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Article

On Eight Structural Conditions Hampering Urban Green Transitions in the EU

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Abstract

The European Green Deal (EGD) aims at driving the green transition in the EU and positions cities as pivotal actors in achieving climate neutrality and environment protection. Despite ambitious policy commitments, significant implementation gaps persist at the local level impeding urban green transitions. This study assesses barriers to the EGD urban implementation by integrating several methods (scoping literature review, expert consultations, and computational network analysis) to identify structural conditions hampering change. Barriers are clustered into five domains and reviewed by experts to distill eight structural conditions perpetuating the status quo of urban development, hindering transformative change. The findings illustrate how the emerged structural conditions, ranked by their in-degree centrality, regard insufficient policy implementation; upgrade of consolidated built environments' layout; short-term mindset; lack of knowledge and data sharing among stakeholders; silos in policymaking and development processes; competition among stakeholders over space use; limited social acceptance; and limited financial resources. Conversely, high-out-degree barriers—such as limited technical expertise in urban departments and GDP-oriented paradigms—emerge as system triggers where targeted interventions could catalyze change. This research provides actionable insights for policymakers by identifying leverage points which could promote urban green transitions and enhance the EGD local implementation for accelerating urban green transitions.

Keywords: European Green Deal; urban green transition; urban policy; system barriers; system lock-ins; system triggers

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1. Introduction

Designed under the Paris agreement and 2030 Agenda [1], the European Green Deal (EGD) aims to "accelerate and underpin the [green] transition needed in all sectors" [2]. Furthermore, its first-ever 'Climate Law' [3] sets out "clearly the conditions for an effective and fair transition", ensuring "that the transition is irreversible" [2] and making Europe the first climate-neutral continent by 2050. As part of this roadmap, the EGD established ambitious mid-term targets, including a 55% reduction in greenhouse gas (GHG) emissions by 2030, supported by the Fit for 55 package introducing stricter environmental standards in highly emitting sectors, such as aviation, maritime, and road transport.

The EGD orchestrates the EU sustainability transition across seven Thematic Areas (TAs) [4], namely TA1—Climate ambition; TA2—Clean, affordable, and secure energy; TA3—Circular economy; TA4—Sustainable and smart mobility; TA5—Greening the Common

Agricultural Policy (CAP) and 'Farm to Fork' strategy; TA6—Preserving and protecting biodiversity; and TA7—Towards zero-pollution ambition for a toxic-free environment. This diversity and mix of policy instruments require experts to investigate and address the multiple barriers to the transformations that the EGD underpins [5].

1.1. Gaps and Objective

Consistent implementation haps have emerged in a recent, comprehensive study reporting on progress towards the EGD [4] across all TAs, specifically at EU and national levels. However, exploring the state of play and major challenges in urban green transitions allows for leveraging cities' role in the EU sustainability journey. In fact, most EGD targets will have to be delivered by subnational authorities and scholars highlighted the need to unveil structural barriers preventing urban environments to play their role in the transition policy implementation [6], further hindered by the absence of effective multilevel governance mechanisms [7,8]. Additional gaps in the EGD implementation have been widely acknowledged by key EU consultative bodies, including the Committee of the Regions [9,10] and Economic and Social Committee [11], which highlighted the insufficient involvement of social partners and subnational authorities in the policymaking process. A rapidly evolving regulatory landscape influenced by shifting geopolitical conditions [12], and resource and skill shortages at both Member State and Local and Regional Authority (LRA) levels [13,14] might additionally hinder the EGD implementation.

Therefore, understanding *what* (and *how*) barriers counteract the EGD and what elements might possibly trigger transformative change [15] to dismantle current systems is of paramount importance, yet unexplored. Ulpiani & Vetters [14] recalled that research risks overlooking non-technological aspects of climate-neutral transition at city level, offering poor actionable knowledge to catalyze sustainability transition [16]. Furthermore, von Homeyer et al. [17] called for better understanding of causal mechanisms linking trends to implementation in the EGD operationalization, reinforcing later stages of policy process. This is timely also considering the 2024-2029 European Commission's priorities, calling for actual implementation of EGD legislation [18].

Based on the assumption that the EGD constitutes the policy framework driving the EU green transition by design at urban level [6], this study conducts a comprehensive assessment of barriers to urban green transitions in EU cities to finally detect structural conditions hampering transformative change for the EGD. Structural conditions—analyzed for the Nature-Based Solutions uptake [19]—are here defined as systemic, self-reinforcing mechanisms embedded within current socio-technical and institutional systems that perpetuate the status quo of urban development and hinder transformative change towards the green transition at EU cities' level. Ultimately, this study aims at informing EU policymaking by identifying potential feedback loops, amplifying system inertia, and system triggers to leverage as "entry-points" to support transformative changes for the EU green transition.

1.2. Background

The EGD is strongly transition-oriented by design. The word 'transition' appears 52 times within the EGD Communication. In these terms, the frequent calls for 'transitions' and 'transformations' of existing socio-technical systems in environmental studies clearly suggest that business-as-usual is not sufficient to keep humanity within a 'safe operating space' [20,21]. Transition and transformation are often employed interchangeably for radical, non-linear and structural change in complex adaptive systems [22]. However, 'transition' is used by the research community meaning fundamental social, technological, institutional and economic change from one societal regime or dynamic equilibrium to another [23]. While some scholars argue that transformations imply more radical, large-scale

and long-term changes [24], some others consider transformations as possible pathways towards transition [25]. Transition and transformation are not mutually exclusive, since they both highlight the urgency for desirable and profound societal change. Despite semantic and conceptual questions, in this research we will use 'urban green transition', in line with the EGD narrative [26], generally referring to the series of interrelated changes that need to happen within urban socio-technical systems to face current ecological crisis in the EU.

Although the national level usually dominates the discourse on transitions [27–29], the quest of sustainable development will largely be an urban challenge [30] due to rapid and growing urbanization [12]. The EGD legal framework underscores the pivotal role of local and regional governments in driving sustainability, as they are often best positioned to implement most transition policies, experiment with tailored solutions and reassess trajectories for the EGD where needed [31,32]. According to the 'State of Regions and Cities 2024' [7], the EGD emphasizes the strategic role of cities in addressing the climate crisis. Urban areas are central to implement 70% of climate mitigation [33] and 90% of adaptation policies [10]. The 'Climate Law' reinforces this narrative, as it mandates inclusive, accessible processes that engage all governance levels and societal actors in achieving climate neutrality by 2050. The EC mission "100 Climate-neutral and smart cities by 2030" [34] and New European Bauhaus initiative are blueprints of the importance of place-based transformation [35] for EGD policy implementation.

The governance framework of the EGD is rooted in the EU's 'multi-level' and 'polycentric' model [36] aligning with the principle of subsidiarity [37]. It ensures that decisions are made at the lowest level possible of governance while engaging a range of stakeholders, including policymakers, civil society, and the private sector. The EU's multilevel governance model is integral to its sustainability agenda, promoting an inclusive and participatory approach that involves a wide array of societal actors, from governments to civil society and the private sector [10]. However, the division of responsibilities among EU Member States and their subnational authorities is not uniform, as it falls under the national competence of each country [38]. Consequently, the scope and distribution of powers vary significantly across the EU, influenced by national traditions, institutional arrangements, and legal frameworks [37]. Nonetheless, even if in diversified contexts, the coherence of ambitions across governance levels [1], orchestration of actors, management of conflicting views [39], and co-creation of a shared understanding are key features for the sustainability transitions [15].

As recalled, transitions imply radical transformations of current socio-technical systems (for example, energy, housing, transport, agri-food systems) [20] which, at the urban scale, co-exist and interact [40]. These systems are often resistant to radical transformation due to entrenched structures, behaviors, and vested interests, which can create inertia and pushback against efforts to shift towards more sustainable practices [41]. Multi-level governance adds an additional layer of complexity, as local, national, and international actors must coordinate efforts to deliver changes [20]. Nonetheless, while enablers for urban green transition have been explored, their interaction with policy frameworks must be substantiated to empower communities in succeeding urban green transitions [42].

1.3. Structure

After having framed the research (Section 1), Section 2 presents rationale and methods. Section 3 reports on the results of the literature review on 100 barriers to urban green transitions, which is instrumental to identify structural conditions, feedback loops, and system triggers via experts' consultation and network analysis. The discussions, explaining major policy implications and study's limitations, are provided in Section 4, while Section 5 concludes the study and opens up to possible future developments.

