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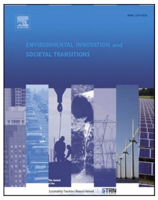

Infrastructure in Transitions: A Systematic Review of How Infrastructure Influences and is Influenced by Sustainability Transitions

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A B S T R A C T

Understanding the current status and historical path dependencies of infrastructures is crucial for planning future interventions in sustainability transitions. However, studies that examine the interplay between sustainability transitions and civil infrastructures remain limited. This paper presents a systematic review of 97 empirical studies that analyze how infrastructure systems and sustainability transitions influence one another. Infrastructure is found to play a dual role—as both a structuring force that enables or constrains transitions, and as a domain reshaped by transition processes. The review identifies key knowledge gaps and transdisciplinary opportunities. Firstly, capacity-related challenges—across technical, managerial, institutional, and policy dimensions—emerge as a shared concern and a promising entry point for deeper integration of infrastructure- and transition-oriented perspectives. Notably, the tactical level, where strategic ambitions are translated into infrastructure practices, remains significantly underexplored across the literature. Finally, most studies focus on individual systems, overlooking interdependencies across infrastructures and transitions, highlighting the need for a more networked, cross-sectoral approach.

1. Introduction

Infrastructure plays a pivotal role in shaping socio-technical pathways to address sustainability and ameliorate climate change impacts (Köhler et al., 2019; Oughton et al., 2018). Serving as key components in sectors like energy and mobility, infrastructures not only provide stability but also pose barriers to the transformative changes required for sustainable transitions, which demand broad shifts in technology, economy, behavior, and institutions. Despite extensive strategies for long-term sustainability in water, energy, and mobility, translating these into practical infrastructure development remains challenging, often hindered by uncertain decision-making environments (Bojórquez-Tapia et al., 2022).

In the face of such uncertainty, traditional infrastructure studies have primarily focused on optimizing and managing systems for efficiency or resilience (Bocchini et al., 2014; Ferrer et al., 2018). While these approaches have advanced operational performance through incremental changes that contribute to the sustainability discourse, they often overlook the fundamental, multi-level transformations in sustainability transitions. Implementing such transformations is inherently difficult due to the unique characteristics of infrastructure systems: physical assets like electricity grids, rail networks, or water pipes have long lifespans, high replacement costs, and involve numerous actors in planning, development, and maintenance. These characteristics make infrastructure systems prone to institutional resistance, economic prioritization, leading strategic and operational practices to reinforce unsustainable investments, neglect radical alternatives, and prioritize narrow value considerations misaligned with sustainability goals (Thacker et al., 2019; Monstadt et al., 2022; Buhl and Markolf, 2023).

This tension—between the need for transformative change and the constraining features of infrastructure systems—has long been

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recognized. A key attempt to address it was made by the special issue edited by Loorbach et al. (2010), which sought to bridge infrastructure research and sustainability transition research by exploring the potential for transition governance in energy (Foxon et al., 2010; Meijer et al., 2010), mobility (Farla et al., 2010; Huétink et al., 2010), and water (De Graaf and Der Brugge, 2010). These studies asked whether relatively rapid, fundamental shifts in infrastructure systems could be feasible—such as the evolution of decentralized energy supply within existing energy infrastructure. However, despite this early call, there remains limited progress in this area (Loorbach et al., 2017), with persistent challenges in practically linking infrastructure and sustainability transition research.

While numerous reviews in infrastructure studies have addressed sustainability—often through lenses such as efficiency, resilience, or environmental performance—they tend to focus on specific sectors or projects without explicitly engaging with systemic and multi-scalar shifts necessary for transitions. For example, Bueno et al. (2015) reviewed tools to integrate sustainability into transport infrastructure decision-making, Thounaojam & Laishram (2022) reviewed sustainability issues in mega infrastructure projects, and Akomea-Frimpong et al. (2023) explored sustainable development with public infrastructure projects. Meanwhile, reviews from sustainability transitions research are increasingly engaging with infrastructure: for example, Carroli (2018) reviews the role of planning infrastructure transitions, Esmail et al. (2020) examine sustainable urban water management systems, and Brauers (2022) focuses on natural gas infrastructure in the energy transition. However, these efforts largely remain siloed within sectors, and few studies investigate how infrastructure systems—particularly through their operational and management practices—can engage with and support systemic transformations (Fratnzeskaki& Loorbach, 2010; Gilbert et al., 2022)

This creates a persistent research gap: no comprehensive review has yet examined infrastructure through the lens of sustainability transitions, across multiple sectors. Specifically, there is a need to understand how the technical, structural, and managerial characteristics of infrastructure constrain or enable sustainability transitions—and how these transitions in turn reshape infrastructure development. This review addresses that gap by synthesizing insights across energy, mobility, and water systems to explore the influences between infrastructure and transition, identifying where integration between the two fields is emerging or still missing.

Framed by the central research question—**How does infrastructure influence sustainability transitions, and how do sustainability transitions influence infrastructure?**—this review investigates the dynamic and co-evolving relationship between infrastructure systems and sustainability transitions, offering a systemic perspective.

In doing so, Section 2 outlines the theoretical background and sets the stage for the thematic analysis in subsequent sections. Section 3 details the approach and methods used to identify and analyse relevant papers. Section 4 presents results that address the main research question through thematic analysis. Section 5 discusses the implications of these findings for academic literature, while Section 6 concludes with the study's main conclusions and recommendations.

2. Theoretical background

This section establishes the theoretical foundation for our review, integrating perspectives from infrastructure and sustainability transitions research. It begins by clarifying what is meant by "infrastructure" and "sustainability transitions" within the context of this review, as these definitions underpin our systematic approach to combining insights from both fields. Also, given the critical role of governance in steering sustainability transitions (Loorbach, 2010; Köhler et al., 2019), we employ the levels of governance activities of the transition management framework to examine how infrastructure and transitions are managed. This framework, which spans strategic, tactical (with reflexive), and operational spheres, will guide our thematic analysis of papers addressing the management and governance of transitions in infrastructure.

2.1. Understanding infrastructure context

Kaijser (2001) defines infrasystems as large-scale, capital-intensive networks with long life cycles, essential for transporting people, goods, and information. These systems, comprising links and nodes, have historically driven urbanization and resource exploitation. Jonsson (2005) categorizes infrasystems into distributive (e.g., electricity, water), accumulative (e.g., waste management), and communicative (e.g., transport) systems, reflecting their diverse functions.

Building on these foundational definitions, infrastructure is often recognized as a socio-technical system, emphasizing the interaction between physical components and organizational, institutional, and social dimensions (Markard, 2011; Große, 2023). This perspective is crucial for understanding the unique challenges infrastructures face in transitions, including their inherent resistance to change due to long asset lifespans, institutional inertia, and path dependencies. For example, Timmerman et al. (2019) show how deregulation, by favoring short-term profits, has increased reliance on fossil fuels and delayed investments in renewable energy within 'technical' energy systems, illustrating the socio-technical entanglements that shape infrastructure trajectories. These insights highlight the importance of strategic planning, management, and operational practices in infrastructure transitions (Farla et al., 2012; Carroli, 2018). Dominguez et al. (2011) emphasize the critical role of organizational capabilities in navigating these transitions, while Markard (2011) advocates for systemic approaches that integrate physical assets with multi-level management processes.

Given this backdrop, we approach infrastructure as a socio-technical system—comprising physical components (such as networked structures) and the social dimensions through which these systems are developed and operated (Loorbach, 2010). This perspective highlights the critical role of existing infrastructures in societal transitions, particularly sustainability transitions, due to their socio-technical nature and profound impact on environmental and societal systems, and the importance of understanding their unique characteristics, including resistance to change, systemic interdependencies and potential to enable transformative pathways.

This review synthesizes the current state of the literature on how these infrastructure characteristics —particularly technical and structural features, along with their (conventional) planning, development, and management—influence (may support or hinder) sustainability transitions. Following Frantzeskaki & Loorbach (2010), we focus on three core infrastructure domains—water, energy, and mobility—where dominant service provision models are undergoing significant shifts. The next section will explore the concept of 'sustainability transitions' and the context in which it is applied in this review.

2.2. Understanding the sustainability transitions context

Sustainability challenges, such as resource depletion, supply uncertainties, and extreme climate events, are often met with "technological fixes" that provide only temporary relief and may lead to unintended consequences (van den Bergh et al., 2010). Addressing these issues requires fundamental changes in consumption and production systems, termed "sustainability transitions" (Grin et al., 2010). Sustainability transitions are long-term, multi-dimensional transformations of socio-technical systems driven by explicit sustainability objectives, such as reducing environmental impact and ensuring social equity, distinguishing them from other transitions through their normative focus and systemic approach (Markard et al., 2012).

Infrastructure systems, traditionally characterized by high sunk costs, strong social dependencies, and the complexity of replacing existing systems, have generally been limited to incremental changes, making transformative shifts a high-risk endeavour. Frantzeskaki and Loorbach (2010) highlight that infrastructure change can occur through incremental dynamics, such as system improvements (e.g., efficiency gains within a single system) or synergies (e.g., cross-system coordination for enhanced efficiency), as well as through fundamental shifts driven by social innovation (e.g., new ways of meeting needs or "new ways of thinking"). Therefore, fundamental shifts in infrastructure—driven by innovations such as new ways of organizing demand, public participation, or redefining service needs through smart grids, modular water systems, or smart mobility infrastructures—go beyond technical optimization and require rethinking how infrastructure is used, governed, and integrated into society.

Therefore, we define *sustainability transitions in infrastructure* as radical changes that drive innovation and reconfiguration within infrastructure systems. These transitions encompass the adoption or influence of sustainable technological alternatives (e.g., renewable energy challenging centralized electricity grids and demands flexible decentralized grid solutions, or electric vehicles necessitating charging infrastructure or changing the role of transport infrastructure from passive network to active energy nodes), implementation of alternative infrastructure designs (e.g., decentralized water reuse systems), or new processes (e.g., circular economy practices). Another key aspect that directs our review is the multi-dimensional and dynamic nature of sustainability transitions, particularly the process of change from niche to regime (Geels, 2002), and how socio-technical regime conditions (e.g., existing infrastructure or institutional logics) influence/or are influenced by innovation (e.g., disruptive technologies or organizational reforms for sustainability) (Fuenfschilling and Truffer, 2014).

Given this backdrop, we approach sustainability transitions as fundamental and dynamic processes of change within infrastructure systems aimed at long-term environmental and social goals. This review synthesizes the literature on how multi-level, multi-scalar transitions influence infrastructure by identifying emerging innovations, required system changes, and necessary organizational processes. Additionally, for studies that approach the governance of transitions in infrastructure, the theoretical frameworks discussed in the following section are used to identify how governance activities at different levels articulate the interplay between infrastructure systems and sustainability transitions.

