



How distributive injustice is produced in nature-based solutions: Institutional pathways across three Brazilian cities

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ABSTRACT

Nature-based Solutions (NbS) have been promoted as promising instruments for climate adaptation and the strengthening of urban resilience, particularly in the Global South. However, evidence indicates that their implementation may reproduce or deepen socio-spatial inequalities when justice criteria are not consistently incorporated into decision-making processes. We investigate how distributive injustices associated with NbS are produced prior to implementation, through institutional arrangements that structure decision-making in urban policies. We propose the Justice Production Cascade Framework, which conceives the procedural, recognition, and distributive dimensions of environmental justice as interdependent stages of a single causal chain. The framework makes it possible to trace how decision-making arenas, institutional knowledge filters, and categories of recognition shape, from the early stages of the public policy cycle, the territorial patterns of NbS allocation. We apply the framework to three Brazilian cities: São Paulo, Campinas, and São José dos Campos. The results show that distributive injustice does not primarily stem from implementation failures, but from the cumulative effect of procedural decisions and recognition mechanisms that stabilize unequal spatial trajectories. By shifting the analytical focus from the late-stage assessment of distributive effects to an understanding of their institutional production, we seek to advance the debate on environmental justice in NbS. We argue that the Global South offers a privileged lens to render these mechanisms visible, with relevant implications for the science-policy interface and for the design of more just policies.

1. Introduction

The global climate crisis has brought Nature-based Solutions (NbS) to the forefront as a promising agenda for adaptation and the strengthening of urban resilience in the Global South [1]. Cities marked by deep social and spatial disparities experience the impacts of climate change unevenly, with effects that fall more heavily on already vulnerable groups in historically disadvantaged contexts such as the Global South and Latin America [2].

Here, the Global South is used as a lens referring to urban contexts shaped by structural inequalities, uneven urbanization, institutional fragmentation, and asymmetrical exposure to climate risks. Within environmental justice scholarship, the concept has been mobilized to examine how unequal state capacities, socio-spatial disparities, and historical power asymmetries condition environmental governance and access to urban infrastructure [3,4] contexts where the combination of

high socio-spatial inequality and limited institutional capacity renders the mechanisms linking procedural decisions to distributive outcomes particularly legible [5].

The Brazilian case is an example of these disparities, as it reveals a scenario of scarcity of urban green areas in regions predominantly inhabited by low-income populations, marked by infrastructure deficits and increasing environmental risks [6]. The most vulnerable communities often reside in areas with limited vegetation or have restricted daily contact with natural areas, and the relocation of marginalized communities with reduced access to natural green infrastructure is also frequent [5].

Consequently, planners and policymakers in these contexts must establish connections between climate responses and broader issues of justice, so as not to reproduce historical inequalities. When climate action ignores unjust power structures, it tends to reinforce the unequal distribution of benefits and to sustain environmental decision-making

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processes that are devoid of substantive meaning. Addressing climate change impacts requires profound transformations across civil society as well as governments, productive sectors, and economic elites [2].

Despite the rapid diffusion of NbS in urban climate policies, little is known about how early-stage decision-making produces unjust spatial outcomes [7]. Prior work has demonstrated that distributive, procedural, and recognition dimensions are interrelated in urban environmental governance and ecosystem service debates [8,9], and research on NbS has documented how exclusionary governance dynamics, selective participation, and uneven territorial allocation frequently co-occur within urban interventions [10–12].

Studies on environmental justice and Nature-based Solutions have demonstrated that NbS may reproduce exclusionary governance dynamics, uneven access to environmental benefits, and forms of socio-spatial marginalization when justice considerations are weakly institutionalized [9,13]. These concerns have been documented across different urban contexts, including processes of green gentrification and the technocratic filtering of participation [13,14] as well as the selective recognition of vulnerable groups and knowledges [3,15].