2. Materials and Methods

The approach presented integrates several methods, integrating two major research streams (desk research and experts' judgment) (Figure 1). The process implies five major steps. The first scoping literature review (SLR) allowed us to identify barriers against urban green transition and EGD implementation, which were then clustered into five domains. Then, a workshop with experts was organized to synthesize the findings. The results were assessed via computational network analysis, employing centrality measures and Causal Loop Diagrams (CLDs) to derive structural conditions hampering urban green transitions as well as feedback loops and system leverages. The outcomes will also inform a local policymakers' consultation of the challenges against EGD implementation at the EU urban level, as specified in Section 5.

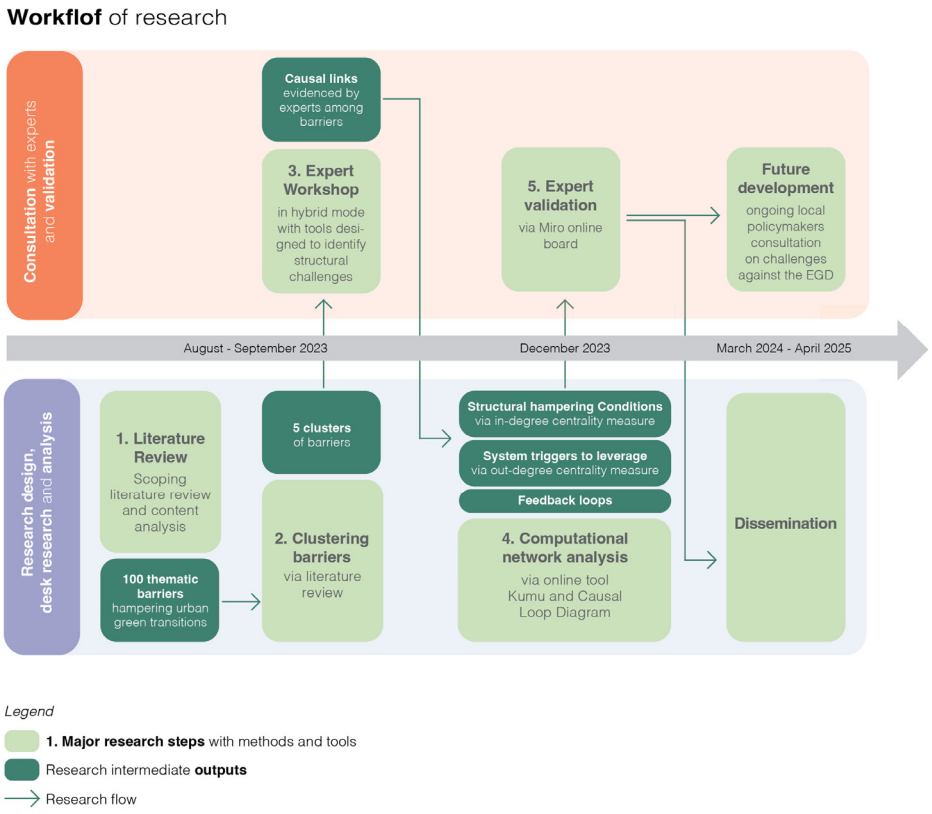


Figure 1. Research workflow with major steps and outcomes. Authors' elaboration.

2.1. Scoping Literature Review

A scoping literature review is defined as a type of knowledge synthesis used to identify and synthesize an existing or emerging body of literature on a given topic [43,44]. Since we were interested in identifying barriers against urban green transitions, we acknowledged that a scoping review would have been suitable to conduct in our study and explore the domain literature [45].

We designed two open strings of keywords and searched both Scopus and Google Scholar to acquire knowledge from academic and gray literature on urban green transitions and transformations. Given the ongoing debate on the opportunity to refer to either green/sustainability transition or transformation to point out changes needed to meet balance with natural capital [22], the investigation was broad to capture the most literature. The first String (S1), regarding urban green/sustainability transition studies, combined the following: "URB*" OR "CIT*" OR "URBAN ENVIRONMENT" AND "SUSTAINAB* TRANSITION*" OR "GREEN TRANSITION*". The second String (S2), regarding urban green/sustainability transformation studies, combines: "URB*" OR "CIT*" OR "URBAN

ENVIRONMENT" AND "SUSTAINAB* TRANSFORMATION" OR "GREEN TRANSFORMATION*". The search ended on 31 August 2023. The selection was restricted to Open Access and English papers only, published from 2015 to 2023. After downloading the results and managing them in a spreadsheet, duplicates were removed. Items were selected according to their alignment to their alignment to the aim of this manuscript, after reading the titles and abstracts. They were finally imported and analyzed via Mendeley Desktop and spreadsheet.

Reports on the European Green Deal

The SLR was complemented by the report "The future of the Green Deal: taking stock and looking ahead" [9], specifically tackling barriers in implementing the EGD from some EU cities and regions. Two authors of this manuscript (M.T. and L.M.) contributed to the analysis of results of such consultation. In fact, the opinions of LRA were gathered under a CoR initiative via the RegHub network, which aims at collecting data on policy implementation experiences from LRAs to make EU institutions benefit from these inputs. The survey comprises 89 questions, mostly combining multiple choices answers and open boxes to let LRA stakeholders have their say on eight major topics (climate adaptation, clean energy production, efficient buildings, sustainable transport, biodiversity protection, sustainable food, pollution reduction, and circular economy). In total, 20 responses were received, coming from different cities, provinces, and regions of the EU-27 and representing 16% of the EU-27 population. In addition, the analysis was enriched by the follow-up report "Regions and cities shaping the European Green Deal 2.0" by the CoR [10], which focuses on identifying barriers to implementation at the regional and local levels across the EGD TAs.

2.2. Clustering Barriers

Barriers are multifaceted obstacles to transformations that must take place to deliver the green transition in EU cities. Barriers to system transition can manifest in various forms and across different policy domains, as they are complex, interrelated, and diverse [36]. However, identifying clusters of barriers can support understanding these obstacles better and finally orient policy action to effectively address them. After having analyzed the results and grounding on system transition literature, barriers to urban green transition have been clustered into five categories:

1. Economic/Financial Barriers relate to the costs, investments, and funding necessary to support the transition. These include inability to access funding [46,47] and high upfront costs for technological innovations [48], uncertainty regarding long-term returns on investment [49], and expenses tied to established design projects and technologies.
2. Socio-Cultural/Behavioral barriers encompass societal norms, values, attitudes, and individual behaviors that influence the acceptance and implementation of sustainable policies [50–53]. These barriers include resistance to change [47], divergent understanding among stakeholders, and cognitive biases that hinder pro-environmental behavior [26,54].
3. Knowledge/Operational barriers pertain to deficits in information accessibility for policy implementation. These include inadequate education, training, and awareness programs [55,56], unreliable or asymmetrical information [57,58], and communication challenges in translating scientific evidence into actionable knowledge [12,26,59,60] and dissemination [61].
4. Technological/Infrastructural barriers reflect limitations in available technologies and supporting infrastructure. These might include a lack of technological advancement

and maturity, insufficient research and innovation [62], and infrastructural lock-ins that reinforce existing industrial networks and delay the adoption of cleaner technologies [20].

5. Political/Institutional barriers stem from multi-level governance challenges [7], policy fragmentation [63] and policy framework rigidity or instability [10] that hinder progress towards the EGD.

One should consider that categories are not mutually exclusive, as barriers can be interrelated and associated with more than one category. However, for clarity purpose, we have attributed each barrier to a unique cluster.

2.3. Experts Workshop

To identify "overarching" structural conditions hampering urban green transitions, an expert workshop was held at Politecnico di Torino on 28 September 2023. Nineteen participants, including academics and science-for-policy experts from the European Commission, contributed to the workshop, bringing diverse expertise on the urban green transition. The workshop was conducted in a hybrid format to maximize participation, with in-person activities using printed cards and A0-format poster, and online contributions facilitated by a moderator via Zoom and a Miro board (Figure 2). Specifically, the cards were colored according to the barriers' clusters. The A0 poster consisted of a three-level order wheel, allowing for detecting first-, second-, and third-order barriers. In addition, wild cards were provided to let the participants eventually add issues.