2.3. Governance and management in infrastructure transitions

Governance plays a critical role in sustainability transitions by aligning diverse actors and actions in the transformation of complex socio-technical systems (Voß and Bornemann, 2011). Transition studies emphasize governance as key to navigating uncertainties, path dependencies, and the multi-dimensional nature of transitions (Meadowcroft, 2009). In infrastructure systems, governance offers a lens to understand how transitions are managed across levels and timeframes. Therefore, a governance perspective is instrumental in revealing how transitions are both shaped by and shape infrastructure.

Among the various frameworks used to understand and steer sustainability transitions, Transition Management (TM) offers a particularly comprehensive approach. It combines long-term strategic visioning with short-term flexibility and engages diverse actor networks to guide systemic change (Loorbach, 2010; Rotmans et al., 2001). While frameworks like Technological Innovation Systems (TIS) and Strategic Niche Management (SNM) focus more on innovation dynamics—technology development (Markard et al., 2015) or protection of emerging niches (Kemp et al., 1998)—TM places stronger emphasis on transforming entrenched structures at sectoral and regional levels, making it especially relevant for infrastructure transitions. Its application in environmental policy (Loorbach et al., 2017), urban water (De Haan et al., 2015), and waste management (Parto et al., 2007) supports its use in this review to understand how governance shapes infrastructure transitions.

The framework (Loorbach, 2010) outlines four types of governance activities: 1) Strategic activities involve vision development and setting long-term goals at the landscape level; 2) Tactical activities focus on establishing agendas and building networks and coalitions at the regime level; 3) Operational activities include practical initiatives such as innovation trials and pilot projects at the niche level; 4) Reflexive activities encompass the monitoring, assessment, and evaluation of policies across all levels of governance. The three spheres - strategical, tactical (referring to tactical and reflexive), and operational (van der Brugge and van Raak, 2007) - from the TM framework will serve as the foundational framework for thematically (deductively) analyzing papers focused on transition management and governance activities within infrastructures. The next section will dive into the methodology of the systematic review.

3. Materials and methods

Systematic reviews are ideal in consolidating the findings of various studies on a specific question, and they can furnish proof of outcomes that can guide decision-making in policy and practice (Snyder, 2019). While systematic reviews already exist in transition studies (Wieczorek, 2018; Sengers et al., 2019) and infrastructure studies with a sustainability focus (Ferrer et al., 2018; Thomé et al., 2016), the purpose here is to review the sustainability transitions of infrastructure, which has hitherto not been done systematically. In this section, the research scope and strategy, the screening process and thematic analysis according to the theoretical background will be explained.

3.1. Research scope and strategy

The scope of our review was on identifying how infrastructure influences and is influenced by sustainability transitions (see Table 1 for the inclusion and exclusion criteria, based on the PICO (population-intervention-comparator-outcome) framework (Petticrew and Roberts, 2008)). As shown in Table 1, the primary reasons for inclusion related to the infrastructure context involve a sectoral emphasis on civil grey infrastructure and a focus on its elements, management, development, and planning, as outlined in Section 2.1. For the transition context, inclusion is guided by a clear focus on sustainability and change process, as outlined in Section 2.2 and an emphasis on empirical studies, rather than purely theoretical or methodological perspectives. Examples of exclusion criteria include papers on expert perceptions of energy transitions that lack a focus on infrastructure, sustainable urban mobility modes with only indirect impacts on infrastructure, and efficiency-driven transitions that do not explicitly address sustainability transitions etc., as shown in the table. In terms of application, all the criteria have been met for the included papers, with various comparisons to be detailed in the thematic analysis section.

This inclusion strategy aligns with the dual approach adopted in this review. First, we focus on "infrastructure-oriented" studies to examine the role of existing infrastructure in sustainability transitions, particularly how the technical and structural characteristics of infrastructure intersect with transition dynamics. Second, we consider "transition-oriented" studies that explore how infrastructures respond to transitions, including the emergence of innovations, new systems, and new organizational approaches to managing change processes.

To ensure our literature review was both comprehensive and focused, we used general keywords from Table 2, related to infrastructure and sustainability transitions. The term "infra*" was chosen to capture a broad range of topics such as planning, development, and design, reflecting a socio-technical approach. This term aligns with the holistic concept of an infra system as discussed by Kaijser (2001) and Jonsson (2005), broadening our search scope. We separated "sustainability" and "transition" to include diverse societal shifts like circularity, digitalization, hydrogen economy, climate change, etc., recognizing that while these shifts may not always be referred to as “sustainability transition”, they are integral to the broader concept of sustainability. The keywords "transition" and "transformation" are vital for depicting large-scale shifts towards a sustainable society. Although they differ subtly in focus, outcomes, and methodologies (Hölscher et al., 2018), this review employs both to encompass the entire spectrum of sustainability pathways. The term "transformation" expands on "transition" by integrating concepts of resilience, as explored by Folke et al. (2010). Thus, this review utilizes both keywords in its query to recognize that achieving sustainability requires both developing disruptive interventions in ‘transitions’ and responding to the change in ‘transformations’ (Hölscher et al., 2018).

To mitigate the risk of missing relevant papers that do not explicitly use the term "infrastructure," alternative search queries, such as "transport network," "mobility," "pipeline," or "power grid," “waterway” were tested. These searches predominantly returned papers

Table 1
Inclusion and exclusion criteria.

Criteria	For inclusion	For exclusion
Population	• Papers addressing sustainability transitions of infrastructure in various sectors and geographical regions.	• Papers that do not focus on civil infrastructure (e.g., energy, transportation networks, mobility, water, waste). • Papers focusing on blue/green infrastructure with nature-based solutions (i.e., not human-made infrastructure) • Papers focusing on transitions without a clear link to sustainability • Papers that are not directly linked to infrastructure management/ planning/development
Intervention	• Papers drawing attention to different technological innovations, change processes, and new ways of working directed at sustainability transitions of infrastructure.	• Papers focusing only on the performance/capacity/ improvements of infrastructure without a clear emphasis on sustainability transitions • Papers focusing on sustainability transitions of a specific infrastructure only from a theoretical intervention perspective (e.g., definitions of MLP, SNM, etc.) • Papers centered on end-user behaviours and acceptance.
Comparator	• Comparison of how infrastructure influences and is influenced by sustainability transitions • Comparison of management-level activities for transitions-in-infrastructure between papers	• N/A
Outcome	• Papers focusing on the influence of the existing infrastructure systems, operation, planning, and management on sustainability. • Papers focusing on different infrastructure sectors’ responses while taking the sustainability transition as the end goal.	• Papers with broader geographical or policy outcomes without a clear focus on the infrastructural elements (e.g., energy policies of Europe, investment in clean energy solutions for specific regions, local and urban-level mitigation measures, etc.)
Additional criteria	• Peer-reviewed journal articles written in English	• N/A

Table 2
Key concepts and keywords.

Key Concept	Related keyword
Sustainability	"Sustainability" **OR** "Sustainable"
	AND
Transition	"Transition" **OR** "Transformation"
	AND
Infrastructure	"Infra*"

focused on services or sectors, such as market or consumer adoption, rather than the tangible aspects of infrastructure networks. This outcome reinforced the decision to use "infra*" as a core search term to maintain thematic alignment with the review's focus on socio-technical infrastructure systems. References of key papers were also manually reviewed to identify additional relevant studies.

This strategy, along with the screening and thematic analysis methods was refined through multiple discussions with a broader consortium of researchers and practitioners involved in sustainability transitions in infrastructure.

3.2. Screening process

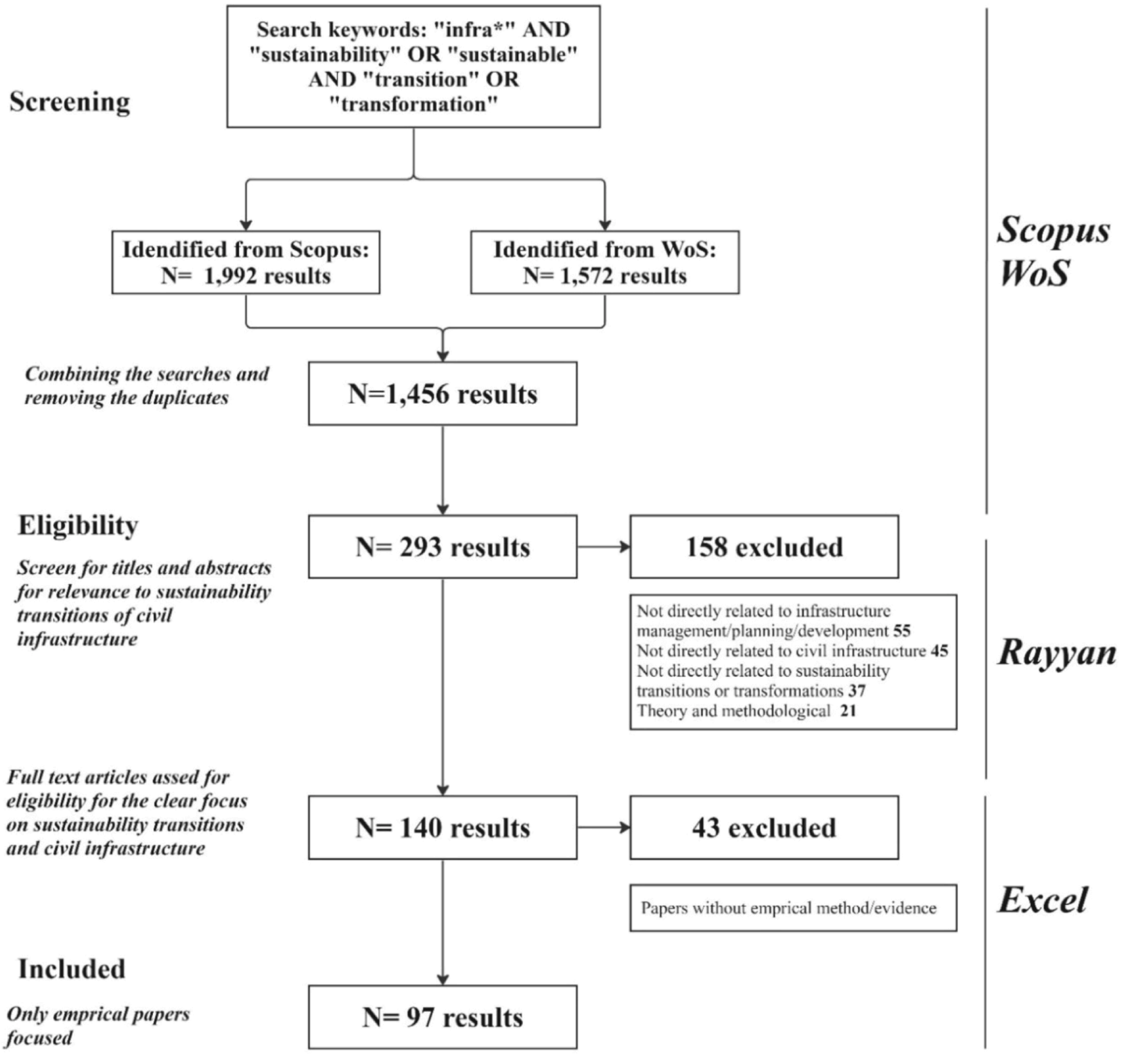

Fig. 1. Methodology of the review.