However, less attention has been paid to how early-stage institutional decisions (regarding who participates, which knowledge counts, and which territories are prioritized) actively shape distributive outcomes upstream in the policy process [16,17]. This gap is particularly consequential in Global South cities, where institutional fragmentation and technocratic governance structures make the mechanisms linking procedural decisions to distributive outcomes more visible and more urgent to address [4,7].

What remains insufficient is how these dimensions interact sequentially across decision-making stages to produce distributive outcomes upstream in the policy cycle, before implementation occurs. Existing approaches have predominantly mapped the co-presence or mutual reinforcement of justice dimensions at a given moment, but have rarely reconstructed the institutional chain through which early procedural configurations constrain recognition criteria, which in turn stabilize territorial allocation patterns prior to any material intervention [18]. This sequential, mechanism-oriented understanding of injustice production, centered on decision-making arenas, knowledge filters, and institutional definitions of vulnerability, is what the Justice Production Cascade Framework is designed to address.

Considering the need for further research examining how solutions interact with existing power structures and asymmetries [16], we do not intend here to address distributive, recognition, and procedural dimensions in isolation, but rather to expose how these dynamics are articulated, or whether they mutually influence one another, in the production of territorial injustices in the cities of the Global South, using Brazilian cities as a case study.

The analysis focuses on NbS governance arrangements in which public institutions play a central role. While it involves non-state actors including community groups, NGOs, and private entities in collaborative or hybrid arrangements NbS initiatives are increasingly documented [19–22], the framework specifically addresses the institutional dynamics through which state-led or state-coordinated planning processes shape territorial prioritization and condition distributive outcomes. This focus is particularly relevant in the Brazilian context, where evidence from urban NbS initiatives suggests that municipal governments and public-sector institutions continue to occupy central agenda-setting, coordinating, and implementation roles in the institutionalization of NbS policies and interventions [23].

By exploring the integration of NbS into political issues and other factors that enable or hinder their realization in the territory [11], we propose a new conceptual approach through the development of a framework that demonstrates how procedural justice and recognition justice produce distributive outcomes, rather than merely coexisting with them.

The remainder of this paper is structured as follows. First, we established the theoretical foundation, discussing the institutional

dimensions of environmental justice in urban NbS and introducing the proposed Justice Production Cascade Framework. Second, we detail the methodological approach and the rationale for selecting the three Brazilian case studies. Third, we present the empirical results, analyzing the procedural, recognition, and distributive mechanisms operating across the selected cities. Finally, we discuss the broader implications of these findings for urban climate adaptation in Brazilian cities and in the Global South, and conclude by highlighting pathways toward more just institutional designs.

2. Institutionalizing injustice: A conceptual framework for NbS

2.1. Institutional decision-making and knowledge filters in NbS

Environmental justice research demonstrates that inequalities are not produced solely through unequal exposure to risks and benefits, but through institutional processes that shape recognition, participation, and access to decision-making power [9,24,25]. In urban contexts, these dynamics are mediated by planning institutions, technical expertise, and political disputes over scale, legitimacy, and territorial prioritization [7, 9,25].

More recently, research on NbS has shown that these interventions may reproduce exclusionary governance dynamics, selective recognition, and socio-spatial inequalities when justice considerations remain weakly institutionalized [18,25–27]. NbS governance operates through fragmented multi-actor arrangements distributed across multiple decision-making arenas and institutional scales [14,24].

Particularly in Global South cities, these arrangements frequently remain constrained by fragmented institutional coordination, uneven state capacities, and historically hierarchical planning structures, reproducing asymmetrical distributions of decision-making power and socio-spatial inequalities [5,7].

Decisions regarding NbS are fundamentally public policy choices shaped by decision-making arenas, knowledge filters, and institutional categories of recognition. Treating the three dimensions of environmental justice in parallel obscures how early-stage decisions condition the socio-spatial patterns of NbS allocation. To address this limitation, we propose an analytical mechanism that conceives these dimensions as interdependent processes, operating in a chained manner throughout the decision-making cycle.