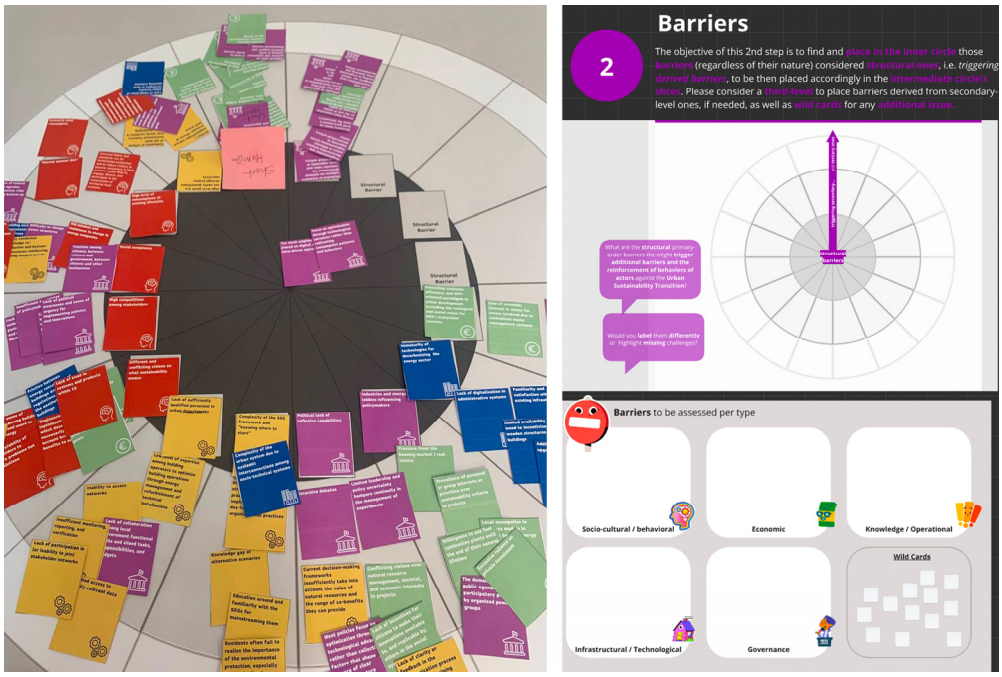


Figure 2. Identifying structural challenges during the expert workshop. Printed A0 poster to place barriers to highlight interconnections on three-level order effects (left); equivalent poster on the Miro board (right). Authors' elaboration.

Participants were asked to identify connections among barriers, i.e., which barriers trigger others, finally placing those "receiving" most connections in the inner circle of the poster. The results fed into the computational analysis described in the following subsection and further validated by experts at a later stage.

2.4. Computational Network Analysis

The identification of the structural conditions grounded on a mixed-method approach, either qualitative (based on the interconnections highlighted during the workshop) and quantitative (via centrality measures based on delineated interconnections). Specifically, to analyze the causal relationships identified during the workshop, a systematic computational methodology was employed to construct a CLD by combining the online tool Kumu (Online, available at: https://kumu.io (accessed on 17 April 2025), Large Language Model (ChatGPT-o4), and Python 3.12 embedded. The relationships between barriers retrieved from the workshop were encoded in a structured dataset in Microsoft Excel, with a 'From' column representing the causal source and a 'To' column representing the target. This dataset was processed to quantify the structural importance of each barrier within the network, leveraging key centrality measures commonly used in network analysis. To further validate findings and ensure robustness, the results of the computational analysis were validated through feedback by experts involved in the workshop. Experts endorsed visual representations of systemic interconnections.

Identifying Structural Hampering Conditions, Leverages, and Feedback Loops

The identification of structural conditions was based on an in-degree centrality analysis, a computational method used to determine the influence of a node within a network by measuring the number of incoming connections it receives from other nodes. This measure identifies barriers that act as major recipients of causal influence, i.e., structural conditions.

Out-degree centrality was computed to assess the number of outgoing connections from each node, representing the extent to which a barrier impacts others (i.e., from which most of the arrows originated in the CLD). High out-degree values indicate that these barriers act as system "triggers", influencing multiple downstream challenges and potentially amplifying systemic inertia.

Barrier interconnections often manifest as feedback loops, i.e., systemic structures in which the outputs of processes or actions feed back into the system as inputs, either reinforcing the initial dynamic (positive feedback) or counteracting it (negative) [64]. Therefore, we also present major feedback loops identified by Kumu in the CLD in the results.

3. Results

The results are presented according to the research steps recalled in Section 2. [Appendix A] Specifically, the descriptive analysis stemming from the SLR is shown in Section 3.1, with barriers synthetized and presented per cluster and with respect to the EGD major policy initiatives in Section 3.2. In addition, the results of centrality measures to derive structural hampering conditions and system leverages are shown in Section 3.3.

3.1. Descriptive Analysis

In Scopus, we retrieved 201 items from S1 and 217 from S2 (Table 1) with a rising interest by scholars over time on urban transition/transformation research domain (Figure 3). We assume 'transition' and 'transformation' of urban socio-technical systems are used interchangeably. However, 'transition studies' are mostly funded by EU research programs (e.g., Horizon) and EU Member States' research institutions, while China's research institutions top the chart of countries from which urban transformation studies mostly come from (Figure 4). In both cases, environmental science studies top the charts in terms of share of research fields, despite social science being more prominent in 'transition' studies than in 'transformation' related ones. As a result, 55 items were considered from S1 in Scopus, while 13 items were derived from S2 in Scopus. Moreover, seven additional papers were retrieved from Google Scholar. Finally, 75 papers constitute the basis of the analysis of this

paper, complemented by the reports as detailed in Section 2.1. The papers were selected according to their relevance with respect to the EGD TAs and major policies involving EU cities for implementation, after reading the titles, abstracts, and keywords.

Table 1. Search string output.

Search String	Number of Papers in Scopus	Selecter Papers in Scopus	Number of Papers in Scholar	Selected Papers in Scholar
"urb*" OR "cit*" OR "built environment*" AND "green transition*" OR "sustainable transition*"	205	72	440	36
"urb*" OR "cit*" OR "urban environment*" AND "sustainability transformation*" OR "sustainabl* transformation*" OR "green transformation*"	217	27	340	17

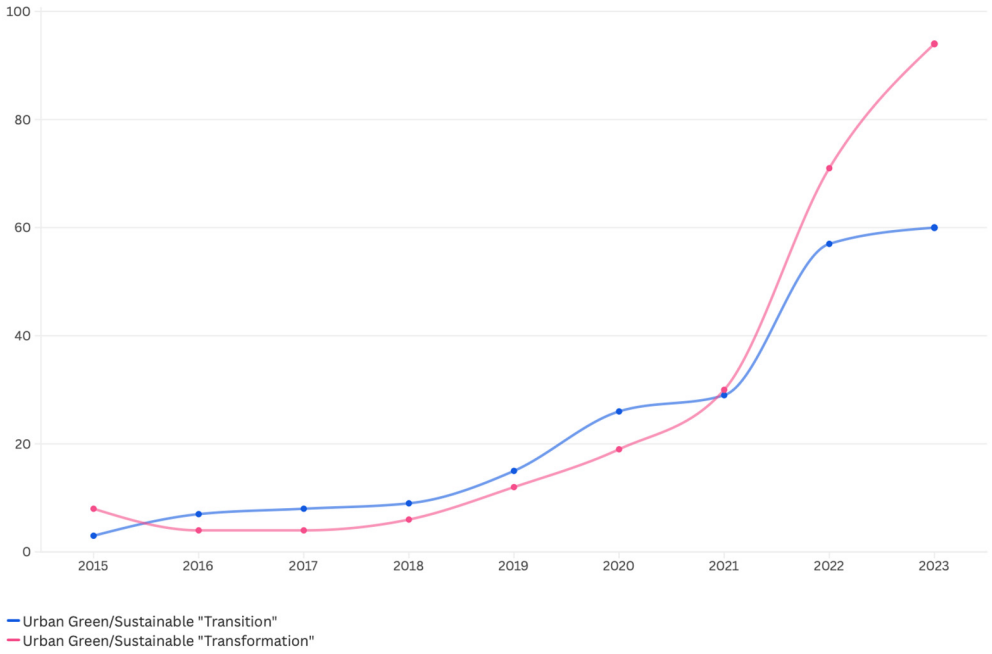


Figure 3. Evolution over time of urban transition- and urban transformation-related studies. Data based on Scopus, elaborated by the authors via Flourish (https://app.flourish.studio/).