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We primarily sourced literature from the Scopus database, recognized as the most extensive abstract and citation database for peer-reviewed publications in sustainability transitions (Markard et al., 2012). Additionally, using identical search terms in the Web of

Science revealed recent, highly relevant studies that are not present in Scopus, such as works by Castán Broto et al. (2014) and Ampe et al. (2020). To ensure a comprehensive review, we utilized both databases and removed duplicate records. The search was conducted in January 2024.

After selecting appropriate keywords, the initial search yielded 1992 results on Scopus and 1572 on Web of Science, limited to peer-reviewed articles in English and excluding unrelated topics. Removing duplicates left 1456 papers for review. Titles and abstracts were then screened for relevance to sustainable civil infrastructure in the built environment. Rayyan software facilitated collaboration among co-authors from diverse backgrounds, ensuring an objective process free from personal connections. This process narrowed it down to 293 papers for further detailed analysis. Of these, 158 papers were excluded for specific reasons outlined in Table 1**:** some were not directly related to infrastructure management, planning, or development, like studies on consumption patterns or energy market analysis without a focus on infrastructure; others lacked empirical data or did not address built infrastructure; and some did not align with sustainability transitions, focusing instead solely on efficiency improvements or asset management without facilitating sustainable transformation. This left 97 empirical papers for the full review.

3.3. Thematic analysis

In this study, we conducted a thematic analysis of 97 papers included in our review using a data extraction template prepared in MS Excel. The template recorded basic details (e.g., author(s), title, publication year, journal) as well as deeper insights such as research questions, geographical focus, empirical contexts, methodologies, and key findings.

Our analysis adopted a dual approach: it began deductively, grounded in the established literature on infrastructure and sustainability transitions (outlined in Section 2), and expanded inductively to explore emerging themes from the reviewed papers, with the aim of answering our research question—how infrastructure and sustainability transitions influence one another. Rather than categorizing studies into rigid groups, we structured our analysis around two complementary entry points: referred to as *infrastructure-oriented* and *transition-oriented* lenses. To understand how infrastructure influences sustainability transitions, we positioned infrastructure—its technical, structural, and managerial aspects—as the subject of influence, and analyzed how these intersect with transition dynamics. Similarly, to explore how sustainability transitions influence infrastructure, we treated transition processes as the subject, examining how they drive change within infrastructure systems through new practices, innovations, and reconfigurations. Table 3 summarizes this framing with illustrative examples from the reviewed studies.

Table 3
Illustrative examples of thematic representation of the review.

Analytical Entry Point	Indicative Focus	Example Topics from Reviewed Papers
Infrastructure-oriented	How do technical, structural, or managerial aspects of existing infrastructure influence transitions?	e.g., Energy grid lock-ins; legacy water treatment systems; asset renewal in rail infrastructure; conventional infrastructure project management
Transition-oriented	How transition processes influence infrastructure through new innovations or governance approaches?	e.g., District energy systems as niches; decentralized water reuse systems; new participatory governance models

The findings section builds on this framework as given in Table 4.

Table 4
Summary of thematic analysis.

Topic	Theme (s)
How does infrastructure influence sustainability transitions?	**Influences of (existing) Infrastructure on Transitions** (Section 4.1): Lock-ins and constraints (Section 4.1.1), Infrastructures as Enablers (Section 4.1.2): **I.** Infrastructure System Integration, **II.** Infrastructure Practice Integration Management of Infrastructure in Sustainability Transition (Strategic, Tactical, Operational analysis) (Section 4.1.3)
How do sustainability transitions influence infrastructure?	**Influences of Sustainability Transitions on Infrastructure** (Section 4.2): Product Innovations (Section 4.2.1), Process Transformations (Section 4.2.2) Management of Sustainability Transitions in Infrastructure (S-T-O Analysis) (Section 4.2.3)

Section 4.1 explores how existing infrastructure systems influence sustainability transitions through their physical, managerial, and structural characteristics—which can constrain or enable change. From the in-depth analysis of the reviewed papers, three inductive themes emerged: **(i)** lock-ins, **(ii)** enabler: system integration, and **(iii)** enabler: practice integration. Section 4.2 examines how sustainability transitions influence infrastructure systems, focusing on how transitions are featured within infrastructure : highlighted in two themes **(i)** product innovations and **(ii)** process transformations. In exploring how the management of infrastructure influences sustainability transitions, and how the management sustainability transitions influences infrastructure, we apply the three levels of governance—strategic, tactical, and operational—as outlined in Section 2.3; these influences are further detailed in Sections 4.1.3 and

4.2.3 respectively. For example, influence of long-term infrastructure planning or transition policy framing was coded as strategic, asset-level practices or niche experiments as operational, and agenda-setting or regime coordination as tactical, often sitting between levels. The thematic structure is also visualized in Fig. 2, which summarizes the two analytical entry points—an infrastructure-oriented and a transition-oriented perspective—and shows how influence unfolds between infrastructure and sustainability transitions, with governance levels (strategic, tactical, operational) represented as cross-cutting dimensions across both perspectives.

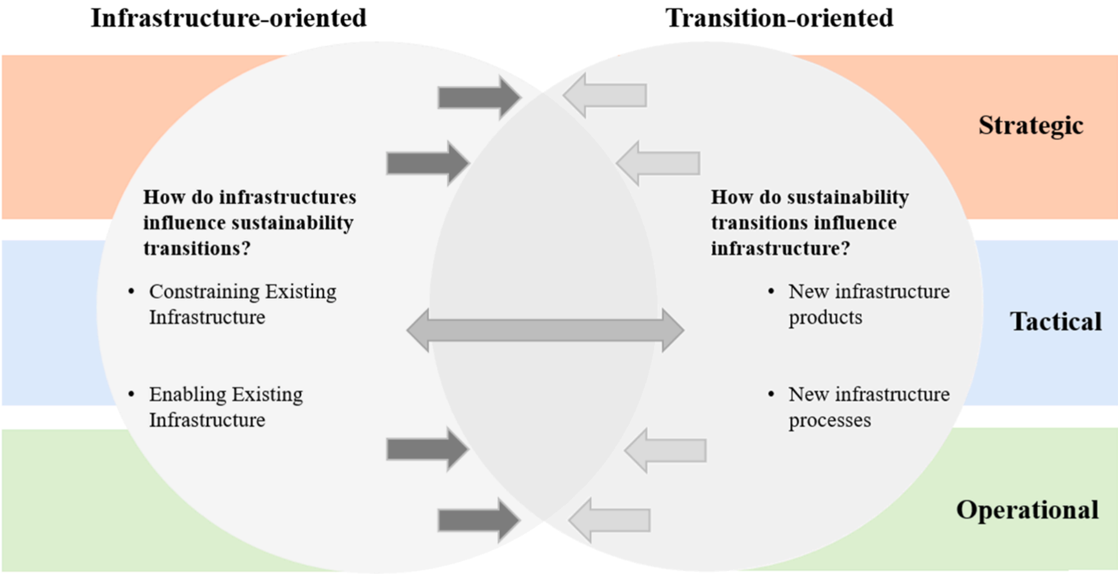

Fig. 2. Visual representation of thematic analysis.

4. Findings

4.1. Descriptive analysis

The yearly distribution of 97 included articles is given in Fig. 3, between 2003 and 2024. Since 2014, interest in the sustainability transformations of infrastructure systems has increased, especially after significant developments following the 2015 Paris Agreement, which led to a universal and legally binding global climate agreement by 2019. This increase is due to the rise in such agreements and comprehensive changes across various infrastructure systems, such as energy transition, water resources, and train lines. Notably, 2018 saw the peak publication year with 13 papers, and interest resurged in 2022 when the focus on infrastructure transitions intensified.

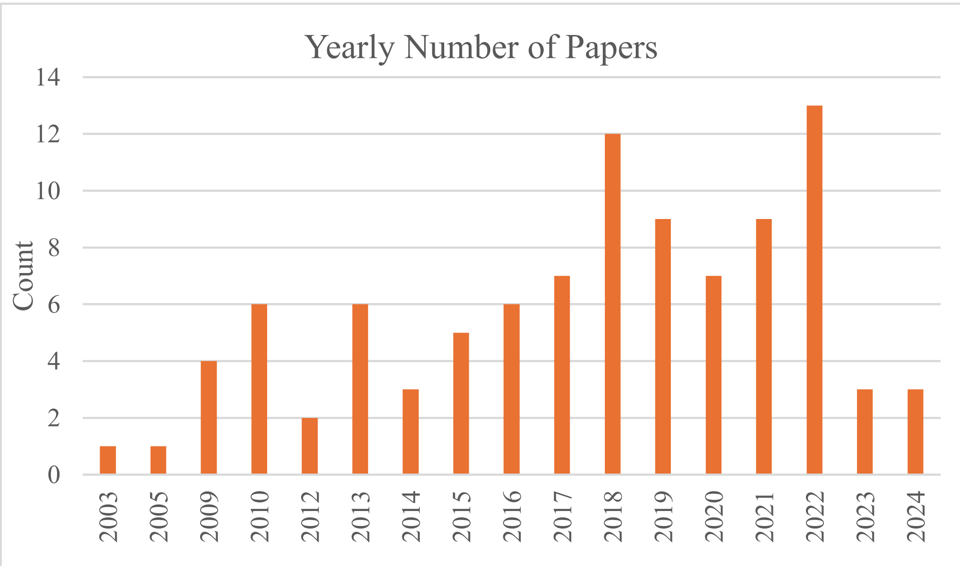

Fig. 3. Yearly distribution of papers.

The six core journals (Technological Forecasting and Social Change, Sustainability, Environmental Innovation and Societal Transitions, Environmental Science and Policy, Journal of Cleaner Production, Research Policy) published three or more papers on the review field publishing almost half of the total included papers, (42 out of 97, 43 %). The Journal of Technological Forecasting and Social Change published the most number of papers during this period, with 11 papers. As shown in Fig.4, the rest of the included papers focused on two areas more infrastructure-focused journals or environmental, and urban planning-related journals.

