2018), through mobilizing stakeholders in co-creating neighbourhood initiatives (Guillen-Royo et al. 2017) in order to avoid centralization in planning (Landholm et al. 2019; Macke et al. 2019; Meira et al. 2020).

Transformative leadership

Transformative leadership manifests in three different ways across the literature. First, there is recognition and evidence that the bottom-up or local leadership to uprooting new ideas, new technologies, and new approaches can lead to transformative outcomes and agendas (Lopes et al. 2018; Christie and Waller 2019; Onubi 2019). Leadership needs to come from diverse levels and be taken up by strategic actors that facilitate cross-collaborations between actors that also have the capacity to recruit other facilitators (Borgström 2019). Crucial concepts within transformative leadership are inspiration and legitimization from ambitious demand-side actors (e.g. governments, businesses) with a shared vision for change and knowledge of the systems' complexity at different scales (Frantzeskaki 2019; Tonks and Lockie 2020).

Second, transformative leaderships are shaped by thematically focussed initiatives with an identified vision and objective. For example, the literature shows that leading green neighbourhood agendas not only improves the city's image, but also shifts the focus from an internal audience, to an increasingly external and international one, which in turn motivates local action and global movements (Lopes et al. 2018; Affolderbach et al. 2019; Christie and Waller 2019; Meira et al. 2020). Thematic initiatives on low-carbon cities link formal institutional arrangements with informal social norms and actions (Chatterton 2013; Guillen-Royo et al. 2017). For example, initiatives aimed at improving the quality of life of local communities and reducing food waste are part of smart city institutional leadership (Christie and Waller 2019; Macke et al. 2019).

Third, transformative leadership needs to connect initiatives and opportunities across the multi-level governance structure (Buijs et al. 2019). The transformation of leadership initiatives and the facilitation of urban transitions require collaboration across sectors and scales to be

institutionalized and mobilized with organizational capacity (Bos et al. 2013; Nicolosi and Feola 2016; Borgström 2019).

Empowered communities of practice

Our review reveals four ways to empower communities of practice. First, social needs and motives in urban projects need to be addressed through inclusive and accessible urban design. For example, it is important to plan transportation systems and accessible neighbourhoods that are walkable with safe footways for pedestrians, visually appealing, and achieve a car-free city centre (Mindell et al. 2011; Chapman et al. 2016; Fink 2016; Cuthill et al. 2019). Active urban design promotes low-carbon mobility by using stairs instead of elevators in outdoor activity areas, and by designing spaces that are conducive to running and cycling without obstacles (Arsenio et al. 2018; Druckman and Gatersleben 2019; Hasanzadeh et al. 2019; Landholm et al. 2019; Leporelli and Santi 2019).

Second, it is important to recognize equity as a value and a guiding principle when formulating urban plans, programs, and initiatives for empowering communities. When equity is the guiding planning principle, the review highlights successful examples including the implementation of leaseholder programs to cooperatively own housing (Chatterton 2013; Schäfer et al. 2018), as well as ensuring fair access to urban green spaces across diverse socio-demographic groups (Nicolosi et al. 2018; Borgström 2019; Zhu et al. 2019). In order to achieve social needs and equitable distribution of benefits and access to opportunities, it is imperative that complementary approaches be taken to identify underrepresented groups and voices (Haase et al. 2017; van der Jagt et al. 2019; Bian et al. 2020).

Third, social learning is a vehicle for empowering communities and can be enacted through social symbols, storytelling, and facilitated alternative lifestyles to shape cultural and cognitive beliefs, such as the bike as a symbol for the city of Copenhagen (Huxley et al. 2019). Social learning is mediated through a sharing economy such as food sharing initiatives (Burgin 2018; Macke et al. 2018; Schäfer et al. 2018) or community food composting (Christie and Waller 2019), to contribute to empowering communities. Social learning may also be achieved through initiatives and platforms for sharing information, and by sharing knowledge about how communities can build resilience (Crowe et al. 2016; Ghanem et al. 2016; Landholm et al. 2019).

Fourth, communities need to be equipped to sustain their empowerment through systemic changes and by removing barriers and altering systemic conditions. This can be realized through access to resources such as funding

support, technology, materials, outreach programs and platforms, training, and accessing to the data (Bos et al. 2013; Gorissen et al. 2018). Other ways to equip communities are through providing them with knowledge-enhancing tools (Scott et al. 2014) for activities, encounters, and connections (Kaae et al. 2019).