3.2. Barriers to Urban Green Transitions

A total of 100 barriers were identified by synthesizing the knowledge gained by the SLR and complementary sources (see Appendix A). The results show that most of the retrieved barriers are of a political-institutional nature (around 30%), followed by socio-cultural, knowledge-operational, and financial-economic (around 20% each), and technological-infrastructural (around 10%).

Considering the definition of urban green transition as a systemic, multidimensional, and collaborative process needing orchestrations of actors [15], the identified barriers suggest the presence of deeply rooted structures and vested interests [41] that preserve the status quo [65] and constrain cities' abilities to lead the EGD implementation [6].

Furthermore, path dependency offers a crucial lens for understanding the persistence of barriers against urban green transitions, highlighting how past decisions continue to shape current practices and limit future options [25], being embedded within historical trajectories of urban development, governance structures, and socio-technical systems.

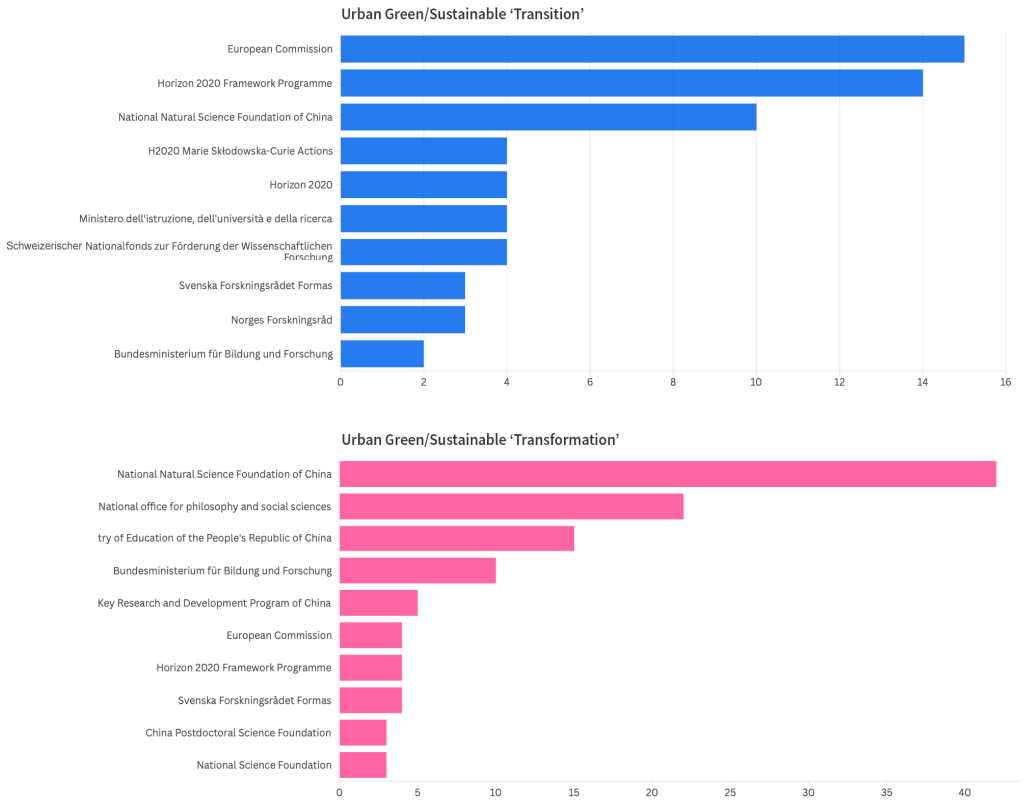


Figure 4. Funding institutions for transition-related studies (above) and transformation-related studies (below). Data based on Scopus, elaborated by the authors via Flourish (https://app.flourish.studio/).

Grounding on the classification proposed, **socio-cultural barriers** represent foundational obstacles to systemic transformation, as they influence individual and collective norms, values, and behaviors. A lack of awareness among citizens and an insufficient sense of urgency [14,66] highlight a critical gap in mobilizing public support for the green transition. The persistence of high-consumption lifestyles, resistance to change, and cognitive lock-ins among stakeholders [67,68] further exacerbate this challenge. The observed mistrust and competition among stakeholders [65,69,70] also reveal a fragmented socio-cultural landscape, which undermines collaboration and hinders the co-creation of innovative solutions. The engineering mindset, focused on optimization rather than systemic benefits [65], reinforces narrow approaches that neglect broader societal impacts.

Knowledge—operational barriers underscore the importance of addressing information gaps, capacity deficits, and inefficiencies in decision-making processes. Specifically, limited familiarity with concepts such as the SDGs and circular economy [71,72] indicates a significant challenge in mainstreaming sustainability frameworks. The inability to translate strategic visions into actionable plans [73] reflects a broader issue of misalignment between high-level goals and local implementation capacities and priorities, reinforcing the need for securing policy coherence and multi-level governance mechanism as a major enabler of the EU green transition. The lack of locally relevant data and insufficient monitoring and reporting mechanisms [9,14] further hinder evidence-based policymaking and adaptive learning processes, which are critical to urban green transition efforts [15] and life cycle

approaches in the building sector [74]. Moreover, poorly conducted bottom-up processes and knowledge co-production [75,76] reinforce existing power asymmetries, reducing the inclusivity and effectiveness of participatory approaches. These barriers align closely with institutional challenges, particularly in their impact on governance structures and stakeholder collaboration.

Political—institutional barriers are particularly significant in shaping the capacity for systemic change. Fragmentation among local government units, siloed responsibilities, and misaligned goals across governance levels [10,14,19] reflect structural weaknesses in urban governance frameworks. The lack of clear governance structures for sustainability transitions [77] exacerbates these challenges, leading to inefficiencies and conflicts among stakeholders. Over-reliance on national governments for regulatory guidance and the absence of reflexive political capabilities [69] further limit the potential for cities to act as agents of change [15]. The dominance of short-term political cycles and vested interests [78,79] reinforces policy inertia, preventing the adoption of innovative and transformative solutions. Finally, it has been evidenced that a highly centralized governance structure might limit cities' room for manoeuvering and the capability to deliver the green transition [80].

Financial—economic barriers often consist of high upfront costs, limited access to funding, and the prevalence of short-term economic paradigms [66,81] which demonstrate the difficulty of aligning financial systems with long-term sustainability goals. The "projectification" of funding, which prioritizes short-term initiatives over sustained investments [82], undermines the continuity and scalability of transition efforts. Competing priorities between social, environmental, and economic objectives [9,73] often lead to trade-offs that might hinder the EGD. The dominance of GDP-oriented development paradigms [65] further marginalizes ecological and social values, reflecting a misalignment between economic structures and the broader objectives of the EGD.

Technological—infrastructural barriers underscore the underlying challenges associated with transitioning physically built environments to carbon neutrality. The immaturity of technologies for decarbonization, coupled with the complexity of urban systems and their interconnections [83], highlights the need for targeted investments in research, innovation, and infrastructure development. Building sector fragmentation [74] and regulatory hurdles [66] further complicate efforts to implement sustainable practices in urban environments. The reliance on existing infrastructures, fostered by path dependency, and the lack of integration of strategies such as urban forestry in local planning schemes [73] reflect entrenched socio-technical regimes that resist change.

Barriers to Localizing the European Green Deal

The targets outlined in the EGD framework involving cities [1] reflect a broad and ambitious 'call to action' for cities to implement policies in all TAs. Granular barriers are often closely tied to specific targets and policies. For instance, implementation gaps outlined in Marelli et al. [4], recalled from the work by Ulpiani and Vetters [14], outline several barriers to the mainstreaming of climate mitigation policies in cities involved in the 100 Climate Neutral and Smart Cities Mission. A key barrier is the lack of long-term political commitment and strategic planning, where misalignment between local and national policies, short-term political cycles, and insufficient public engagement undermine sustained action. On a regulatory level, unstable or unambitious policies create uncertainty for investors, while local governments often lack the fiscal and legislative autonomy needed to enact impactful measures [9].