Within NbS planning, participatory processes are mobilized as normative ideals for knowledge co-production, although tensions persist between discourse and actual implementation practices [28]. Merely formalizing participatory mechanisms does not guarantee actual influence over decision-making, especially in contexts marked by technocratic structures and institutional power asymmetries [12,29]. Decision-making arenas tend to operate selectively, privileging certain types of expertise, potentially converting participatory processes into late-stage or performative consultative practices [30]. In such cases, justice in NbS depends not only on who participates, but on which forms of knowledge are considered legitimate, operational, and relevant for guiding public policy decisions [28].

Ignoring justice criteria in NbS design risks privileging specific social groups, perpetuating pre-existing inequalities [31]. In the Global South and Latin America, environmental and climate policies typically tend to operate under top-down logics within hierarchical decision-making structures [32], compounded by the fragmentation of knowledge systems and the rigidity of planning structures, which hinder intersectoral and interdepartmental coordination [33]. The Brazilian case is particularly critical, as its environmental policies under federalism often manifest as a mosaic of overlapping competencies and disarticulated actions across levels of government [34] which have hindered or rendered the implementation of solutions in the territory unfeasible [7]. Incorporating justice criteria into NbS policies does not occur linearly, but is mediated by institutional processes that structure who participates, which problems are recognized, and which forms of evidence

inform decision-making [3].

In urban NbS policies, recognition criteria shape who is defined as a priority population, which territories are considered eligible for intervention, and which forms of knowledge are mobilized in decision-making processes. The definition of these parameters is heavily mediated by technical-administrative criteria and the availability of institutional data, which are often oriented by biophysical framings. This produces selective visibility, contributing to the underrepresentation of peripheral territories and socially vulnerable populations [7].

Public policies are operationalized through data, indicators, and criteria that structure what can be recognized and prioritized in decision-making processes [35]. Thus, in NbS planning, the absence of disaggregated social data constitutes a mechanism of injustice that produces persistent institutional blind spots. An overreliance on narrow technical data and criteria generates these persistent epistemic injustices by producing institutional blind spots, shaping decisions and reproducing patterns of distributive injustice [10].

Taken together, these dynamics reveal that distributive injustice in NbS accumulates across successive institutional stages rather than emerging from a single point of failure. What remains underspecified is the causal chain connecting them, how procedural configurations constrain recognition criteria, and how those criteria stabilize distributive patterns upstream. The Justice Production Cascade Framework addresses this gap [18].

2.2. The Justice Production Cascade Framework

To address these systemic gaps, we propose the Justice Production Cascade Framework (Fig. 1), which reconstructs the production of environmental injustice as a chained causal mechanism. Within this framework, procedural decisions and institutional recognition criteria operate as the structuring conditions for the distributive patterns observed in the implementation of Nature-based Solutions.

We argue that the decisions about NbS (where the state operates as the central node of agenda-setting, resource allocation, and territorial prioritization, even when non-state actors participate in governance arrangements) are fundamentally public policy decisions involving disputes over technical criteria, knowledge filtering, the production of institutional categories of vulnerability, and choices regarding the territorial allocation of resources. The framework specifically examines governance arrangements in which public institutions occupy central roles in these processes.

While community-driven and grassroots NbS initiatives may emerge outside to institutional planning dynamics [10,36], the focus here is on the institutional mechanisms through which state-coordinated NbS governance structures distributive outcomes in urban policy processes. In this process, three interdependent mechanisms operate sequentially: procedural mechanisms configure who decides and under what terms; recognition mechanisms determine which territories and populations become institutionally legible; and distributive mechanisms materialize these prior choices into spatial patterns of resource allocation. This ordering follows the institutional logic of public policy and justice dimensions.