Systems awareness and memory

Urban planning has a major role in lifting systemic barriers to set agendas and deliver plans and interventions that promote low-carbon transformations. The synthesis of our review provides evidence on two ways of improving system awareness: First, an urban strategy needs to be based on a systems perspective that takes into account both desirable and undesirable effects brought by plans and programs. The use of standards and certification systems prove to be effective for elucidating opportunities and barriers to uptake and implement urban green mobility innovations (Guillen-Royo et al. 2017; Affolderbach et al. 2019). Studies that also demonstrate systems awareness focuses on comprehensive analyses to examine key patterns for green space design and urban regeneration, taking into consideration interdependent social–ecological dynamics (Bartesaghi-Koc et al. 2019a; Bian et al. 2020; Du and Zhang 2020).

Second, to raise system awareness, it is necessary to showcase, advocate for, and collect evidence on the performance of low-carbon solutions. From an urban planning and governance perspective, this can accelerate their adoption. For example, for shifting to low-carbon municipalities, it is important to stimulate low-carbon practices such as cycling, which requires investing in cycling infrastructure, setting up bike rental schemes and organizing cycling training (Hausknost et al. 2018). Evidence of the performance of innovations can be collected, systematized, and used to lift barriers and shift narratives and perceptions about the value and effectiveness of innovations while addressing issues of environmental justice (Zhu et al. 2019); that is crucial, for example, for prioritizing nature-based solution investments (Frantzeskaki et al. 2019a, b). In addition, several studies show that it is possible to unlock transformative capacity by challenging planning's status quo agenda through participatory designs and engagement of urban planners in research projects (Mindell et al. 2011; Bartesaghi-Koc et al. 2019b; van der Jagt et al. 2019).

Sustainability foresight

Our synthesis of the review provides three insights about how sustainability foresight as a transformative capacity component can be designed for urban low-carbon

innovation projects/interventions. First, to enable sustainability foresight, knowledge co-production must be organized with experts that have the capacity to scale out lessons learnt and knowledge from local innovations through participation mechanisms over time. This can include delivering curated processes through the collaboration of active citizens and NGOs (Buijs et al. 2019), through platforms that foster the exchange of knowledge and experimentation formats (Frantzeskaki et al. 2019a, b; Yan and Roggema 2019; Tonks and Lockie 2020), as well as through building or strengthening existing networks (Ehnert et al. 2018).

Second, knowledge about the predicted benefits of low-carbon innovations within different sectors requires inter- and transdisciplinary inputs. As an example, several studies show that co-housing initiatives can promote many benefits, including community interaction, wellbeing and safety, and leverage low-carbon behaviours by adopting passive practices and connections with nature (Chatterton 2013; Hagbert and Bradley 2017; Lopes et al. 2018). Transdisciplinary knowledge can also reveal how local populations appreciate and identify the benefits of low-carbon innovations, including recognizing the social and cultural advantages of urban green infrastructure related to climate benefits (Joffe and Smith 2016; Affolderbach et al. 2019).

Third, innovative low-carbon pathways comprise disruptive, conforming, and incremental innovation mixes that co-shape the way to radical alternative futures. Among such mixes are, for instance, green retrofit technologies like green roofs combine with biomass-based cooling materials in housing construction (Sandberg 2018; Adabre et al. 2020; Foster 2020), shifting to low-carbon lifestyles which allows people to spend more time with family and friends locally, and the adoption of work-from-home as a regular practice, along with car-sharing and electric vehicles (Liu et al. 2016; Druckman and Gatersleben 2019; Hasanzadeh et al. 2019; Meira et al. 2020). Further, incorporating radical future low-carbon initiatives, such as car-free zones and light-rail systems, requires multiple stakeholder co-creation envisioning mechanisms (Crowe et al. 2016; Cuthill et al. 2019; Tonks and Lockie 2020).

Community experimentation

In the literature, experiments are deliberately employed to disrupt and challenge status quo practices, organizational methods, and ways of knowing across a wide range of domains, including housing (Caprotti et al. 2015), sustainable mobility through e-bike sharing schemes (Liu et al. 2016; Plazier et al. 2017; Arsenio et al. 2018), household practices (Christie and Waller 2019), and using vacant lots for urban agriculture (Carlet et al. 2017). For community experiments to yield low-carbon innovations

with transformative capacity, our synthesis reveals that experiments need to be developed through a co-production/co-design process that emphasizes on social learning and progressive management across different actors and scales (Bos et al. 2013; Carlet et al. 2017; Bartesaghi-Koc et al. 2019b; Buijs et al. 2019).