Path dependencies in infrastructure, combined with financial constraints and regulatory rigidity, might create lock-in effects that prevent cities from adapting urban spaces to

low-carbon models. This is particularly relevant for the building sector, where the persistence of GDP-oriented urban planning paradigms might slow renovation rates envisaged by some of the most significant EGD initiatives (e.g., *Renovation Wave*, *Renewable Energy Directive III*, and *Energy Performance of Buildings*), impeding the diffusion of energy efficiency measures and green infrastructure, especially in historic buildings [84]. Similar challenges have been observed in previous studies on urban retrofitting, where policy fragmentation and the absence of dedicated financial mechanisms were found to hinder large-scale transformation [80] and wider technological upgrade [74]. These challenges, often hindered by over-bureaucracy [66], finally result in insufficient policy implementation, as outdated infrastructures create logistical and financial barriers to policy execution.

From an operational perspective, departmental silos within city administrations, inefficient data collection, and slow procurement processes hinder the ability to coordinate complex climate initiatives. EGD energy efficiency and building renovation targets might be hindered by technological and operational barriers, including a lack of statutory requirements for energy performance, fragmented building sectors, and complex permit procedures. Cross-border cooperation, vital for integrated energy systems, is insufficiently recognized, limiting resource and knowledge sharing in turn [7]. Energy poverty affects 30 million EU citizens, and cities lack adequate frameworks at MS and sub-national levels to combat this phenomenon or empower energy prosumers. A critical gap lies in integrating energy goals with urban spatial planning. Misaligned infrastructure development and building retrofitting initiatives might reduce the effectiveness of local interventions. Additionally, public procurement policies also play a crucial role in driving the energy transition, yet the potential of green and circular procurement practices remains underutilized at the city level [9]. The insufficient recognition of the potential of soil to mitigate the GHG emissions while contributing to a zero-pollution dimension might specifically impede a toxic-free environment [7].

Similarly, circular economy ambitions from the CEAP (e.g., doubling the circular material use rate) [4] or recycling rates for packaging materials might be obstructed by gaps in knowledge and operational frameworks. Insufficient awareness of circular economy principles among stakeholders as well as centralized waste management systems might result in a lack of interest in products by circular processes. Insufficient use of circular public procurement might further hamper this policy area [7].

Knowledge and operational gaps are specifically impeding the biodiversity preservation at the subnational level, biodiversity mainstreaming, urban greening, and nature-based solutions fostered by the new Nature Restoration Law [4]. Cities frequently face limited access to quality data and insufficient guidance for designing and implementing effective measures, such as pollinator protection and urban green space planning. These gaps lead to operational inefficiencies, where urban initiatives fail to integrate the latest scientific knowledge or evidence-based methodologies, mirroring the challenges noted in knowledge and operational barriers like poor knowledge co-production and a lack of localized data [7,9]. Capacity-building deficiencies further compound these issues, with urban administrations often lacking the expertise to translate EGD targets into actionable local policies. This aligns with the identified barriers such as low levels of technical expertise among urban stakeholders and insufficient monitoring frameworks in this domain.

On the other hand, some barriers exhibit a more cross-cutting nature, transcending thematic boundaries and affecting multiple areas simultaneously. These barriers often relate to governance, socio-cultural inertia, and institutional fragmentation, which hinder the integration and coordination necessary for systemic change. For example, the lack of trust and collaboration among stakeholders, coupled with fragmented responsibilities within local government units, undermines efforts to address interconnected challenges like

reducing greenhouse gas emissions, promoting urban greening, and transitioning to zero-pollution systems. Climate ambition targets like reducing GHG emissions intersect with many energy efficiency goals, low-carbon mobility, and biodiversity preservation, requiring a coordinated approach to address shared barriers. Specifically, financing mechanisms for climate action in the context of the EGD remain insufficient and challenging to access [9].

3.3. Structural Conditions Hampering Urban Green Transitions

Based on Dorst and colleagues' work [19,65], who identified structural conditions against a wider nature-based solution uptake, structural conditions are defined as systemic, self-reinforcing mechanisms embedded within current socio-technical and institutional systems that perpetuate the status quo of urban development and hinder transformative change. These conditions are characterized by their interconnectedness and influence over multiple domains, creating feedback loops that amplify their effects and make them resistant to change. Thus, structural conditions can be understood as the underlying, often invisible architecture of constraints that determine the trajectory of urban socio-technical systems (Figure 5).

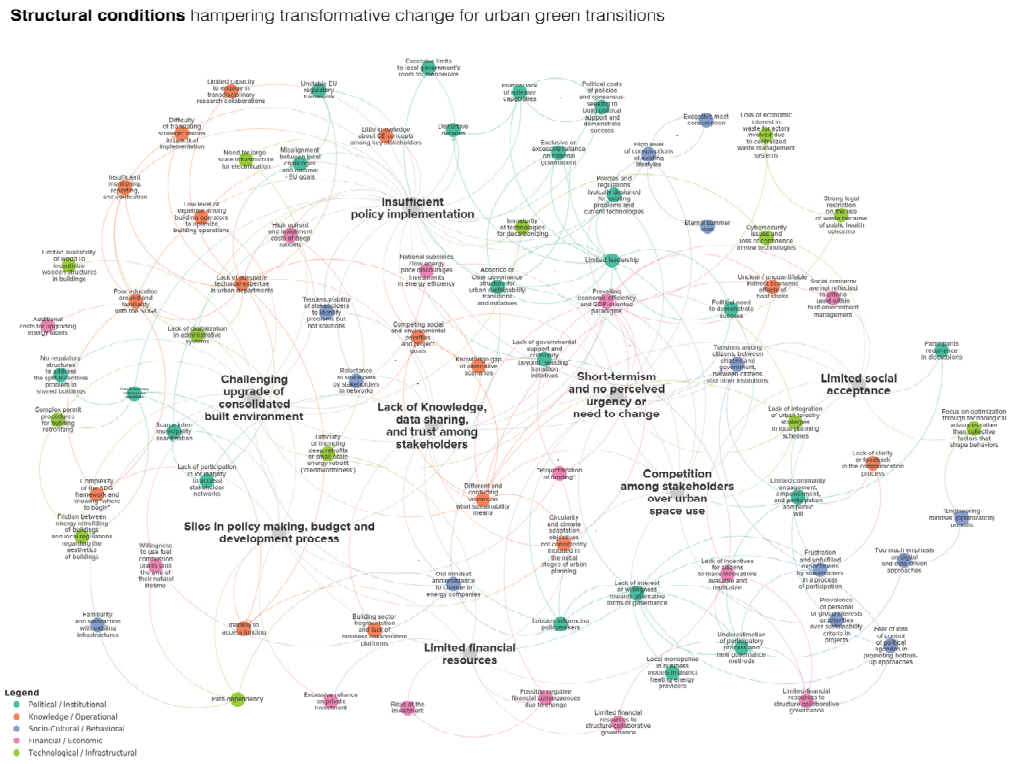


Figure 5. Relations between barriers, clusters of barriers, and emerging structural conditions (in gray), with reinforcing feedback loops ('+'). Authors' elaboration via www.kumu.io (accessed on 5 April 2025) and based on experts' feedback.

As reported in Table 2, the emerged structural conditions, ranked by their in-degree centrality, are insufficient policy implementation (29), challenging the upgrade of consolidated built environment layout (17), short-termism and no perceived urgency or need to change (13), lack of knowledge, data sharing, and trust among stakeholders (12), silos in policymaking, budget, and development processes (11), competition among stakeholders over urban space use (10), limited social acceptance (9), and limited financial resources (8).

Table 2. In-degree centrality measure to determine structural conditions. Author's elaboration via www.kumu.io and based on experts' feedback.