These dimensions are conceived as interconnected stages of a single institutional chain, in which decisions made in early phases constrain, guide, and amplify the possibilities for either justice or injustice in subsequent phases. The metaphor of a cascade captures the directional and cumulative character of institutional effects. Early procedural choices expand or restrict the recognition criteria subsequently available, which in turn channel distributive possibilities toward certain territories and away from others. While the cascade can be interrupted (when implementation fails, political priorities shift, or funding expires), the directional logic remains; distributive patterns observed on the ground bear the imprint of prior procedural and recognition configurations, even when the outcome falls short of what was planned.

The sequential relationships between stages are grounded in prior

studies, the constraining effect of procedural configurations on recognition processes draws on evidence that the design of participatory arenas (including which actors are admitted, at what point engagement is opened, and which forms of knowledge are treated as legitimate) determines whose interests and which values enter decision-making processes [12,24,25]. When participation is opened only after core technical decisions have been made, or structured in ways that favor certain expertise over local knowledge, the range of vulnerabilities and populations that become institutionally legible is correspondingly narrowed [9]. It should be emphasized that these studies do not themselves propose a sequential framework; they provide the building blocks that the Justice Production Cascade Framework assembles into an explicit causal chain.

The stabilizing effect of recognition criteria on distributive outcomes draws on evidence that dependence on aggregated technical data and the exclusion of locally-held knowledge produce persistent institutional blind spots, where populations and territories not captured by available indicators tend to remain absent from prioritization decisions regardless of their actual exposure to risk [7,10].

The pluralistic understanding of justice as encompassing distribution, recognition, and participation simultaneously, and the insight that distributive injustice cannot be understood without examining the recognition and procedural mechanisms that produce it, is foundational to environmental justice scholarship more broadly [16,18]. The Justice Production Cascade Framework builds on these demonstrated relationships, formalizing them into an explicit sequential causal chain that makes the institutional production of distributive injustice traceable across the full cycle.

By operationalizing environmental justice as a chain of mechanisms, the framework directly connects decision-making arenas, knowledge categories, and public policy instruments to the spatial and social patterns of access to NbS.

The first stage refers to the procedural configuration of decisions regarding NbS, including the definition of decision-making arenas, the distribution of agenda-setting power, and the initial design of the criteria that guide the policy. Crucially, this stage operates prior to implementation and to the formal opening of participatory processes. This stage draws on studies examining how institutional arenas and asymmetric participation structures shape environmental decision-making, determining which actors gain influence and which forms of knowledge become operationally recognized in planning processes [7, 12,17,24].

In contexts marked by heavy technocratization and institutional fragmentation, strategic decisions tend to be monopolized by technical bodies and specialized teams, with strong reliance on feasibility criteria, the adoption of standardized models, and previously established indicators. Analyzing this stage allows for the identification of formal and informal decision arenas, administrative routines, moments of criteria definition, and knowledge-filtering mechanisms that set the trajectory for the entire subsequent policy cycle.

The second stage focuses on institutional recognition processes in which populations, territories, and vulnerabilities are classified into formal categories of intervention, conditioned by prior decisions. Recognition operates as a filtering mechanism through which technical-administrative categories, available indicators, and existing databases delimit who is considered a priority public and which territories are defined as eligible for the implementation of NbS. Consequently, vulnerabilities not captured by these instruments tend to remain institutionally invisible, regardless of their social or territorial relevance. This stage allows for the examination of how official diagnoses are constructed, which social markers are incorporated or excluded, and how the absence of disaggregated data produces persistent institutional blind spots. Importantly, recognition is not treated merely as a normative principle, but as an active classification mechanism that conditions subsequent distributive possibilities.