Effective sustainability innovations embedding

Embedding sustainability innovations in urban planning and urban living requires three core aspects. First, a capacity development program needs to benefit several groups to allow resources to flow and knowledge to be shared. In this case, co-learning processes, platforms, and spaces for exchanging and building knowledge to produce a catalogue of sustainability approaches can help build co-learning models (Gorissen et al. 2018; Borgström 2019; van der Jagt et al. 2019). Pilot projects also provide an opportunity for in-depth exchanges of ideas and experiences from local knowledge, which can be translated to other groups through networks and hubs for managing social–ecological infrastructures in various cities (Buijs et al. 2019).

Second, it is suggested that identifying, mainstreaming, and implementing sustainability innovations is achieved by generalizing the project's processes and methods and by providing a holistic perspective that can be adapted to different local parameters and circumstances (Guillen-Royo et al. 2017; Du and Zhang 2020). Consequently, it creates new models for maintaining and mainstreaming public–private partnerships (Frantzeskaki et al. 2019a, b). The literature showcases several innovative ideas with generalizing potential that include integrating domestic resources into eco-villages and co-housing for low-impact living and housing (Hagbert and Bradley 2017), setting co-creation visions to have generalizable, out-scaled, and umbrella learning characteristics (Frantzeskaki 2019; Frantzeskaki, et al. 2019a, b), and retrofitting all new affordable housing units from experiences learned in energy, and socio-economic retrofits applied to aged affordable housing facilities (Adabre et al. 2020).

Third, according to the review, policy and regulation amendments or changes should involve local initiatives and embed active citizenship participation through a process of reflexivity (Borgström 2019). Eco-cities, for example, embed sustainability in their policies through the hybridization of existing environmental features while considering social sustainability and interactions between urban systems (Caprotti et al. 2015; Chapman et al. 2016). Regulatory frameworks can be influenced and modified in various ways. For example, through a mosaic governance approach, local governments can actively embed active citizenship, upscale local initiatives, and integrate them

into policies and frameworks (Buijs et al. 2019). Some examples include the implementation of new legislations that support green construction practices (Onubi 2019), changing individual behaviour to a more practice-oriented problem (Chapman et al. 2016; Schäfer et al. 2018; Huxley et al. 2019), mandating green retrofitting for aged housing facilities, and identifying context-sensitive solutions to encourage use of natural materials (Chatterton 2013; Affolderbach et al. 2019; Landholm et al. 2019; Adabre et al. 2020). Alternatively, communities can activate the changes at both the local and municipal levels through disruptive local initiatives (Kaae et al. 2019).

Social learning

Reflecting on the learning and capacity building processes is well developed in the literature. We identified three main dimensions. First, project ideation and development require critical discussions and analysis. For example, for urban heat mitigation planning requires decision-making processes that reflect on not only on climate regulation as one ecosystem service, but also its applicability to other ecosystem services, while also reflecting on different scales of analysis (Bartesaghi-Koc et al. 2019a). In some studies, sustainable affordable urban housing analyses include the high cost of sustainable building materials and green building technologies, the delay on the government approval process, and the need for an integrated approach addressing social sustainability (Sandberg 2018; Affolderbach et al. 2019; Adabre et al. 2020). For promoting low-carbon activities to improve subjective wellbeing, there is no literature to indicate that changing the transport modes and increasing the green spaces would affect wellbeing (Joffe and Smith 2016; Liu et al. 2016; Druckman and Gatersleben 2019; Hasanzadeh et al. 2019). Also, one study finds that active travel reduces social cohesion among communities and marginalized communities (Chapman et al. 2016), and another study argues that planners and residents prefer aesthetic landscaping over ecological concerns (Caprotti et al. 2015; Leporelli and Santi 2019).