Rank	Label	Value
#1	Insufficient policy implementation	29
#2	Challenging upgrade of consolidated built environment layout	17
#3	Short-termism and no perceived urgency or need to change	13
#4	Lack of knowledge, data sharing, and trust among stakeholders	12
#5	Silos in policymaking, budget and development process	11
#6	Competition among stakeholders over urban space use	10
#7	Limited social acceptance	9
#8	Limited financial resources	8

System Triggers

High out-degree values were computed to possibly identify 'triggers', influencing multiple downstream challenges and potentially amplifying systemic inertia (Table 3). The barrier with the highest out-degree centrality is the lack of adequate technical expertise in urban departments (11). This barrier serves as a foundational impediment according to workshop participants, influencing a wide range of issues such as insufficient policy implementation, fragmented knowledge-sharing, and limited capacity for innovation in urban sustainability. For example, without adequate expertise, urban departments might struggle to implement advanced energy-efficient technologies, decarbonization strategies, or nature-based solutions, which in turn might reinforce other barriers like limited financial resources and competition over urban space use. This highlights the cascading effects of addressing—or failing to address—technical expertise within local administrations.

Table 3. Out-degree centrality measure to determine "triggers". Author's elaboration via www.kumu.io and based on experts' feedback.

Rank	Label	Value
#1	Lack of adequate technical expertise in urban departments	11
#2	Limited leadership	10
#3	Prevailing economic efficiency and GDP-oriented paradigms	10
#4	Different and conflicting visions on what sustainability means	9
#5	Over-bureaucracy and excessive regulations	6
#6	Lobbies influencing policymakers	6
#7	Underestimation of participatory process and new governance methods	5
#8	Lack of interest or willingness towards alternative forms of governance	5
#9	Absence of clear governance structure for urban sustainability transitions and initiatives	5

Limited leadership (10) emerges as another critical barrier, exerting influence across the network by perpetuating fragmented decision-making, lack of strategic vision, and insufficient prioritization of sustainability transitions. Weak leadership might exacerbate barriers such as short-termism and the underestimation of participatory governance methods, as decision-makers fail to champion innovative, inclusive, and long-term approaches.

The prevailing economic efficiency and GDP-oriented paradigms (10) similarly hold a pivotal role in shaping systemic resistance. This barrier prioritizes short-term economic gains over long-term sustainability goals, influencing a wide array of challenges such as limited social acceptance, insufficient policy implementation, and competition among stakeholders potentially. For example, the continued emphasis on economic growth metrics might discourage investments in green infrastructure or circular economy practices, reinforcing structural inertia and undermining the transformative potential of urban green transitions.

Different and conflicting visions on what sustainability and green transition means (9) represent another highly influential barrier according to workshop participants. This misalignment among stakeholders creates tensions that hinder collaborative governance and exacerbate siloed policymaking. Conflicting interpretations of sustainability objectives lead to fragmented efforts and prevent the development of cohesive strategies, feeding into barriers such as competition over urban space use and lack of trust among stakeholders. Other barriers, such as over-bureaucracy and excessive regulations (6), lobbies influencing policymakers (6), and underestimation of participatory processes and new governance methods (5), also demonstrate significant out-degree centrality.

4. Discussions

The methodological approach, integrating the literature review with experts' opinions and network analysis, allows for a deeper understanding of challenges underlying urban green transitions. This study contributes to the growing body of research on urban sustainability transitions [85,86], seen as "processes of societal change and innovation with multiple causes, drivers and dynamics" ([87], p. 2) by systematically assessing the barriers hampering the transition. In fact, the transition towards sustainability might be constrained by a variety of interrelated issues based on dispersed knowledge that should be addressed by policymakers and other actors [88,89]. In a transition process, policymakers are called to orchestrate and facilitate interaction among actors, discussions, learning, foresight, and information exchange [20]. Therefore, knowledge on how barriers prevent these processes from happening could be seen as instrumental for policymakers to leveraging elements and dismantle system inertia.

This study provides a first systematization of these barriers and, as an added value, explores at the interface between barriers, enablers, and policy, being potentially instrumental to illuminate the mechanisms by which policy deliver change in socio-technical systems [90] and shape governance processes enabling the transition [91]. Previous studies also called for improved understanding of mechanisms framing urban sustainability transitions beyond domain-oriented approaches and under the EGD [1,29]. Research by Ulpiani and colleagues on the 100 Climate Neutral Cities' Mission highlighted possible risks for cities involved in the mission journey. However, the present study opens to reflections beyond mitigation targets, encompassing the climate and environmental policy mix paradigm envisaged by the EGD policy initiative [4,5].

The descriptive analysis by the SLR reveals that the topic has been gaining momentum, especially after 2021 for what concern both the urban 'transition' and 'transformation' domains. This seems to align with the EGD mainstreaming phase [92] (Borchardt et al., 2025—forthcoming) and entry into force of its major pieces of legislations, among which the 'Climate Law' and following 'Fit for 55' package emerge as cornerstones. Furthermore, the 2021 call for 100 climate neutral and smart cities by 2030—coupled with Horizon work program 2021-2022 for financing research on European Commissions' Missions (Online, available at: https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-12-missions_horizon-2021-2022_en.pdf (accessed in 7 February 2025))—might have had an impact. This seems to be also confirmed by major

programs supporting urban green transition and transformation studies, with several institutions in the EU topping the chart of research funders. Finally, the new European Bauhaus initiative was launched in 2021 as "an enabler for the green transition of our societies and economy" [93], giving guidance on how "transformative" projects should be implemented.

The identification of eight structural conditions and the mapping of high-out-degree barriers as system triggers provide an analytical lens through which urban policymakers can better understand the mechanisms constraining transformative change. This section critically discusses lessons learnt from the process, key findings' broader implications for policymakers, and research limits.

4.1. Lessons Learnt

First, the findings emphasize the need for interventions that simultaneously target multiple barriers, recognizing their interdependence, rather than relying on piecemeal solutions that fail to address root causes. Urban green transitions imply undertaking a system approach, as transformations of socio-technical systems embedded in urban environments and involved actors interact with each other. Barriers function as nodes within a tightly interwoven network where their interactions amplify or inhibit transformative potential. This means that tackling a barrier might have effects, either reinforcing or mitigation, against others in a cascading effect which should be taken into consideration and monitored. However, overcoming multi-faceted challenges is grounded on the orchestration of actors and intents as well as political will.

As a second take-home message, the results indicate that the most influential structural condition is insufficient policy implementation, which has the highest in-degree centrality and might be intricately tied to nearly every other condition. This finding suggests that despite the existence of ambitious EGD policy frameworks, their execution at the local level might remain fragmented and ineffective. Such inertia is closely linked to short-termism, lack of strategic planning, and limited multi-level governance coordination. This reflects a persistent issue in urban transitions, where cities often act as implementers rather than agenda setters [7,94] constrained by national regulations, fiscal limitations, and political cycles that prioritize short-term success [78].

As a third element, the underestimation of knowledge-sharing mechanisms, which directly influences policy inefficiencies. The study finds that inadequate data-sharing practices and a lack of technical expertise in urban departments might act as significant opponent to change, reinforcing governance silos and delaying policy implementation. The interplay between lack of knowledge, data sharing, and trust among stakeholders and other structural conditions further highlights their mutual reinforcement. Poor knowledge-sharing mechanisms reduce the ability to build consensus and align efforts across diverse actors, which is essential for overcoming silos in policymaking and improving policy implementation.

Finally, silos in policymaking might further exacerbate implementation challenges by fragmenting efforts across departments and budgets, limiting coordination and integrated approaches necessary for effective urban transitions. Short-termism and no perceived urgency or need to change play a pivotal role in sustaining the inertia of other structural conditions and confirm the capital role of behavioral insights in delivering the green transition [95]. This condition is directly connected to limited social acceptance, confirming that the absence of long-term vision often undermines efforts to build public trust and support for transformative initiatives like the EGD [92] (Borchardt et al., 2025—forthcoming). The resulting lack of social acceptance, in turn, might diminish stakeholder engagement, reinforcing competition over urban space use, where immediate economic interests might be

prioritized over long-term environmental objectives. Horizontal urban departments could facilitate and orchestrate actors; EU-national-dedicated transition funding programs could also favor the adoption of a more holistic view in the envisaged transition beyond projects and sectoral approaches.

4.2. Leverage Points for System Transformation

Dismantling the identified structural conditions requires interventions at critical nodes. High-out-degree barriers, such as the lack of adequate technical expertise in urban departments or limited leadership, are not just contributors to systemic inertia but also critical leverage points. Addressing these barriers might offer concrete opportunities to create cascading positive effects across the system, disrupting entrenched pathways and fostering conditions for transformative change. For example, while prevailing economic efficiency and GDP-oriented paradigms shape decisions across the network, they also reinforce other barriers, such as competition over urban space use, revealing that systemic resistance often stems from deep-seated socio-cultural and institutional norms.