Within the sphere of infrastructure-focused scholarly journals, energy infrastructure dominates with 13 publications, followed by 9 journals on water-related issues. Journals are primarily categorized by their infrastructure focus in Fig. 4, yet some studies, like Mejia-Giraldo et al. (2012) on integrating energy and transportation infrastructure, demonstrate interdisciplinary integration, while

Core Journals on Sustainability Transitions of Infrastructure	Number
Technological Forecasting and Social Change	11
Sustainability	10
Environmental Innovation and Societal Transitions	9
Environmental Science and Policy	5
Journal of Cleaner Production	4
Research Policy	3
Total number of papers in core journals	**42**

System focus	Infrastructure focused journals	Number
Energy	Energies	2
	Energy Policy	2
	Energy Research & Social Science	2
	Energy Technology	1
	Front. Energy	1
	Nature Energy	1
	Renewable & Sustainable Energy Reviews	1
	International Journal of Hydrogen Economy	1
	International Journal of Sustainable Energy Planning and Management	1
	Journal of Energy Engineering	1
	Total number of energy-focus journals	**13**
Water	Water Science and Technology: Water Supply	4
	Water	2
	Water Resources Research	1
	Urban Water Journal	1
	Water Research	1
	Total number of water-focus journals	**9**
Transportation	Transport Policy	1
	Transportation Research Part D	1
	Total number of transport-focus journals	**2**

Urban and Environment Focus Papers	
Journal of Environmental Policy & Planning	2
Urban Studies	2
Resources Conversation& Recycling	2
10 journals with 1 paper	10
Total number of environment and urban focus	**16**

Journals without specific focus on transitions of infrastructure	Number
15 journals with 1 paper	**15**
Total numbers of papers	**97**

Fig. 4. Distributions of papers per journal.

appearing in the Journal of Energy Engineering. Sustainability transitions within infrastructure were studied globally, with a notable emphasis in Europe, as detailed in Table 5. Of these, 58 papers (53 %) focused on Europe, followed by North America (13 %) and Oceania (12 %). Within Europe, the Netherlands led with 12 papers (24 % of European papers), followed by the UK with 8 papers (16 % of European papers) and Germany with 6 papers (12 %).

Table 5
Distribution of papers per geographical region.

Geographical Region	Number of Papers	Percentage
Europe	51	53
North America	13	13
Oceania	12	12
Asia	10	10
World	7	8
Africa	2	2
South America	1	1
Total number of papers	97	100

4.2. Infrastructure influences Transitions: Lock-ins and Enablers

This section explores insights from reviewed studies that examine how existing infrastructure systems influence sustainability transitions. Through inductive analysis, two key themes were identified: (I) Lock-ins and Constraints, referring to the existing structural, technical features of infrastructure that inhibit change; and (II) Enablers via System and Practice Integration, which captures how existing infrastructure can support transitions either through physical system integration or through adaptations in conventional managerial and operational practices.

4.2.1. Infrastructure as Lock-ins and Constraints

The concept of lock-in mechanisms, widely recognized in the literature on urban infrastructure transformations for sustainability (Malekpour et al., 2015; Monstadt et al., 2022), emerges as a prominent theme in empirical studies examining infrastructure's role in sustainability transitions. For instance, Sorensen & Brenner (2021) investigated urban property systems in rapidly growing cities and found that institutional lock-ins and sunk costs were among the most critical barriers to low-carbon transitions. Similarly, Birch (2016) emphasized how the materiality and long lifespan of transport infrastructure contribute to inertia, with climate considerations often overlooked due to cost pressures, lowest-bidder procurement, and the absence of institutional mandates (e.g., tools and codes for engineers). To avoid future lock-ins, the study proposed distributing innovation costs across the infrastructure's lifespan rather than across isolated projects, and emphasized targeting life-cycle performance in design and maintenance.

In the energy transition, the constraining roles of existing infrastructure are widely emphasized in the reviewed literature. For example, transport electrification increases power demand in new locations—such as for charging electric vehicles or powering grid-connected trains —yet limited grid capacity poses major challenges, requiring upgrades, smart grids, and flexibility solutions for decentralized loads (Van Baal and Finger, 2020). Similarly, integrating renewables, such as increasing the share of solar energy, faces challenges due to poor existing grid infrastructure, often leading to curtailment. Maassen (2012) highlighted how locked-in grid systems in European cities long prohibited feed-ins from renewable sources due to centralized production and distribution models that were incompatible with decentralized processes. Significant investments in grid development are needed to support renewables, raising concerns about energy affordability in the transition (Phoumin et al., 2021). Additionally, low trust in existing grids deters local users from adopting district energy systems (Tong et al., 2020). This reluctance is compounded by regulatory gaps that limit markets for low-carbon energy sources like biogas and sewage waste heat, as well as lengthy permitting processes that delay infrastructure projects.

Rather than physical lock-ins, Ampe et al. (2020) show that market-pull discourse politically and economically drives the Dutch wastewater transition, favoring existing large-scale systems such as sewer networks and centralized treatment plants over sustainable alternatives. Similarly, Mühlemeier et al. (2019) highlight that public utilities face inertia due to tensions between the need for democratic control and the pressure to stay competitive in liberalized energy markets, reinforced by legacy infrastructure and engineering mindsets. Marlow et al. (2017) note that while drought and population growth create pressure for change, sustainability-driven business models are still constrained by internal priorities shaped by politicized investments, sunk costs in centralized systems, narrow focus on financial value, and limited customer willingness to pay.

Regarding the role of existing water infrastructure in transitions, many authors have argued that the dominance of centralized solutions and incremental hybridization processes perpetuates lock-ins and hinders adaptation to climate change. These barriers are driven by normative values, vested interests, risk perceptions, and performance uncertainties, creating both technological and institutional lock-ins (De Graaf et al., 2009; Marlow et al., 2013; Heiberg et al., 2022). The authors emphasized the need to consider the socio-economic value of solutions. Similarly, for wastewater and sanitation infrastructure, centralized systems have been likened to a "prison" that restricts the adoption of new decentralized circular solutions (Särkilahti et al., 2017).

Thus, the literature highlights that infrastructure itself—due to its longevity, capital intensity, and embedded practices—is inherently prone to creating lock-ins, not only in technology but also in institutional and behavioral contexts, underscoring the need for long-term strategies and broader policy responses.

4.2.2. Infrastructures as Enablers: The importance of System and Practice Integration

4.2.2.1. Infrastructure System Integration. Another emerging theme from the reviewed papers highlights the role of existing infrastructure as a catalyst for adaptation through system integration. These studies highlight how the technical and structural features of existing infrastructure systems can be leveraged to support and accelerate transitions. In the energy transition, leveraging existing energy grids has become a key focus in recent literature. Hydrogen, for instance, is increasingly recognized as a key enabler of low-carbon transitions, offering inter-seasonal storage and coupling power, heat, and transport sectors. "Power-to-gas" initiatives exemplify this by converting surplus renewable electricity into hydrogen and injecting it into gas networks, providing flexible demand-side solutions while supporting gas system decarbonization. McDowall (2014) argues that using existing gas infrastructure—such as pipelines and storage—can facilitate hydrogen deployment by reinforcing its socio-technical legitimacy in transport. Similarly, Hasankhani et al. (2024) emphasize repurposing geological reservoirs and gas pipelines, while noting operational challenges like high costs, safety risks, and technical complexity. Kigle et al. (2024) highlight the need for integrated planning to repurpose gas networks for hydrogen transport, build hydrogen grids for storage, and align them with electricity and renewables. To avoid reinforcing gas-based lock-ins, these efforts must align with long-term decarbonization strategies centered on renewables. These studies also highlight growing energy–mobility interdependencies, as hydrogen and electricity infrastructures increasingly intersect with transport.

The concept of integrated energy systems, which links diverse energy sources, consumption sectors, and carriers (e.g., power-to-gas, power-to-heat), has gained significant traction as well. Particularly in Germany, these approaches are recognized for enhancing system reliability and reducing environmental impacts (Amanpour et al., 2018; Kigle et al., 2024). Such strategies illustrate the growing recognition of system integration as a pathway to accelerate energy transitions while maximizing the utility of existing infrastructure.

In the water sector, the potential of existing infrastructure to enable sustainability transitions lies in supporting the integration of decentralized, modular, and flexible innovations. Zimmermann et al. (2018) highlight the need for water systems to balance flexibility (e.g., to climate or demographic changes) with compatibility with existing infrastructure. They show how centralized systems can gradually integrate decentralized modules—like modular separation, alternative rainwater management, and local reuse—which can also create synergies with energy systems, such as heat recovery from wastewater. . Similarly, Sharma et al. (2010) suggested that decentralized systems could help centralized water systems operate sustainably without major capacity expansions.

This review underscores that the infrastructure's role in sustainability transitions extends beyond its traditional perception as a barrier. Building on its locked-in position, system integration can, in some cases, allow existing infrastructure to support innovation and socio-technical adaptation. Concepts like "windows of opportunity" (Sunio and Mateo-Babiano, 2022) and niche empowerment (Tongur and Engwall, 2017) highlight the dynamic potential of infrastructure to simultaneously support transitions and overcome constraints.

4.2.2.2. Infrastructure Practice Integration. Beyond physical infrastructure, studies also emphasize how conventional managerial practices of infrastructure—including established planning and development routines— can be adapted to support the integration of sustainability transitions. Effective communication among stakeholders is repeatedly identified as a critical enabler. For example, Barendsen et al. (2021) highlight embedding sustainability communication into project routines by clarifying goals, tailoring information to different team roles, and fostering internal knowledge exchange. Similarly, Li et al. (2022) emphasize the need for structured communication practices—like formal coordination channels among government bodies, engineers, owners, and designers—to align expectations and support sustainable infrastructure delivery.

Rather than focusing solely on project scope, the integration of sustainability practices into asset management, resource-efficient operations, and infrastructure investment processes emerges as a key enabler in this review. Alegre et al. (2016) emphasize embedding sustainability in asset management—through data-driven planning, performance-based monitoring, and smart flow meters—to sustain long-term service quality while optimizing resources. Roelich et al. (2015) similarly call for a shift from siloed, linear operations toward integrated service-oriented management, where infrastructure is operated collectively across sectors to maximize resource efficiency and extend asset lifetimes. Tongur and Engwall (2017) demonstrate how infrastructure investment planning can enable the commercialization of sustainable niche technologies like zero-emission trucks, when supported by road expansion projects that incorporate electric road infrastructure. Moreover, Nasr et al. (2021) propose incorporating climate risk and uncertainty analysis into standard asset design methodologies, ensuring that long-lived infrastructure systems are not only resource-efficient but also climate-adaptive from the outset.

Planning practices represent another area where the existing operational paradigm of infrastructure has been leveraged to enable sustainability transitions. Quentin et al. (2023) show how reallocating road space, expanding low-carbon transport networks, and integrating future-oriented planning into local decisions can reshape mobility systems. Similarly, Mejia-Giraldo et al. (2012) call for embedding adaptability into long-term planning by linking sustainability to infrastructure lifespan and resiliency, measured through cost-effective recovery from disruptions.