Second, another important aspect of social learning is analysing the outcome of the studies to show that lessons and solutions are only applicable if they demonstrate innovative approaches (Wolfram 2019). One study reports on project outcomes through enacted activities, the way the project affected space, the way it connected with the real world, and the way it affected social interactions (Kullman 2013). Evaluation of high-density and mixed-use projects, for instance, promotes more equitable transportation models with the better access for the pedestrian and cycling, which reduce vehicle emissions and improve citizens' wellbeing (Mindell et al. 2011; Adabre et al. 2020). Similarly, post-carbon design in cities promotes car-free

and green shared spaces as well as using electric vehicles for decreasing greenhouse gas emissions (Chatterton 2013; Arsenio et al. 2018; Landholm et al. 2019).

Third, reflective practices are examined through methods, processes, and tools of practice-oriented projects and embedded case studies in order to improve social learning (Bos et al. 2013). For example, the mobilized resilience process is evaluated for its capabilities to enhance the co-management and co-design of identified shared challenges, which are influenced by people's day-to-day activities and values, and less by their demographic, income, or educational background (Chelleri et al. 2016; Crowe et al. 2016; Ghanem et al. 2016). Other studies highlight that connecting green spaces and environmental wellbeing can improve social learning outcomes in which community members could participate in leisure time gardening activities, such as community gardens, urban farming, and on-site composting (Joffe and Smith 2016; Burgin 2018; Christie and Waller 2019). Methods and tools for the delivery of green infrastructures introduce practical and evidence-based paradigms for initiating change through activities like presentations and reflections on the processes (Borgström 2019). Communications and interaction are identified as effective methods for obtaining citizen feedback to improve time-sensitive decision making and the environment (Onubi 2019), for example, with the help of e-bikes, cyclists can choose from enjoyable routes over more direct and faster routes in smart cities (Plazier et al. 2017; Macke et al. 2019).

Working across human agency levels

The review of the literature in terms of capacity building across various agencies highlights the importance of including diverse stakeholders, such as policymakers, planners, politicians, citizens, communities, marginalized groups, and NGOs, all in collaboration between governments and civil society. First, the literature shows that building capacities across diverse communities could be designed through different phases and activities, as well as training and knowledge sharing. For example, different groups of society could be engaged in planning water-sensitive events, set aside leisure time to garden, and raise awareness about environmental projects for disadvantaged groups (Burgin 2018; Gorissen et al. 2018; Lopes et al. 2018; Buijs et al. 2019). Second, multi-level collaborations among different government agencies and municipalities can facilitate partnerships and promote successful projects (He et al. 2019). The zero-carbon city project in the literature is a good example of this, where policymaking, finance, land use planning, transport, and engineering teams must work together (Chapman et al. 2016), also in the eco-city development, this collaboration is evident

among architects, planners, and local government departments (Caprotti et al. 2015; Schäfer et al. 2018). Third, government experiments that foster the connection and relationship between local municipalities and civil society enhance the project's procedures, for example, NGOs can play an important role in expanding the flow of knowledge between the public and local governments through scaling up and scaling out the capacities of different groups at different levels (Gorissen et al. 2018; Buijs et al. 2019; Frantzeskaki 2019; Tonks and Lockie 2020).

Working across political and administrative level and geographical access

To create a transformative capacity, project activities must build capacity at different levels of geography and administration. The results show that the general principles to support low-carbon innovations can emerge at three different levels: global and regional (a set of the countries), state and national, and local and municipal scales. At the global level, the transition movement develops capacities to build networks across different countries as well as interconnect, collaborate, and exchange the shared values among them (Kilkiş 2016; Nicolosi and Feola 2016; Burgin 2018; Hausknost et al. 2018; Affolderbach et al. 2019; Buijs et al. 2019; Landholm et al. 2019). Several contributions from the literature are identified to capacity building across regional scales in several forms, including how to connect societies with similar developing /developed geographies to assess climate functions and variables (Adabre et al. 2020; Bockarjova et al. 2020; Chelleri et al. 2016; Meira et al. 2020). In northern countries where the winter is cold, for example, the housing conditions need to improve to make it more energy efficient, while learning from one another's experiences in cold-weather locations (Sandberg 2018). Strengthening capacity building at the national and state levels supports benefits of nature-based innovations and promotes urban planning strategies for areas with large population densities (Bos et al. 2013; Kaae et al. 2019; Nicolosi et al. 2018). Taking the review from a local perspective, it is apparent that the local government should exploit the emerging expressions and lessons of the review in a variety of projects, such as within urban centres and suburbs, in order to inspire the local citizens for engagements (Nicolosi and Feola 2016; Aiken 2017; Gorissen et al. 2018; Frantzeskaki 2019; Frantzeskaki, et al. 2019a, b; Tonks and Lockie 2020).