Barrier interconnections often manifest as feedback loops, systemic structures in which the outputs of processes or actions feed back into the system as inputs, either reinforcing the initial dynamic (positive feedback) or counteracting it (negative) [64]. As such, they might form lock-ins that reinforce systemic inertia. The role of feedback loops further emphasizes the systemic nature of transition-related challenges. For instance, the relationship between excessive reliance on national governments for governance and policymaking, limited leadership, and the absence of clear governance structures for urban sustainability transitions exemplifies a reinforcing feedback loop in the CLD based on experts' inputs. A dependency on national governments might undermine local leadership initiatives, which in turn might perpetuate the lack of a clear governance framework, reinforcing the initial reliance on centralized control. Such loops illustrate how systemic conditions can self-reinforce, trapping cities in a cycle of inaction and incremental change hampering the urban green transition and EGD achievement. Identifying and intervening in these loops is of primary importance for dismantling structural challenges and fostering systemic transformation.

4.3. Policy Implications

The findings have several implications for EU- and urban-level policymaking, which are recalled as outlined below.

i **Leveraging system triggers**. Addressing nodes with high systemic influence (i.e., those from which the most causal relationships emanate and have the greatest potential to disrupt reinforcing hampering mechanisms) could constitute strategic areas of intervention for policymaking. Cities frequently lack the specialized knowledge required to navigate complex sustainability policies, apply for EU funding, and implement innovative climate strategies. Many sustainability trade-offs stem from the fact that urban planning and investment decisions remain primarily driven by short-term economic efficiency metrics mostly due to knowledge gaps of alternative scenarios. This paradigm reinforces spatial competition and limits experimentation with circular and regenerative economies. Consequently, the following are noted:

- Addressing highlighted knowledge gap through dedicated capacity-building programs, knowledge-sharing, and urban policy learning networks could act as a systemic enabler, improving governance efficiency and enhancing cities' abilities to formulate and execute long-term transition plans.
- Investing in urban leadership development, peer-learning initiatives among cities, and governance innovation models (e.g., urban climate assemblies) could coun-

teract the reinforcing feedback loop that perpetuates centralized control and governance fragmentation.

- Policy interventions should focus on expanding urban economic performance indicators beyond GDP to incorporate climate resilience, well-being, and ecosystem services into urban decision-making frameworks to capture broader sustainability dimensions envisaged by the EGD [96]. In addition, such complementary beyond-GDP metrics could be reflected in EU funding opportunities and financing schemes.

ii **Enhancing Policy Coherence**. Many urban sustainability initiatives suffer from piecemeal funding that lacks continuity. Establishing clearer links between EGD objectives, national funding schemes, local priorities, and budgets would improve cities' ability to secure stable, multi-year financing. This could be achieved by mainstreaming EGD targets into regional and urban development plans and local agenda setting, reducing reliance on fragmented, project-based grants and ensuring better access to fundings.

iii **Allow for experimentation, replicability, and scaling up**. Urban experimentation has emerged as a key strategy in the literature review for advancing the green transition, with Urban Living Labs and small-scale pilot projects serving as critical testbeds for innovation [97,98]. These initiatives enable cities to trial innovative solutions in controlled settings, addressing local challenges while generating knowledge transferred to broader settings. However, urban experimentation in projects and processes should be embedded within innovative governance structures [15] to facilitate scaling up beyond niches. Experimentation alone is insufficient unless mechanisms for institutional learning, policy integration, and financial support are in place. This implies the support of the following:

  – Adaptive and iterative monitoring exercises to assess how pilots align with and contribute to systemic sustainability transition goals [99].
  – Institutionalized reflexivity in governance [100] that allow cities to dynamically refine strategies based on real-world feedback.
  – Embedding experimentation outcomes into formal policymaking processes [31,101], ensuring that successful solutions transition from temporary pilots to the innovation of law, governance and technology [102].
  – Enhancing local strategic autonomy [10], since cities serve as hubs of innovation [103], but their ability to scale up and replicate successful transition models might also depend on how urban-level experiments are connected to the EU policymaking level. Initiatives like the EU Mission for 100 Climate-Neutral and Smart Cities have proven how direct EU-city engagement benefits the engagement with social parties in co-creation process. Similar initiative for localizing the EGD, beyond a solely GHG emission-related paradigm, could enhance cities' potential towards broader natural capital preservation in the EU and enhance experimentation.

4.4. Limitations

The approach adopted, integrating methods and tools from various domains, constitutes an additional element of novelty of this study, which could be replicated by future research by testing it in real-world settings (see Section 5). However, it faces limitations. First, it should be clearly highlighted that findings are not intended to be as fully exhaustive and that the emerging structural conditions depend on the interconnections qualitatively detected by experts. Therefore, they must not be considered valid in all contexts, as some of these barriers or causal connections might not be necessarily true per se or additional challenges could emerge. Different regional power distribution and governance structures

might determine challenges. First and foremost, this exercise aims at raising awareness about complex system dynamics characterizing the transition envisaged by the EGD at the urban level and connections among identified barriers, enablers, and policies.

Second, computational analysis has limits as well. While network-based methods such as out-degree centrality and feedback loop identification are powerful tools for highlighting systemic relationships and leverage points, they rely on the assumptions embedded in the input data, which was driven by experts' judgment and the qualitative connections pointed out. In this regard, the analysis does not encompass measures of strength of interconnections among nodes (the barriers) as well as possible mitigating effects (i.e., barriers can not only reinforce but also potentially counteract each other). Third, the SLR cannot be intended as a comprehensive literature screening by design; therefore, it should not be intended as fully exhaustive. Conversely, it was instrumental to equip the workshop with experts for the identification of highlighted structural hampering conditions. As such, this analysis can be understood as a first theoretical exercise but should pave the way for further explorations in specific applicative contexts. For instance, the study by Dorst et al. (2022) [65], which investigated structural in different contexts and found varying results concerning the uptake of NBS in several member states, highlights the importance of adapting systemic analyses to local circumstances.

5. Conclusions

This study provides a systemic assessment of barriers to urban green transitions, identifying structural conditions that reinforce system inertia and hinder the local implementation of the European Green Deal. By integrating a scoping literature review, expert consultation, and computational network analysis into this study, the findings revealed how governance fragmentation, financial constraints, socio-cultural patterns, and knowledge gaps contribute to systemic inertia in urban sustainability policies. This study further identifies high-out-degree barriers as key leverage points, where targeted interventions could disrupt reinforcing feedback loops and unlock transformative change. It advances the field of urban sustainability transitions by moving beyond the identification of individual policy barriers toward a systemic understanding of structural conditions and leverage points.

In the upcoming research by the authors, these findings will be subjected to validation by EU local policymakers dealing with the EGD implementation through online consultation. In terms of future research development, we envisage diverse possibilities. First, the research might engage in complementing these findings with quantitative empirical validation, possibly using longitudinal data, case study comparisons, and real-world policy evaluations to test the impact of identified barriers and triggers on urban sustainability transitions. Second, conducting real-world sessions with stakeholders could test the replicability of the approach while strengthening the place-based dimension of the EU sustainability transition, in light of context-specific values, governance settings, and power structures. This could eventually lead to the co-identification and co-creation of specific solutions to transform systems via shared understanding. Furthermore, testing with different actors could allow for overcoming most of the highlighted limits. Third, understanding feed-back loop mechanisms and how barriers reinforce or mitigate each other should deserve attention in future applications.

By deepening and contextualizing this analysis, policymakers and practitioners might develop targeted interventions that address systemic barriers while catalyzing transformative change. This iterative process will be critical to overcoming systemic inertia and accelerating urban green transitions, in line with the EGD program.

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Appendix A

Table A1. Detail barriers retrieved from the scoping literature review.