Conventional water and sanitation planning can support sustainability transitions when expanded to include foresight, reflexivity, and broader engagement. The authors demonstrate how these practices enable transitions by embedding participatory foresight and stakeholder engagement—such as involving municipal decision-makers and co-developing regional scenarios to address uncertainties, technologies, and stakeholder values (Störmer and Truffer, 2009; Störmer et al., 2009; Truffer et al., 2010). Likewise, Malekpour et al. (2016) demonstrated how planning interventions for sustainability transitions could be incorporated into conventional water infrastructure planning, emphasizing broader thinking, exploratory scenarios, and multi-level actor engagement (Yasmin et al., 2018).

4.2.3. *Management of Infrastructure in Sustainability Transition*

The influence of infrastructure systems on sustainability transitions has also been analyzed through the lens of managerial levels—strategic, tactical, and operational. In this section, we position the reviewed papers according to their primary governance focus, based on the reasoning used during coding. Only those papers with a clear emphasis on one of these levels are included. Papers that sit at the intersections—between strategic/tactical or tactical/operational levels—are placed in the grey zones, reflecting their relevance to the periphery of tactical considerations, as shown in Table 6.

Table 6
How infrastructure systems influence transition management?.

	Analyzed Papers	Strategic (S)- Tactical (T)- Operational (O) Focus
Lock-ins and Constraints	Lock-ins and sunk costs (Sorensen & Brenner, 2021)	**Strategic** (long-term physicality)
	Locked-in engineering activities, high costs, and financial constraints (Birch, 2016)	**Strategic** (Long-term development cost) **to Tactical** (Engineering regime)
	Discursive lock-ins (Ampe et al., 2020; Mühlemeier et al., 2019); Business models (Marlow et al., 2017), institutionalized central systems, vested interests, normative values (Marlow et al., 2013; Heiberg et al., 2022)	**Strategic** (Long-term political-economic perspective of actors, Long-term agenda/ transition trajectories)
	Centralized water system (De Graaf et al., 2009; Särkilahti et al., 2017)	**Strategic** (Policy-making) **to Tactical** (Receptivity-Reflexive, Incumbent regime conditions)
	Locked-in existing energy grid and high infra cost (Van Baal & Finger, 2020; Phoumin et al., 2021), Centralized production/distribution model (Maassen, 2012)	**Strategic** (Long-term interventions)
	Low trust in locked-in grid, insufficient market, and capital investment (Tong et al., 2020)	**Strategic to Tactical** (business strategies, institutions)
System-level Integration	Using existing gas networks (McDowall, 2014), power-to-gas, power-to-heat (Amanpour et al., 2018)	**Strategic** (Transition pathways/roadmaps, long-term goal) to **Tactical** (setting agenda for existing infrastructure)
	Integrated energy systems (Hasankhani et al., 2024; Kigle et al., 2024)	**Tactical** (Stakeholder engagement, multi-level interactions)
	Integrated water infrastructure (Zimmerman et al., 2018; Sharma et al., 2010)	**Strategic** (Long-term technologies) **to Tactical** (setting agenda for existing infrastructure)
Practice-level Integration	Integrating sustainability practices project (Barendsen et al., 2021; Li et al., 2022) and asset management (Alegre et al., 2016), recourse-efficient operations (Roelich et al., 2015)	**Operational** (project-focused, concrete actions, service delivery with lowest resource use)
	Sustainable infrastructure investment planning (Tongur & Engwall, 2017)	**Operational** (Experiment project)
	Leveraging existing planning paradigms (Quentin et al., 2023; Meija-Giraldo et al., 2012)	**Strategic** (long-term planning) **to Operational** (actions of planners)
	Conventional water infrastructure planning (Störmer et al., 2009; Truffer et al., 2010; Malekpour et al., 2016)	**Strategic** (long-term planning) **to Operational** (stakeholder engagement)
	Conventional water infrastructure planning (Yasmin et al., 2018)	**Tactical** (Reflexive (adaptive capacity)

The analysis reveals that lock-ins are predominantly addressed at the strategic level, reflecting their deep entrenchment in long-term infrastructure governance. Infrastructure system integration, on the other hand, tends to be positioned at the tactical level, bridging strategic and operational considerations. This placement reflects the dual focus of these papers on long-term strategies for infrastructure systems while acknowledging the enabler role of integration within existing regime conditions, including physical and structural capacities.

Papers emphasizing how existing infrastructure practices can support sustainability transitions are more operationally focused, covering aspects such as project management, asset management, and planning. Planning papers, while operational in nature, often incorporate strategic features due to their long-term perspective on infrastructure development. A notable exception is Yasmin et al. (2018), which offers a tactical focus on building the adaptive and reflexive capacity of conventional water infrastructure planning. The study emphasizes not only the physical capacity of infrastructure but also the importance of "soft capacities," such as learning, multi-level interactions, and stakeholder engagement, as critical enablers.

4.3. Transitions influence Infrastructure: Innovation Products and Process

This section explores insights from reviewed studies that examine how sustainability transitions drive or enable the reconfiguration of infrastructure. Through inductive analysis, two key themes were identified: (I) Product-Focus, referring to innovative products (e.g., the development of niche technologies and new infrastructure requirements); and (II) Process-Focus, referring to innovative processes (e.g., changes in organizational, institutional, regulatory, and market mechanisms) that support these transitions.

4.3.1. Product innovations

This section examines how infrastructure systems are reshaped by emerging technologies in response to sustainability transitions, focusing on innovations that alter or replace physical components. Frantzeskaki and Loorbach (2010) note that distributive systems (e.g., energy, water) often decentralize, while communicative systems (e.g., mobility) adopt alternative designs. The reviewed papers highlight developments in new products and technologies driving the sustainability transitions. While many also address related transition processes, the primary focus here is on the "new infrastructure," "technologies," or "products" emerging in response to these transitions, rather than the processes themselves.

In energy transitions, Verbong and Geels (2010), using the MLP framework, identify three sustainability pathways in the electricity sector: transformation (e.g., centralized renewables), reconfiguration (e.g., a European Supergrid), and de-alignment/re-alignment (e.g., decentralized microgrids). Each requires major infrastructure investments—from high-voltage grids to technologies like microgrids and smart systems. . Though multiple paths were expected, recent trends show a shift toward decentralization, driven by renewables and posing challenges like declining incumbents and increased complexity for utilities (Sataøena et al., 2015; Markard, 2018).The maturity of renewable technologies requires investments in new infrastructure like energy storage, smart grids, and multi-energy conversion systems (Phoumin et al., 2021). Bolwig et al. (2019) examined energy flexibility's sociotechnical dynamics, identifying needed infrastructure—EV charging infra, microgrids to connect prosumers, storage, and digital control systems for demand-side response—requiring utilities-ICT linkages. They stress that adoption depends on supportive regulation, market arrangements, and state direction, while incumbents often resist change to protect existing grid investments, given weaker policy support for such complementary infrastructure compared to renewable generation. Hiteva and Watson (2019) highlight smart grid development's reliance on digital infrastructure (e.g., sensors, networks) and new governance for electricity-ICT interdependencies. Bolton et al. (2016) show that low-carbon electricity reforms generally aim to attract private investment in large-scale infrastructure projects, such as generation assets, transmission lines, or transformers, yet this approach often reinforces existing regimes by sidelining community-owned systems and demand reduction innovations. Stringer and Joanis (2022) similarly emphasize that remote renewable projects require significant transmission investments to connect to urban centers, requiring government support to scale up infrastructure like microgrids and market integration.

District energy systems (DES), including District Heating (DH) and Combined Heat and Power (CHP), are promising niche innovations for energy transition, providing efficient thermal energy services to multiple buildings (Tong et al., 2020). However, barriers such as low grid trust, regulatory gaps, lengthy permitting, and high capital costs limit adoption. While business model innovation helps create value, Bolton and Hannon (2016) argue that broader political and regulatory reforms are needed to scale these technologies. Bioenergy villages offer another decentralized heating option, emphasizing local initiatives and cooperation between regional and national policymakers in fostering development (Roeslerand Hassler, 2019).

In the transport sector, multiple technological pathways have emerged to support sustainability transitions, including biofuels, plug-in hybrids, battery electric vehicles (BEVs), and hydrogen fuel cell vehicles (FCVs). FCVs are often viewed as a long-term option, while biofuels and hybrids remain more feasible short-term due to their compatibility with existing infrastructure (Köhler et al., 2009). Battery electric vehicles may become dominant for their environmental benefits, but this requires expanded charging networks and possibly trolley wires for long-distance travel—building on existing electricity systems and potentially costing less than a full hydrogen rollout. In contrast, hydrogen requires entirely new infrastructure for production, distribution, storage, and refueling, along with adaptations to current gas assets (McDowall, 2014; Hasankhani et al., 2024). These insights underscore that each pathway entails distinct infrastructural demands shaped by the interplay between niche innovations and incumbent systems, and that large-scale investments in one pathway can create interdependencies—and potential constraints—for others across resources, technologies, and integration capacities (Farla et al., 2010).

Dyrhauge (2021) highlights how establishing alternative transport fuels infrastructure—especially for electro-mobility—requires building a new energy-transport paradigm through closer coordination between the electricity and mobility sectors. Similarly, Van Baal and Finger (2020) advocated for an integrated energy-mobility system to electrify Swiss highways, addressing challenges like regulatory fragmentation by proposing charging stations near highways, a unified system operator, and cohesive policies. Similarly, Lucas-Healey et al. (2022) analyzed the vehicle-to-grid niche using MLP and SNM frameworks, finding it still at an embryonic stage due to underestimated non-technical factors and user behavior, and existing infrastructure constraints. Without directly stating “nexus,” these studies illustrate the growing interdependencies between energy and mobility systems—highlighting how sustainability transitions in transport are increasingly shaped by developments in energy infrastructure and governance.

In water infrastructure, innovations focus on decentralized solutions like local wastewater treatment and recycling. These approaches require strategic urban planning, suitable locations, and visible social benefits to succeed (Särkilahti et al., 2017; Truffer et al., 2010). Heiberg et al. (2022) noted that centralized systems are deeply institutionalized, creating barriers to change, while external shocks like floods and droughts open opportunities for modular and decentralized technologies. However, van Duuren et al. (2019) warned that isolated decentralized measures, without a systems-thinking approach, can lead to failures and inequalities, such as over-reliance on wells and increased water costs.