DISCUSSION

Our review and synthesis extend the original framework by Wolfram (2016) to include system characteristics for every

capacity component that showcase how low-carbon social–ecological urban innovations can be recognized in urban settings as well as demonstrate their transformative capacity. There is currently no operational extension of the framework in the scholarship. To progress this knowledge-bridging, in the following paragraphs, we propose a way to introduce transformative thinking through the extended transformative capacity framework to urban planning research and practice that can facilitate the use of the framework for designing and planning for transformative low-carbon innovations.

Planning low-carbon urban innovations guided by the transformative capacity framework

To upscale and mainstream low-carbon social–ecological innovations, we argue for the importance of investigating the relation of the transformative capacity framework with planning systems including participatory planning and strategic planning. We find this bridging is critical in terms of behavioural and institutional preferences in supporting other social–ecological planning approaches such as “Community-Centered Climate Planning” or “Climate Action Planning” in designing and planning low-carbon urban environments (Pan et al. 2019; Lieberknecht 2021). Given that conventional Western planning approaches currently shape urban development, particularly in the Global North, (re)framing participatory and strategic planning is key to achieving transition to sustainable futures. In our proposal, low-carbon transformative and innovative solutions could be positioned at the policy-making strategic level by setting long-term goals and visions for the city. This, however, can be accomplished through citizen collaborations by designing and delivering inclusive decision-making processes. The following sections explore the conceptual link between the components of the transformative capacity framework and specific activities, dimensions, and outcomes within participatory and strategic planning. A particular focus is on how each transformative capacity component can guide and/or inform planning programs, interventions, and activities towards low-carbon futures. It is our argument that this bridging offers a practical step for implementing transformative social–ecological programs that are designed by multiple stakeholders guided by urban planners and policy strategists in order to achieve low-carbon urban environments. Figure 3 illustrates a bridging approach for strategic and participatory planning activities in design and implementation that is guided and shaped through and with the application of the transformative capacity framework. Tables S4, S5 and S6 in Supplementary Material present detailed explanations of how the transformative

capacity dimensions of low-carbon urban innovations could be integrated into strategic and participatory planning activities with regard to expected outcomes and implications for urban planning in creating and/or designing such low-carbon projects.

Strategic planning activities

Strategic planning aims to manage the urban long-term growth and development and integrate different approaches and practices to build sustainable policy development (Maginn et al. 2016). Setting up long-term visions for the cities can be enhanced by integrating transformative thinking (Frantzeskaki and Tilie 2014). In this sense, the transformative capacity framework can assist and guide strategic planning to develop different activities and outcomes. As Fig. 4 presents, we conceptually connect four components of the transformative capacity framework to the scope of strategic planning for low-carbon urbanism.

Participatory planning activities

Participatory planning approaches aim to improve social outcomes and decisions through sharing power and collaborating with citizens. To achieve this, we adopted the International Association of Public Participation (IAP2) framework to define participation and the public role in decision-making processes (Brown and Chin 2013). This participatory planning framework has been developed for local government adoption by introducing five levels of participation: inform, consult, involve, collaborate, and empower (De Leiuen and Arthure 2016). Figure 5 shows the different levels of participation which we relate to seven components of the transformative capacity framework. In doing this, we highlight a shift towards collaborating and empowering dimensions. This is consistent with urban and participatory planning, resulting in a long-term commitment and engagement of citizens in the planning process.

Underlying conditions to enable a shift towards transformative capacity thinking in urban planning

For urban planning to take on board transformative thinking through the application and/or uptake of our proposed extended transformative capacity framework, three overarching conditions are required (from a synthesis of our review):

Set bold low-carbon agendas at programmatic level: Urban planning can create an innovative push through setting bold agendas for low-carbon urbanism that direct