Cluster	Barriers	Reference
Socio-cultural/ Behavioral	Different and conflicting visions on what sustainability means	[104]
	Actors' own cognitive lock-in (no perceived need for transition)	[67]
	Lack of trust and collaboration among stakeholders and/or incumbent/entrant actors	[70,83,105]
	High level of consumption of existing lifestyles	[105]
	Lack of trust in systems and products within CE	[105]
	"Universal labels and standards can de-territorialize production and to reduce citizens to passive consumers in food systems"	[75]
	"Eternal summer diet"	[68]
	Excessive meat consumption	[68]
	Lack of sense of urgency among building owners and users to save energy	[66]
	Frustration and unfulfilled expectations by stakeholders in a participation process of participation	[106]
	"Participants recurrence in discussions might limit democratization of sustainability transition agendas, motivation, innovative solutions, resource mobilization"	[106,107]
	Emotions and negative effects of negotiation processes	[106]
	Tendency/ability of stakeholders to identify problems but not solutions	[106]
	"Lack of path dependence, i.e., active memory determined by past decisions having influence on future decision-making, leading to repeat errors again and again"	[108]
	'Engineering mindset' (optimization) prevails which does not necessarily take into account broader benefits to society	[65]
	Reluctance to share data by stakeholders in networks	[9,109]
	Lack of trust and collaboration in stakeholder networks	[14]
	High competitions among stakeholders	[69]
	"Old mindset and resistance to change in energy companies"	[83]
	Social acceptance	[83]
	Insufficient awareness of citizens	[9,14]
Knowledge/ Operational	Education around and familiarity with the SDGs for mainstreaming them	[71]
	Complexity of the SDG framework and "knowing where to start"	[1,71]
	Limited access to locally relevant data	[71,110]
	High level goals are not easily quantifiable through project objectives	[111]
	Unclear/unquantifiable indirect economic effects of heat stress	[111]
	"Evaluation of effects of the built environment features over social variables is highly challenging"	[111]

Table A1. *Cont.*

Cluster	Barriers	Reference
Knowledge/ Operational	Social concerns are not reflected in criteria used within built environment management	[111]
	"Circularity and climate adaptation objectives not consistently included in the initial stages of urban planning"	[111]
	Little knowledge about CE concepts among key stakeholders	[72,105]
	"Poorly conducted knowledge co-production and bottom-up processes reinforcing existing unequal power"	[76]
	"Low level of expertise among building operators to optimize building operations through energy management and refurbishment of technical installations"	[66]
	"Lack of clarity or feedback in the communication process further undermining motivation to engage"	[106]
	"Lack of participation in (or inability to join) stakeholder networks"	[19,69,112]
	"Knowledge gap of alternative scenarios"	[81]
	Limited capacity to engage in transdisciplinary research collaborations	[69]
	Decision-making frameworks insufficiently consider the value of natural resources and co-benefits they can provide	[19]
	Difficulty of translating strategic visions to practical implementation	[73]
	"Residents often fail to realize the importance of the environmental protection, especially in marginalized areas"	[113]
	Lack of sufficiently qualified personnel in urban departments	[9,14]
	Insufficient monitoring, reporting, and verification	[9,14]
Political/ Institutional	Fear of loss of control of political agendas and/or reputation risks in promoting bottom-up approaches	[114]
	Lack of collaboration among local government functional units and siloed tasks, responsibilities, and budgets	[9,14,19,73,108, 111,114]
	Too much emphasis placed on digital and data-driven approaches	[115]
	Incremental focus on optimization through technological advances rather than consumption patterns and behaviours	[115,116]
	Lack of interest or underestimation for participatory process and new governance methods	
	Lack of interest in CE	[105]
	Exclusive or excessive reliance on national government for concrete rules and laws, especially in centralized unitary states	[82,105]
	Uncertain and changing regulatory framework	[9,14,83,105]
	Strong legal restriction on the use of waste because of public health concerns (e.g., food waste)	[72]
	Absence of clear governance structure for urban sustainability transitions and initiatives	[69,77]
	Tensions among citizens, between citizens and government, between citizens and other institutions	[69,77]
	Fragmentation and disconnection between actors in different implementation levels, especially in decentralised unitary states or specific domains (e.g., energy)	[14,74,82]
	Difficulty in coordinating and aligning activities across municipalities to address horizontal cross-domain challenges, especially in decentralized unitary states	[9,82]
	Lack of governmental support beyond "seeding" transition initiatives	[82]
	Misalignment between local specific challenges, regionalized guidelines, and nationally focused goals	[9,14,71]
	Difficulty to change power structures	[81]
	Limited leadership and policy uncertainty hampers continuity in the management of experiments	[69]
	The domain of the public agenda and participatory processes by organized power groups	[106]

Table A1. *Cont.*

Cluster	Barriers	Reference
Political/ Institutional	Political need to demonstrate success	[69,73]
	Political lack of reflexive capabilities	[69]
	Over-bureaucracy and excessive regulations can hamper collaborative governance processes	[14,106]
	Discursive debates	[81]
	Policies' focus on optimization through technological advances rather than collective factors that shape behaviours	[116]
	Industries and energy lobbies influencing policymakers	[83]
	Insufficient awareness of policymakers	[83]
	Tasks and responsibilities (and budgets) are 'siloed', leading to fragmented urban planning and development efforts	[9,14,19,73,108, 111,114]
	Lack of political awareness and sense of urgency for implementing policies and innovations	[9,14,73,83,108]
	"Policies and regulations typically designed for existing problems and current technologies and approaches"	[19]
	"Limited community engagement, empowerment, and participation and public will"	[14,108]
	Excessive limits to local government's room for menoeuvre	[7,9,14]
Financial/ Economic	Loss of economic interest in waste for actors involved due to centralized waste management systems	[72]
	Prevalence of personal or group interests or priorities over sustainability criteria in projects	[105,111]
	Inability to access funding	[7,9,10,14]
	Conflicting environmental-economic interests in planning	[14,105]
	Excessive reliance on private investment	[105]
	Difficulty of financing deep retrofits or small-scale energy retrofit ('creditworthiness')	[66]
	High upfront and instalment costs of deep retrofits	[66]
	Limited financial resources to structure and facilitate the processes of collaborative governance	[106,114]
	Lack of incentives for citizens to make their innovations available to, and replicable by, others in the social system	[67]
	Lack of resources for monitoring	[9,69]
	Choices mostly reflect short-term private costs and benefits but not long-term socio-ecological ones	[66,81]
	Possible negative financial consequences due to change	[81]
	Willingness to use fuel combustion plants until the end of their natural lifetime	[83]
	"Projectification of funding" leading to more easily obtainable funds for short-term, project-based funding than long-term decision-making needed to sustain transition initiatives	[81,82,106,117]
	Local monopolies in business models in district heating energy providers	[83]
	Risks of the investment	[83]
	National energy pricing schemes/Low energy price discourages investments in energy efficiency	[66]
	Prevailing economic efficiency and GDP-oriented paradigms in urban development excluding the ecological and social value for NBS/ecosystem services	[19,108,113, 118]
	Potentially competing issues between social and environmental priorities and project goals	[9,73,107,119]
	Limited funding, budget cuts, austerity	[14,19,65,105, 108,112,120]
	Pressure from the housing market	[19,65]
	Conflicting visions over natural resource management, societal, and economic interests in projects	[9,14,65,73,105, 107,119]

Table A1. *Cont.*

Cluster	Barriers	Reference
Technological/ Infrastructural	Lack of digitalization in administrative systems	[14]
	Limited availability of wood to incentivize wooden structures in buildings	[121]
	Lack of statutory requirements for the energy performance of existing buildings makes it difficult to incentivize building owners to invest in energy efficiency	[66]
	Friction between energy retrofitting of buildings and local regulations regarding the aesthetics of buildings	[66]
	Complex permit procedures for building retrofitting	[66]
	No regulatory structures to address the split-incentives problem in shared buildings	[66]
	Additional costs for upgrading energy labels	[66]
	"Building sector fragmentation and lack of business collaboration platforms between market actors to develop integrated solutions"	[66]
	Difficulties in engaging with physical change of the built environment in cities (due to socio-technical regimes involved and as result of high investment costs)	[122]
	Complexity of the urban system due to its systemic interconnections	[40,83]
	Immaturity of technologies for decarbonizing the energy sector	[83]
	Familiarity and satisfaction with existing infrastructures	[81]
	Lack of integration of urban forestry strategies in local planning schemes	[81]
	Need for large-scale infrastructure for electrification	[73]
	Cybersecurity issues and loss of confidence in new technologies	[14]

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