In the context of decentralized water solutions, China’s membrane bioreactor technology represents a promising niche for industrial leapfrogging and transformation, though durability concerns remain (Yap and Truffer, 2019). Ferguson et al. (2013) proposed a comprehensive diagnostic procedure for transformative change, merging transition and resilience approaches, which has driven shifts from conventional drainage to the Water Sensitive Urban Design (WSUD) niche. This shift has been motivated by ecosystem protection, societal needs, and pollution control and has evolved through projects, knowledge sharing, and regulatory changes. Similarly, Mguni et al. (2022) examined WSUD and nature-based solutions in African cities, highlighting their alignment with broader visions but also the challenges posed by coordination and capacity gaps due to limited social networks and high-order learning.

4.3.2. *Process transformations*

Transitions reshape infrastructure systems not only through new technologies but also through emergent processes such as systemic reorganization, institutional and social restructuring, and evolving coordination mechanisms. This section highlights how previous studies have examined infrastructure transformation through such processes, rather than focusing solely on technological or product innovations.

Learning and adaptation are central to infrastructure transitions. Johannessen & Mostert (2020) highlight the role of social learning in integrating sustainable nature-based solutions into urban water governance. Using MLP and SNM frameworks, Schaube et al. (2018) found renewable energy niches to be advanced, supported by formal networks, project-based learning, and favorable regulations, but hindered by centralized governance, economic instability, and large geographic areas. Similarly, Castán Broto et al. (2014) argue that shocks, such as power grid failures, enable higher-order learning by exposing systemic flaws and fostering experimentation with niche innovations, which reconfigure infrastructure systems for sustainability. This learning-driven reconfiguration aligns with Malekpour et al. (2020), who suggest combining Transition Management tools (e.g., visioning, social learning) with DMDU methods (e.g., scenarios, modelling) to balance preparation and action, enabling actors to navigate complex transitions more effectively.

As another systemic new process, circularity has emerged as a transformative response to sustainability transitions, driving significant changes across sectors. In construction and transportation, cognitive silos among practitioners hinder the adoption of circular economy practices in projects like high-speed railways and bridges (Liu et al., 2019; Coenen et al., 2020). Meath et al. (2022) emphasize the importance of collaborative platforms and multilevel coordination to bridge knowledge and practice gaps in infrastructure-intensive industries. Circularity also accelerates decentralization in the energy-water nexus, fostering innovations like solar panels, wind turbines, decentralized sanitation, and water filtration. These shifts require governance changes, pushing infrastructure providers to evolve from traditional "provide, monitor, and sanction" roles to integrative coordination across energy and water systems (Kiparsky et al., 2013; Giezen, 2018).

Institutional and governance restructuring has emerged as a critical response to the demands of infrastructure transitions. In the water sector, conflicts among regime actors led to the formation of System Governance Organizations (SGOs) to manage technological conflicts and stakeholder relations (Hess and Brown, 2018). Similarly, in electricity transmission, pilot projects demonstrate the need for new governance approaches to improve dialogue among TSOs, NGOs, and policymakers (Komendantova et al., 2015).

In the energy sector, infrastructure governance often prioritizes short-term efficiency, hindered by institutional weaknesses and regulatory limitations, necessitating more inclusive governance mechanisms (Lockwood, 2023). Bolton & Foxon (2015) emphasize the need for tailored governance strategies throughout the infrastructure transition lifecycle, such as local authorities building financial and organizational capacity for district heating expansion. Transition timelines are influenced by the power of incumbents, who maintain regime stability in renewables like nuclear and solar through financial, regulatory, and media resources (Mori, 2019). Spatial dimensions are equally significant, as Calvert et al. (2019) emphasized the need to integrate land-use planning and the social values embedded in those spaces into energy planning.

Instead of viewing decentralization solely as a technological shift, it can also be seen as a process for fostering adaptability and innovation. Dobre et al. (2018) demonstrate how decentralized governance enables stakeholder engagement and innovative approaches, such as transitioning stormwater systems from underground to surface-level designs, echoing Rijke et al. (2013), who show that the water system requires a mix of centralized and decentralized, formal and informal approaches. Hartman et al. (2017) emphasize the importance of dynamic capabilities—sensing, seizing, and reconfiguring—for incremental and radical innovations in water utilities, recommending public awareness campaigns, cross-sectoral collaboration, and inter-city learning networks (Dunn et al., 2017). Similarly, van der Brugge et al. (2005) highlight the Netherlands’ shift from technocratic to participatory water governance, addressing gaps between macro-level strategies and micro-level implementation through multi-level governance models like TM.

Integrated water management processes, such as One Water, address siloed structures and institutional constraints, with decentralization and stakeholder engagement as central elements (Rogers et al., 2015; Díaz et al., 2016; Bolson et al., 2018).

In the mobility sector, recent studies emphasize the importance of institutional and governance processes to advance sustainability transitions. Liu et al. (2024) argue that improving multilevel coordination between local, regional, and national actors is essential for advancing sustainable mobility, especially by shifting from infrastructure-centric funding toward the institutionalization of collaborative governance. In ports, Bjerkan and Ryghaug (2021) highlight how social processes—such as shared expectations, actor networks, and learning—shape transition work, guiding ports along different pathways beyond mere technological substitution. Similarly, Damman and Steen (2021) frame ports as multi-functional actors engaging in institutional work across roles such as regulators, landlords, and community managers. They show how ports take on multi-functional roles to enable climate action—not only through technological upgrades, but by reshaping stakeholder coordination and mobilizing place-based networks, market dynamics, and social relations to activate radical innovations, illustrating the energy-mobility interface (e.g., shore power for ships, hydrogen fueling for trucks, electric charging for logistics vehicles).

At the urban scale, redevelopment projects and experimentation create strategic fields for new transition processes. Jain & Rohracher (2022) highlight urban redevelopment as an opportunity for decentralized infrastructure supporting sustainable services like energy, water, waste, and mobility. Similarly, Lee et al. (2023) highlight collective governance in smart city transitions, where integrated platforms enable open information flow and social innovation. Urban Living Labs (ULLs) function as experimental spaces for urban sustainability transitions through citizen engagement, collaboration, and empowerment. While locally rooted, their innovations can spread through adoption and cross-sectoral partnerships (Puerari et al., 2018; von Wirth et al., 2019). Valencia et al. (2022) conceptualize metropolitan regions as living organisms, modelling energy and material flows within the food-energy-water-waste nexus toward circular economies. While infrastructure development provides 'protective spaces' for sustainable experimentation, it often faces institutional, organizational, and political challenges (Newton and Frantzeskaki, 2021; Mauw et al., 2023).

The insights from transitions' influence on infrastructure, as new products and processes are summarized in **Appendix I,** which also includes the reviewed papers' theoretical focus. While MLP is the most frequently applied framework, theories like SNM, TIS, and Neo-Institutional Theories also feature prominently, highlighting a dual focus on product innovations (e.g., hydrogen technologies) and process transformations (e.g., governance restructuring), underscoring the multi-dimensional nature of sustainability transitions.

4.3.3. Management of Sustainability Transitions in Infrastructure

The influence of sustainability transitions on infrastructure systems has also been analyzed through the lens of managerial levels—strategic, tactical, and operational—guided by the multi-level TM framework. The positioning of transitions within these levels is reflected in the coding rationale, based on how each paper approaches the management of transitions in infrastructure contexts. Papers situated between strategic/tactical and tactical/operational levels—representing the periphery of tactical considerations—are indicated in the grey zones.

Predominantly, the review suggests that transitions tend to influence infrastructure from a strategic-level perspective (with nearly 20 papers reflecting this, see Table 7). Transition management is commonly approached through long-term policymaking and strategic planning, often framed as forward-looking 'transition pathways'. These may include technology-specific strategies (Yap and Truffer, 2019), policy instruments and institutional reform (Mori, 2019), and programs that combine envisioning with learning (Ferguson et al., 2013). Economic perspectives also appear, focusing on long-term investment dynamics—such as transition costs (Stringer and Joanis, 2022), low-carbon energy investments (Bolton et al., 2016), and the market potential of decentralized water systems at the European scale (Eggimann et al., 2018). Additionally, several studies examine future roadmaps and technological pathways, addressing questions of which innovations to adopt and how transition trajectories may unfold (Farla et al., 2010; McDowall, 2014).

Papers with an operational perspective often explore transitions through experimentation, particularly in pilot and trial projects (Bulkeley et al., 2014; Tongur and Engwall, 2017). This includes learning-by-doing approaches that support niche-building (Schaube et al., 2018), reconfiguring actor relationships (Bulkeley et al., 2014), and implementing experimental initiatives (Komendantova et al., 2015; Butu and Strachan, 2022; Lucas-Healey et al., 2022). These studies show how niche innovations in infrastructure emerge through internal dynamics and are shaped by external conditions such as policy, community acceptance, and skilled labour—factors essential for scaling into mainstream practice.

Categorizing papers exclusively at the tactical level is challenging due to their ambiguous positioning between strategic and operational perspectives. Many papers blend strategic elements—such as transition pathways and visions—with tactical concerns like system conditions, organizational challenges, and regime capacities: Coenen et al. (2023) link a national circularity vision to regime-level barriers; Hölscher et al. (2023) translate strategic frameworks into practice by tracing niche pathways, while Hiteva & Watson (2019) show how historical regimes and sectoral interactions shape smart grid strategies. This intersection forms a strategic-tactical hybrid, where strategic planning directly influences tactical implementation.

Simultaneously, other studies integrated operational aspects, such as niche design and implementation, with tactical references to regime conditions, creating an operational-tactical blend. This blending across strategic, tactical, and operational levels reflects the multi-layered complexity of transition management, making it difficult to isolate a purely tactical focus. Only three papers predominantly take a tactical perspective: Meath et al. (2022) examine collaborative models for translating circularity strategies, while Ferguson et al. (2013) and Novalia et al. (2018) propose diagnostic frameworks—one offering an operational procedure to assess the transformative capacity of urban water systems, the other showing how strategic agency can leverage institutional opportunities for infrastructure change. Both are positioned at the reflexive level of the TM framework. As also indicated in the table, process-oriented approaches—unlike product innovations which often situated at the strategic level —tend to align more closely with tactical concerns, likely due to their focus on stakeholder engagement, collaborative governance, and institutional processes that bridge strategy and operation through regime-level adaptation.

Table 7
How transition management influences infrastructure systems? (Barreto et al., 2003; B.C. Ferguson et al., 2013; Pollák et al., 2021; Taniand Morone, 2020).