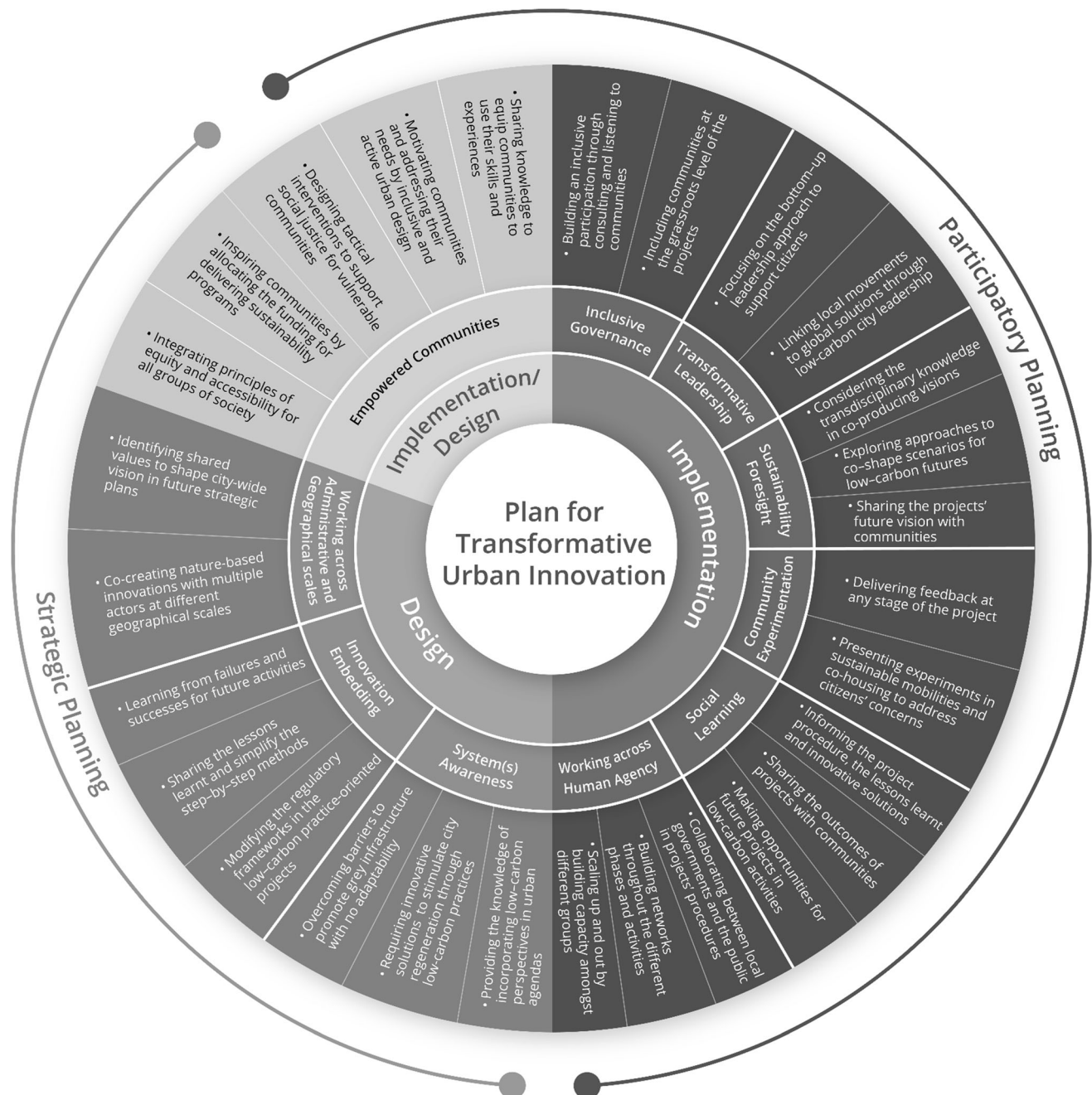


Fig. 3 Plan for transformative urban innovation through activities informed and guided by transformative capacity framework in strategic and participatory planning

social–ecological innovations to contribute to alternative futures. Our analysis highlights the importance of providing strategic directions as a selection environment for emerging and planned innovative projects and experiments. This can be enabled by employing sustainability foresight methods that are co-produced between diverse groups of society. A low-carbon agenda can be set by modifying the regulatory frameworks in the low-carbon, practice-oriented

projects such as affordable housing, eco-cities/villages, co-housing, and setting green infrastructures at the strategic level of policymaking that inspire communities to deliver sustainability programs.