The third stage corresponds to the territorial and social

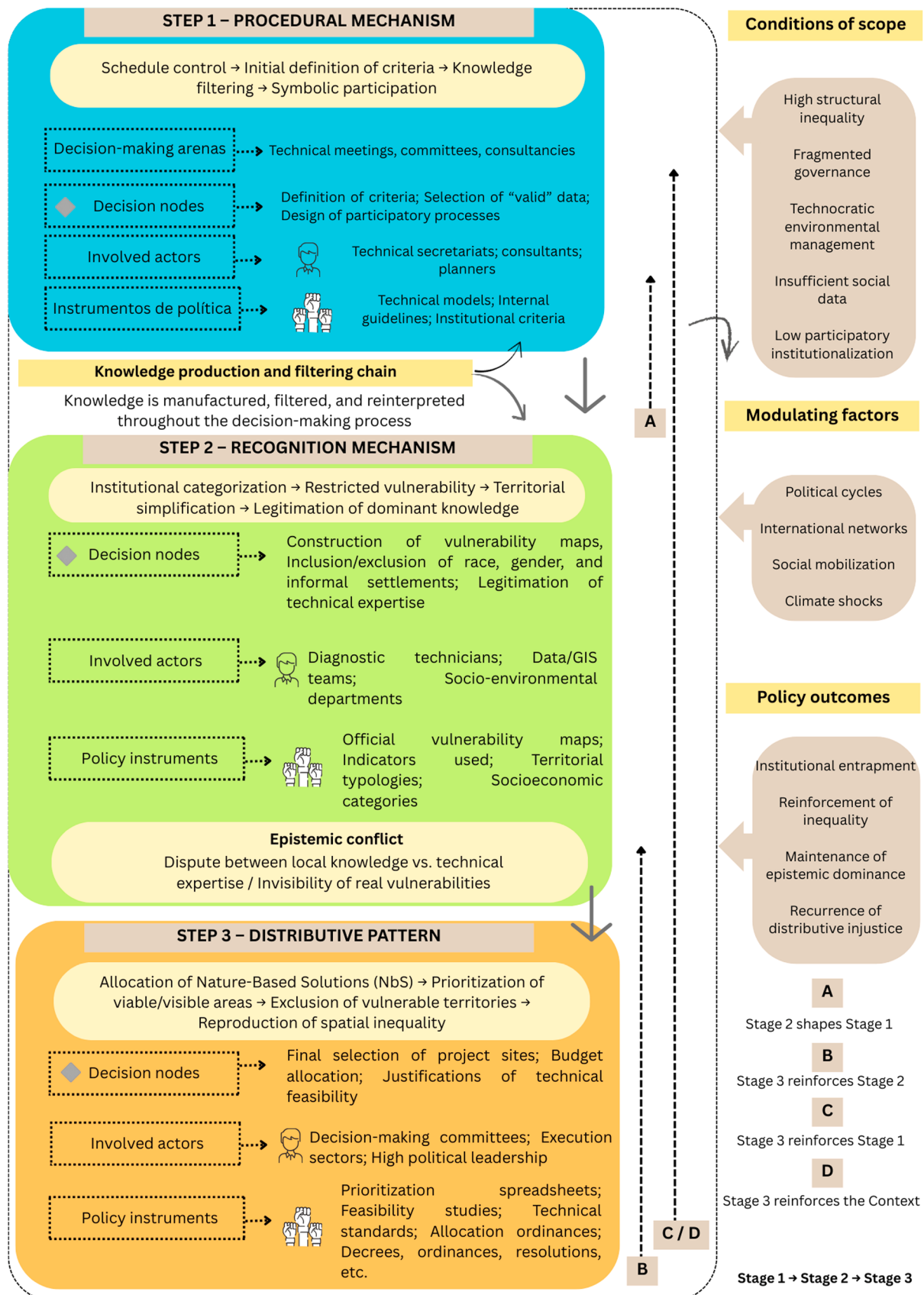


Fig. 1. Justice Production Cascade Framework. Author's own elaboration.