	Analyzed Papers	**Strategic (S)- Tactical (T)- Operational (O) Focus**
Product Innovations	Decentralized low-carbon energy and hydrogen infrastructure (Barreto et al., 2003; Verbong & Geels, 2010; Markard, 2018; Mori, 2019; Pollák et al., 2021; Phoumin et al., 2021; Bolton et al., 2016; Tani& Morone, 2020; Stringer& Joanis, 2022) Transport and mobility pathways (Köhler et al., 2009; Farla et al., 2010; McDowall, 2014; van Baal& Finger, 2020) Decentralized water solutions (Truffer et al., 2010; Yap & Truffer, 2019; Eggimann et al., 2018); Water sensitive urban design (Ferguson et al., 2013)	**Strategic** (Transition pathways; long-term policy-making, strategic planning) (Long-term economic cost, investment planning)
	Smart grids (Hiteva& Watson)	**Strategic to Tactical** (Development pathways and Regime conditions)
	District energy systems (Tong et al., 2020) Water sensitive urban design (Mguni et al., 2022); Decentralized niche wastewater solutions (Särkilahti et al., 2017)	**Operational to Tactical** (Niche design or implementation with regime conditions (e.g., regulations)
	Vehicle-to-grid niche (Lucas-Healey et al., 2022); community project (Butu& Strachan, 2022)	**Operational** (Innovation and experimentation in projects)
Process Transformations	Port visions and stakeholder engagement (Damman & Steen, 2021; Bjerkan & Ryghaug 2021) Circularity processes (Coenen et al., 2020). Collaborative governance and institutional learning (Liu et al., 2024; Hölscher et al., 2023) Decentralization as a process in water systems (Dunn et al., 2017; Dobre et al., 2018)	**Strategic to Tactical** (Long-term policy alignment to regime coordination (e.g., organizational challenges of circularity, visions, and capacities for ports)
	Transformative governance and diagnostic tools (Ferguson et al., 2013; Novalia et al., 2018) Multi-level collaborative models (Meath et al., 2022)	**Tactical** (Operationalization of strategic goals; use of diagnostic tools; tactical collaboration for strategy-operations bridge)
	Innovation learning and adaptation (Schaube et al., 2018; Castán Broto et al., 2014) New governance processes in pilots (Komendantova et al., 2015) Urban experimentation and learning (Jain& Rohracher, 2022; Bulkeley et al., 2014; Puerari et al., 2018; von Wirth et al., 2019; Valencia et al., 2022; Newton & Frantzeskaki, 2021; Mauw et al., 2023; Lee et al., 2023)	**Operational** (Innovation, experimentation, pilot projects)

5. Discussion, conclusions, and recommendations

In this review, empirical studies on how infrastructure influences and is influenced by sustainability transitions have been analyzed. In examining how infrastructure influences sustainability transitions, studies done in a range of sectors, including energy, mobility, and water sectors, have demonstrated how infrastructure can be both a constraining force through structural lock-ins and as an enabler of innovation and adaptation in transitions.

While prior research has emphasized lock-ins in terms of the challenges of changing physical structures, recent studies—especially at the strategic level—also highlight economic and political lock-ins, pointing to the need for research on sociopolitical dimensions and "lock-out" practices in decision-making. At the same time, the review findings also suggest a potentially enabling role of existing infrastructure, such as leveraging energy grids for transitions and integrating sustainability practices like communication and stakeholder engagement into project management. These insights on enablers illustrate how, if we look beyond the constraints of physical infrastructure, the capacity to embrace sustainability transitions can be stimulated through exemplary practices such as reflexive planning and multi-stakeholder engagement for fostering systemic change.

In examining how sustainability transitions influence infrastructure, both product innovations (e.g., hydrogen systems, decentralized wastewater solutions) and process transformations (e.g., governance reforms, circular economy practices) have been found. Thus, transitions reshape both the physical and organizational aspects of infrastructure systems, demonstrating that systemic innovation requires not only new technologies but also institutional, regulatory, and social restructuring.

Our observation from the reviewed papers was that more infrastructure-oriented studies—those concentrating on the role of existing infrastructure's technical, structural, or managerial aspects—often do not engage deeply with transition dynamics, such as the emergence of niche innovations, their interaction with regime conditions, or the governance mechanisms required. Conversely, more transition-oriented papers—those asking how transitions influence infrastructure—tend to focus on conceptual and theoretical aspects of transitions, but do not always reflect on the (existing) capacity required from infrastructure systems. These emphases reflect different analytical entry points into the relationship between infrastructures and sustainability transition. That said, there is growing dialogue in which perspectives of (existing) infrastructure and (more future-oriented) sustainability transitions are increasingly being integrated. For instance, some papers examine how hydrogen niches can be accelerated not only by considering the role of regime actors but also by leveraging existing gas grid infrastructure. These studies highlight the potential for closer alignment between transition ambitions and infrastructure realities, while also pointing to opportunities for future research to deepen this dialogue.

5.1. Influences in infrastructure transitions: capacity as a cross-cutting theme

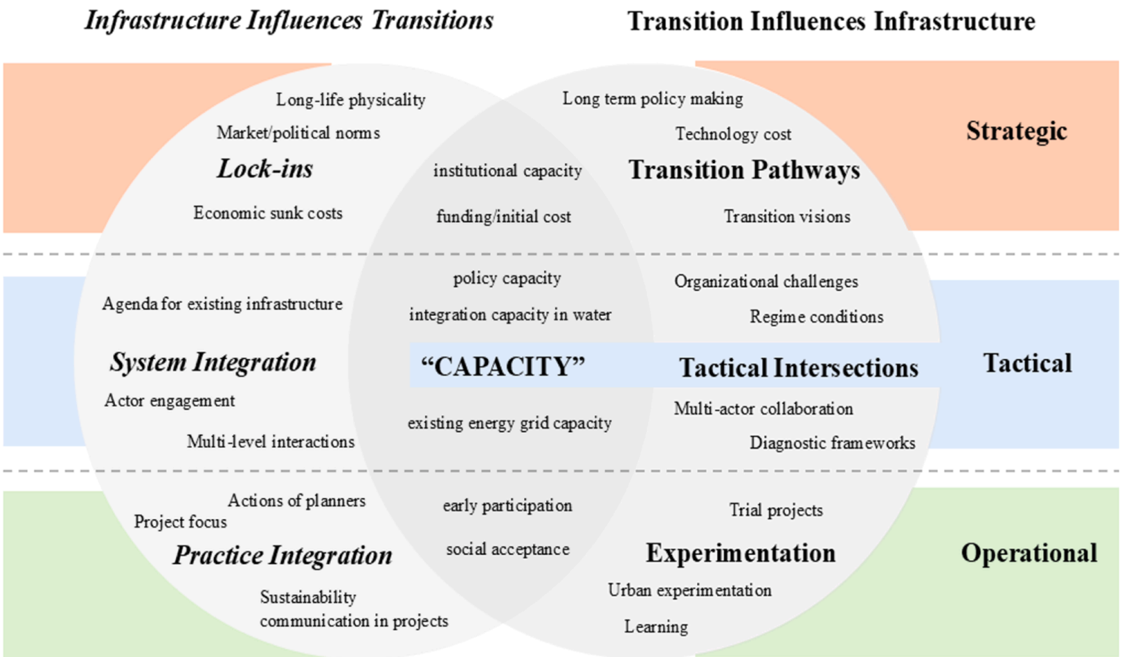

Fig. 5. Influences in infrastructure transitions.

A central, cross-cutting theme emerging from this review is the notion of **capacity**—not only as a physical constraint but also as an institutional, financial, and collaborative condition for sustainability transitions. Infrastructure is no longer seen merely as a passive backdrop but as a dynamic space where innovations must interact with existing systems. Fig. 5 visually synthesizes these insights, drawing directly from the coded findings summarized in Table 6 and Table 7. Capacity is articulated differently across governance levels—where infrastructure realities intersect with transition ambitions. These range from funding and institutional capacity at the strategic level (e.g., Farla et al., 2010; Kiparsky et al., 2013), to grid and policy capacity at the tactical level (e.g., Hasankhani et al., 2024; Kigle et al., 2024), and early participation and social acceptance at the operational level (e.g., Puerari et al., 2018).

As highlighted in the findings, certain papers integrate the dual perspective of leveraging existing infrastructure while advancing innovations. The hydrogen transition, for example, shows how existing gas pipelines and storage networks can support new hydrogen technologies (McDowall, 2014; Hasankhani et al., 2024; Kigle et al., 2024), while circular waste systems enable biogas integration into existing gas grids (Särkilahti et al., 2017). In the water sector, shocks like floods and droughts have opened up space for modular solutions that connect centralized and decentralized systems. Yet, without systematic planning, such adaptations risk reinforcing future lock-ins—such as carbon-intensive hydrogen inputs or reinforced gas lock-in (Kigle et al., 2024), or inequities in cost distribution (van Duuren et al., 2019).

Similar dynamics are visible in energy transitions. Studies on grid flexibility highlight both physical and socio-technical constraints, as limited capacity, spatial congestion, and fragmented regulations continue to hinder the uptake of decentralized systems— (e.g., Tong et al., 2020; van Baal and Finger, 2020; Lockwood et al., 2022). Many of these papers converge on themes of "**infrastructure system integration**" and "**product innovations,**" raising the question of how "**infrastructure process integration**" (e.g., sustainability-oriented project management, planning, and asset management) might align with **"process transformations**" (e.g., organizational and institutional shifts).

While much attention has been given to experimentation and niche-level innovations, there is still limited understanding of how these insights feed back into regime-level change (Stam et al., 2023). This raises key questions: Do long-term strategic visions for transition pathways effectively account for the integration of operational practices? Or do they remain disconnected from established norms in project development and asset management? Addressing this gap could help align planning and implementation, unlocking synergies across levels.

Consequently, **capacity** emerges as a pivotal theme at the interface of infrastructure and transition studies. What capacities are necessary—or already available—to drive sustainable innovations in infrastructure transitions? These may include policy frameworks, institutional structures, financial means, the physical condition of infrastructure, or collaborative capabilities within and between organizations. We therefore call for more sustained dialogue between infrastructure and transition perspectives, with a focus on the practical objectives of capacity planning.

While infrastructure capacity is often framed in terms of physical limits and planning, transition capacity relates to embedding technological innovation within broader institutional and governance change (Kiparsky et al., 2013). Yet neither is sufficient in isolation. Advancing sustainability transitions requires these capacities to work in tandem, enabling a more integrated and adaptive approach—one that channels information and aligns objectives between transition ambitions and infrastructure realities. This review highlights the importance of aligning them—analytically and practically—to better understand the interplay between infrastructure and sustainability transitions.

5.2. Rethinking the "tactics" for infrastructure

While strategic and operational levels are well-explored through various frameworks and models, and whereas the strategy-implementation gap has been widely acknowledged (e.g. Köhler et al., 2019), this review points to a significant gap in examining the tactical level—an arguably crucial intermediary space that translates strategic visions into operational actions. This gap is particularly evident in the grey zones of literature where tactical considerations are indistinctly merged with strategic intentions or operational necessities, without clear focused analysis (as can be seen from Tables 6 **and** 7) —remains poorly defined and inadequately studied. This may be due to limited scholarly attention or perhaps because the tactical level is not clearly defined—or even fully institutionalized—in practice. More specifically, the definition and role of the tactical level, how it intersects and interacts with strategic and operational levels in ongoing infrastructure practices, and how far it can stretch in shaping sustainability transitions remain promising lines of future inquiry. Future research could further examine the tactics employed across infrastructure systems, focusing on the capacities required at the tactical level—whether in knowledge, skills, or coordination—and how these can be strengthened to support sustainability transitions.