Foster collaboration and institutional flexibility: Urban planners need to better engage with the different modes and activities associated with participatory planning that go beyond consultations, building capacity, and the

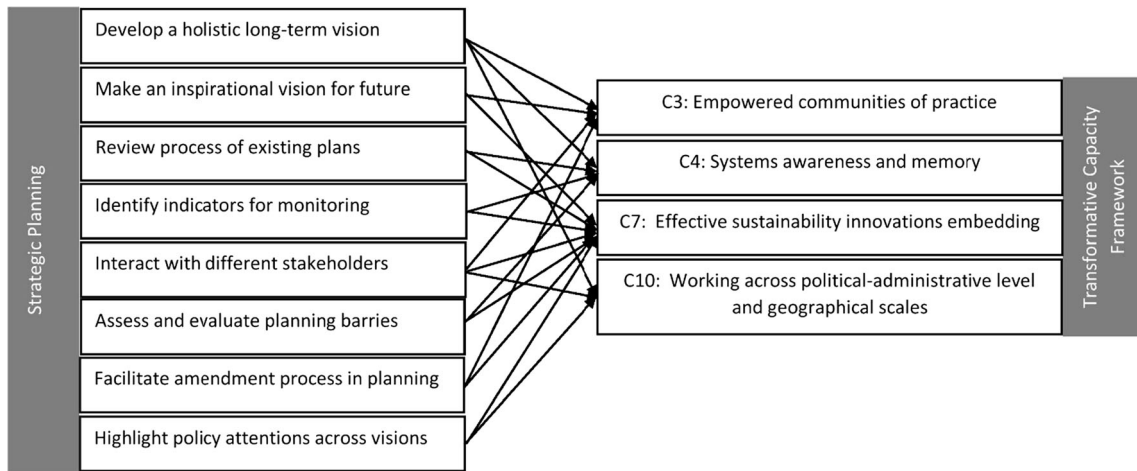


Fig. 4 Connecting the scope of strategic planning to transformative capacity framework’s dimensions

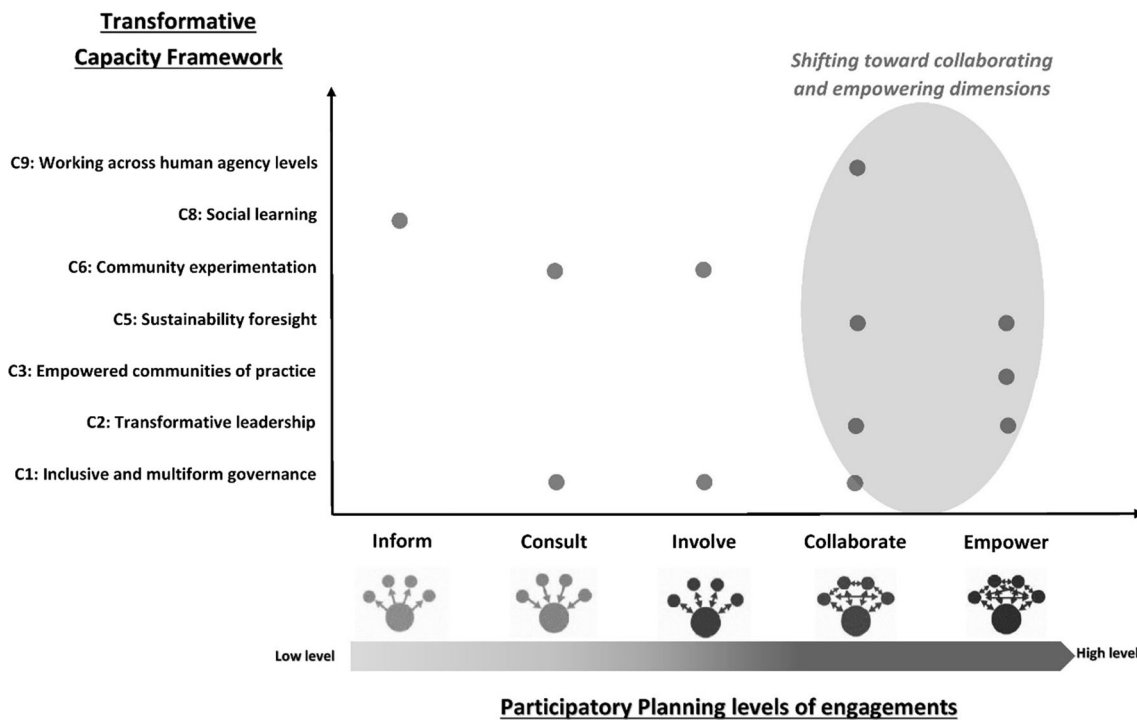


Fig. 5 Connecting transformative capacity dimensions to participatory planning (adapted from IAP2 framework)