materialization of the decisions made in the previous stages, through the concrete allocation of solutions. Within this framework, the distributive patterns observed are not understood as isolated or contingent outcomes, but as the accumulated institutional effects of procedural and recognition mechanisms. At this stage, public policy instruments, prioritization criteria, and administrative routines operate under previously established constraints, guiding where, how, and for whom NbS are implemented. The final distribution reflects the combination of closed decision-making arenas, restrictive recognition categories, and technical parameters stabilized throughout the process. Here, we trace how earlier decisions translate into spatial and social patterns of access to NbS, linking initial institutional choices to observable distributive outcomes in the territory. We propose the Justice Production Cascade Framework. This framework overcomes approaches that treat justice dimensions in parallel, allowing them to be analyzed as a continuous causal chain that connects early procedural decisions to observable distributive outcomes in the territory.

3. Methods

3.1. Selecting the studies

Given the historical presence of heavy technocratization, vulnerability, low public participation, and administrative fragmentation observed in Brazil [29,37], we selected three municipalities to test the applicability of the framework. To control for in-state variables, we focused our selection within the State of São Paulo, adopting the cities of São Paulo, Campinas, and São José dos Campos. These cities share the same state-level political and administrative context but present relevant variations in how NbS are institutionalized and operationalized.

The cities were chosen due to their growing interest in implementing NbS and because they represent distinct institutional configurations within the same federative context, allowing us to observe how procedural and recognition mechanisms operate under different state capacities, governance arrangements, and public policy trajectories.

The specific criteria for selecting the cases were: (i) the incorporation of NbS into formal environmental or climate policy instruments; (ii) the existence of multiple decision-making arenas and actors; (iii) the availability of technical instruments and documentary records that allow for tracing criteria and knowledge filters; and (iv) the feasibility of empirical access for interviews and triangulation. By applying the Justice Production Cascade Framework, we analyzed the NbS decision-making processes, examining how procedural and recognition mechanisms shape distributive patterns. We chose to concentrate the selection of cities in the State of São Paulo to control for inter-state variables.

3.2. Data collection

During the first half of 2025, we conducted 27 semi-structured interviews with key stakeholders from the public and private sectors, research and teaching institutions, non-governmental organizations, and international cooperation agencies involved in the case studies. The full profile of participants, including institutional type, role, and scale of operation across the three municipalities, is provided in Supplementary Material.

Interview participants were selected through purposive and snowball sampling based on their involvement in the planning, implementation, coordination, or mediation of NbS-related policies or projects in the selected municipalities. The sampling strategy sought to include actors occupying different institutional positions within NbS governance arrangements, including public managers, technical staff, researchers, consultants, NGOs, and international cooperation organizations. The interview guide, provided in Supplementary Material, was organized around the three dimensions of the Justice Production Cascade Framework, covering questions about territorial prioritization criteria, forms and quality of population participation, mechanisms of

resistance and institutional response, and the actors and networks involved in NbS decision-making

Interviews and documentary materials were analyzed jointly through a hybrid thematic analysis combining deductive categories derived from the Justice Production Cascade Framework with inductive identification of recurring institutional dynamics across the material. Coding was conducted using the software Atlas.ti and proceeded iteratively through successive readings, with categories refined through cross-case comparison to identify recurring mechanisms connecting procedural arrangements, recognition dynamics, and distributive outcomes. Documentary sources were used to identify formal policy instruments, institutional arrangements, and territorial prioritization criteria, while interviews provided evidence regarding decision-making practices, participation dynamics, knowledge legitimacy, and implementation processes

All participants were informed about the research objectives and participated voluntarily under prior consent. The study was conducted in accordance with ethical guidelines for qualitative research with human subjects, and participant identities were anonymized throughout the analysis and presentation of findings

4. Results

4.1. Procedural justice: arenas, agenda-setting, and symbolic participation

The procedural configuration of NbS decision-making (the first stage of the justice production cascade) established distinct institutional conditions for how vulnerability would subsequently be recognized and how benefits would ultimately be distributed across the three cities.