In studies that emphasize (limitations of) existing infrastructure management, for instance, scholars have either focused on long-term strategic challenges such as long-life physicality, sunk costs, or incumbent business models (e.g., Mühlemeier, 2019) or on operational problems when embedding sustainability into practical domains such as project execution, asset management, and planning practices (e.g., Barendsen et al., 2021). In studies that consider (future possibilities in response to) sustainability transitions, scholars have focused either on long-term, strategic technology pathways and policy visions (e.g., Liu et al., 2024) or on operational aspects addressed in niche innovations and experimental projects (e.g., Lucas-Healey et al., 2022). There are notable exceptions where some scholars begin to bridge the tactical gap between strategic and operational levels. For example, Yasmin et al. (2018) explored how adaptive capacity can be fostered by connecting stakeholder engagement at the operational level and strategic, multi-level coordination in infrastructure planning. Similarly, Novalia et al. (2018) and Meath et al. (2022) offer possibilities in terms of developing collaborative and diagnostic tools to operationalize strategies and while simultaneously addressing strategic regime conditions.

A more extensive exploration and dialogue at the tactical level is crucial, as this is where strategies and operational activities (can) connect and converge. Fostering dialogue between the tactical approaches in infrastructure management and transition processes could facilitate integrative frameworks that address physical, socio-technical and socio-political dimensions of sustainability transitions. Moreover, considering that the tactical level in transition management (Loorbach, 2010) is defined as the 'processes of agenda-building, negotiating, networking, and coalition-building', it directly emphasizes the need for collaboration among various systems and actors. Recent studies, such as multi-level collaboration for circularity (Meath et al., 2022), engagement of regime and niche-level actors (Mguni et al., 2022), and the significance of collaboration between formal institutions and informal networks (Dobre et al., 2018), highlight collaboration. However, there is a significant lack of research specifically examining the multi-actor environments within infrastructure transitions (e.g., actors from different systems such as water, energy, transport).

Given that infrastructures are part of larger systems-of-systems, integrated policy frameworks have been proposed to support cross-sectoral coordination (Van Baal and Finger, 2020). Nonetheless, most studies still analyse actors and their interrelations from a single-sector perspective, focusing on isolated transition challenges. Therefore, future research should explore the complex interplay within multi-actor environments across infrastructure sectors, particularly how collaboration unfolds across strategic, tactical, and operational levels within and between organizations.

5.3. Lack of nexus approach among infrastructure and transitions

In recent years, nexus-thinking has gained growing attention as a way to address complex sustainability challenges. It refers to approaches that recognize and engage with interdependencies and interfaces across infrastructure systems—such as energy, water, and transport—including resource flows and institutional coordination (Monstadt et al., 2022).

However, our review found few empirical studies that explicitly address interdependencies between infrastructure systems during transitions. Some refer to energy–mobility or energy–water interfaces—for example, grid needs for mobility (e.g., Kigle et al., 2024), ports as energy–mobility hubs, or circular and decentralized water–energy solutions (e.g., Giezen, 2018)—but these remain limited and are seldom framed within a broader nexus perspective. This may reflect broader patterns of fragmented infrastructure governance, as mentioned by the liberalization, privatization, or unbundling (e.g., Mühlemeier, 2019; Van Baal and Finger, 2020; Dyrhauge, 2021).

As with most studies in this review, transitions are still primarily analyzed from the perspective of individual infrastructure systems. As in most studies reviewed, transitions are still approached from within individual infrastructure systems, with few explicitly examining how these systems influence one another during transitions (see e.g. Gürsan et al., 2023, as a rare exception). These examples point to the 'splintering' of urban infrastructure networks and suggest a need for more cohesive development strategies, such as sector coupling and nexus-thinking. They also highlight the potential value of a more integrated, networked infrastructure perspective—one that considers how different systems may co-evolve and constrain one another over time. In this light, capacity may need to be rethought not only within individual systems but across them. As interdependencies grow, there may be increasing need to consider a *nexus of capacity*, where space, labor, and system limitations are aligned across sectors to support more coordinated transitions.

Crucially, this may also reinforce the importance of strengthening the tactical level—potentially the space where cross-sectoral tensions can be negotiated, and where strategic ambitions meet operational constraints. Nexus-thinking not only broadens how transitions are understood across systems-of-systems, but may also highlight the need for tactical capacity to support integrated and coordinated transitions.

While this review provides a synthetic overview of the different foci of infrastructure research and transition scholarship and where these overlap (or not), a number of limitations are also noteworthy for future consideration. For example, the scope of this review was confined to civil or 'grey' infrastructure, such as energy, water, and transport. Future research may therefore consider the potential contributions of emerging nature-based, or 'blue/green,' infrastructure, which may significantly promise in the future.

As with any systematic review, the analysis is limited by what is included in the sample of studies reviewed. In this review, our starting point in the search strategy was to search for studies with an explicit mention of 'infrastructure' as a keyword. While this may have missed out other studies that use other keywords such as "energy," "mobility," and "water" to represent 'infrastructure', the review has nevertheless found empirical examples across these different sectors.

To conclude, we have argued for a more integrated approach to infrastructure and sustainability transitions. Addressing the gaps in tactical governance, cross-sectoral nexus thinking, and capacity planning will be essential for guiding infrastructure systems through the transformative changes required to meet global sustainability challenges.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT and Grammarly to improve the clarity and cohesion of the English writing. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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CRediT authorship contribution statement

Hazal Deniz Kaya: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Paul W. Chan:** Writing – review & editing, Validation, Supervision, Conceptualization. **Daan Schraven:** Writing – review & editing, Visualization, Validation, Supervision, Project administration, Funding acquisition. **Martijn Leijten:** Writing – review & editing, Validation, Supervision, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Sector	Product Approach	References	Theory: MLP	LTS	TIS	TM	SNM	Other	N/A
Energy	Decentralized renewables	Verbong & Geels (2010)	☑						
		Phoumin et al. (2021)							
		Sataøena, et al., 2015	☑	☑				☑	
		Markard et al., 2018						☑	
		Bolwig et al. (2019)							☑
		Hiteva & Watson (2019)						☑	
		Bolton et al. (2016)	☑					☑	
		Stringer &Joanis (2022)							☑
	Decentralized heating infrastructures, district energy systems (DES) including CHP/DH	Tong et al. (2020)	☑						
		Bolton & Hannon (2016)	☑	☑					
		Roesler & Hassler (2019)	☑						

Process Approach	References	Theory: MLP	LTS	TIS	TM	SNM	Other	N/A
Learning from decentralized niche energy systems	Schaube et al. (2018)	☑				☑		
	Malekpour et al. (2020)				☑			
Effect of institutional weaknesses and regulatory limitations on infrastructure governance	Lockwood, 2022	☑						
Need for new governance approaches to create better dialogue between TSOs, NGOs, and policymakers.	Komendantova et al., (2015)							☑
Inclusive, tailored governance across the transition lifecycle	Bolton & Foxon (2021)		☑					
Influence of governance structure, incumbents and institutions in transitions.	Mori, 2019	☑						
Integration of spatial dimensions like land-	Calvert et al. (2019)						☑[3]	

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										use planning in energy transitions.								
										The importance of connecting local and regional experimentation to national policies	Liu et al. (2024)							☑
										Circularity as an accelerant for decentralization in energy-water nexus.	Kiparsky et al., 2013							☑
											Giezen, 2018						☑[4]	
Water	Decentralized solutions, modular water technologies and sustainable urban water management measures	Särkilahti et al., (2017)	☑							Decentralization as a process for fostering adaptability and innovation.	Dobre et al. (2018)						☑[5]	
		Truffer et al., (2010)							☑		Rijke et al. (2013)							☑
		Heiberg et al. (2022)						☑[1]			Hartman et al. (2017)						☑[6]	
		van Duuren et al., (2019)	☑															
	Membrane bioreactor technology	Yap & Truffer (2019);			☑					Integrated water management (One Water) processes	Rogers et al. (2015)						☑[7]	
	Water Sensitive Urban Design	Ferguson et al. (2013)				☑		☑			Bolson et al. (2018)							☑
		Mguni et al. (2022)					☑			Institutional and governance restructuring	Hess & Brown, 2017							☑
										The need for multi-level governance and knowledge sharing through city learning networks for urban water transitions.	Dunn et al., 2017							☑
											van der Brugge et al. (2005)				☑			
Transport	Hydrogen infrastructure	Köhler et al. (2009)	☑							Social networks hosted and unique feedback loops and institutional	Bjerkan & Ryghaug, 2021							☑
		Barreto et al., 2003							☑		Damman& Steen (2021)	☑						

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										contributions created by ports.								
		Huétink et al. (2010)						☑[2]		Circularity as a transformative response to sustainability transitions in transportation.	Liu et al., 2019							☑
		Hasankhani et al., 2024							☑		Coenen et al., 2020							☑
		McDowall (2014)							☑		Meath et al. (2022)							☑
	Transport decarbonization, electrification and charging infrastructures.	Dyrhauge (2021)						☑										
		Pollák et al. (2021)							☑									
		Van Baal & Finger (2020)							☑									
		Lucas-Healey et al. (2022)	☑				☑											
	Vehicle hybridization, liquid biofuels, natural gas, and hydrogen as transportation fuels	Farla et al. (2020)			☑	☑												
Urban										Urban Living Labs (ULLs) as spaces for testing and scaling sustainability innovations.	Puerari et al. (2018)							☑
											von Wirth et al. (2019)							☑
											Valencia et al. (2022)							☑
										Urban redevelopment projects and experimentations serve as openings for implementing alternative solutions to unsustainable infrastructure systems.	Jain & Rohracher (2022)				☑		☑[8]	
											Newton & Frantzeskaki (2021)							☑
											Mauw et al., 2023						☑[9]	

[1] Neo-institutional theories Fuenfschilling & Truffer (2014)
[2] Diffusion of Innovations (Rogers (2003)
[3] Sociotechnical transitions (Geels, 2014) and Neo-institutional theories Fuenfschilling & Truffer (2014)
[4] Institutional Work Theory (Lawrence et al., 2013)
[5] Transition activities stage (Rijke et al., 2013)
[6] Dynamic capabilities (Teece, 2007)
[7] New institutional theory (Scott, 2008)
[8] TM and Neo-institutional theories Fuenfschilling & Truffer (2014)
[9] New institutional theory (Scott, 2013)

Data availability

No data was used for the research described in the article.

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