development of skills to design and implement in more empowering, and community-engaged modes of planning. According to our review, transformative outcomes are produced by collaboration across sectors, levels, and scales. Transdisciplinary modes of research need to be supported and prioritized in order to foster collaborative modes of engagement. Collaborative initiatives could include bottom-up leadership approaches to support

citizens and build new relationships with the government system in low-carbon cities and green neighbourhoods’ programs while incorporating grassroots community consultation processes that result in co-creation and co-design of the active urban design projects.

Plan for un-planned interventions to allow self-organization for social–ecological innovations: Our review found that un-planned interactions, self-organization, and self-

governance generate more innovative practices and approaches with greater transformative potential. The planning process needs to ‘plan to be un-planned’ to allow for more dynamic interactions that fit into the place and space of reference. The un-planned interventions could enhance social justice and provide the knowledge of incorporating low-carbon perspectives in setting projects and activities such as food composting projects, urban green mobilities, low-carbon wellbeing, and sustainable community gardens.

CONCLUSIONS

This paper investigates the current state of the art in low-carbon social–ecological innovations through a scoping review of the academic literature. We use the transformative capacity framework as a theoretical–analytical tool to examine the literature and propose an operational extension of the framework to provide practical implications for strategic and participatory planning. The review showed consistency in the types of transformative capacity characteristics across different types social and ecological solutions and innovations. Community empowerment, grassroots initiatives, and engagement are the main drivers of transformative capacity activation in cities. However, the practice of transformative leadership and its embedding within public policy and planning play a catalytic role in sustaining the transformational impact of social–ecological projects. By exploring how the transformative capacity framework can inform and transform planning perspectives and interventions, our analysis highlights the commonalities among urban innovations, and introduces a more integrative approach to understanding which dimensions of social–ecological innovations in cities enact and contribute to transformative capacity. The proposed bridging framework links strategic and participatory planning activities in design and implementation with the application of the transformative capacity’s framework to assist urban planners and policymakers in determining the practical solutions and actionable elements of low-carbon urban futures.

The review identified gaps in the current scholarship that require further research regarding the theoretical understanding of low-carbon social–ecological innovations, as well as aspects of urban planning for urban innovations. We identified three gaps: First, the connection of nature-based solutions and innovations with low-carbon urban transitions needs strengthening. Our paper offers a first basis for such a conceptualization based on the review of selected research papers and a more comprehensive analysis of urban transformative capacity. Second, there is a limited understanding of issues of justice within low-carbon urban innovations; social and environmental justice

have been discussed in a limited way in the reviewed literature. This reflects the need to develop more integrated approaches, such as tackling social, environmental, and ecological justice. Third, there is a lack of integrated social–ecological–technological systems analyses. System awareness, analysis, and recognition of path dependencies appear to be partitioned since each study takes a lens from governance to social–ecological perspectives.

Future research needs to learn and evaluate closer tactical urbanism interventions as seeds for transformative innovations. Even though tactical urbanism interventions can be limited or with smaller budgets, they can offer an excellent opportunity for communities to participate in a real action plan at a small scale and be a bottom-up approach in urban transformative leadership. From our review, tactical urbanism can help to test out any plans before major funding investments and in small scales, but with high transformative impact potential. Some of these tactical low-carbon innovations include using low-cost traffic calming devices in neighbourhoods, temporary wayfinding signs to encourage walking inside the neighbourhood, potted plants to create traffic diverters, temporary cycling/walking/skateboarding routes during the weekends or in the summer, pop-up planning for the parking lot along the street such as mini-parks and parklets or place for small gathering, community workshops and festivals, and bike-sharing systems. Future research thus needs to work at the interface of science–planning–community to develop new tools and approaches to help transformative leadership through action planning, roadmaps, and implementation programs in partnership with the community and planners. In the same line, future research can further examine the role of different actors (business, government, third sector) play in eliciting or hurdling every component of transformative capacity in cities so as to inform multi-actor interventions and policies for better governing urban low-carbon innovations.

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