São Paulo exhibits a distinct misalignment between its institutional and technical framework for Nature-based Solutions and the decision-making processes that actually guide their implementation on the ground. Although strategic instruments and technical guidelines are formally centralized in departments such as the Executive Secretariat for Climate Change (SECLIMA) and the Municipal Secretariat for Green Areas and the Environment (SVMA), critical decision-making arenas and nodes tend to fragment across sub-municipal scales (called *sub-secretariats*). In this context, agenda control is not exercised in a coordinated manner through planning instruments, but is instead conditioned by factors such as residual resource availability, budgetary windows, the political visibility of interventions, and the specific interests of sub-municipal administrations (PanClima, 2021; Interview 1, public manager, São Paulo; Interview 2, research institution, São Paulo). This often results in fragmented decisions that are weakly aligned with broader municipal NbS strategies.

Interviewees indicated that technical typologies and parameters are frequently reinterpreted or flexibilized during implementation. Interventions are often being classified as NbS regardless of their actual ecological or hydrological function, based on immediate feasibility or political opportunity (Interview 3, private sector/academia, São Paulo).

Although formal participatory mechanisms exist, their operation is typically episodic and consultative, with limited capacity for co-decision or influence over pre-determined decisions (Interview 1, public manager, São Paulo). Participation thus tends to occur reactively or *ex post*, serving primarily to institutionally legitimize choices that have already been made.

In contrast, Campinas planning employs a more structured and coordinated procedural design, led by the Municipal Secretariat for Climate, Environment, and Sustainability (SECLIMAS). Key decisions are articulated within formalized intersectoral arenas, particularly through the Campinas Working Group (GT Campinas), which brings together technical secretariats, municipal bodies, and public agencies (Campinas Municipal Decree 22.780, 2023; Interview 23, NGO/international cooperation, Campinas). Within this arrangement, the agenda is defined in advance and guided by integrated environmental planning

instruments, technical diagnostics, and cooperation with organizations such as WRI Brasil, ICLEI, and Cities4Forests. This collaboration ensures greater consistency to the initial definition of priorities, criteria, and scales of intervention.

Procedural criteria are operationalized through municipal plans and programs that function as institutional instruments for coordination and knowledge filtering. Although participatory experiences are more structured than in the other case studies, these spaces still operate predominantly in a consultative manner, with limited co-decision over criteria that have already been technically defined (Interview 23, NGO/international cooperation, Campinas; Interview 24, research institution, Campinas).

In São José dos Campos, decision-making processes are characterized by a centralized, top-down structure, driven by the municipal executive and technical secretariats that concentrate key decision nodes. Relevant decision-making arenas operate internally and hierarchically, with early agenda control over priorities and intervention typologies. Although the municipality has multiple plans, programs, and guidelines that mobilize the NbS discourse, the documentary analysis indicates the absence of a clear operational definition of what effectively constitutes an NbS (São José dos Campos Master Plan, 2018; Interview 9, research institution, São José dos Campos).

This results in flexible and unstable procedural criteria. Social participation occurs in a late and episodic manner, with low capacity for co-decision and limited influence over criteria already defined, characterizing a pattern of predominantly symbolic participation (Interview 11, private sector, São José dos Campos). By combining decision-making centralization, loosely defined criteria, and restricted openness to participation, the procedural mechanism observed in São José dos Campos shapes agenda setting from the outset, determining which problems enter the agenda, which alternatives are considered legitimate, and which vulnerabilities become visible in subsequent stages of the cascade.

These procedural differences shaped recognition dynamics in distinct ways across the three cases. In São Paulo, fragmented decision nodes allowed centrally produced vulnerability diagnostics to be overridden by sub-municipal feasibility logics. In Campinas, formalized intersectoral arenas enabled integrated socio-environmental criteria to enter territorial prioritization processes. In São José dos Campos, centralized executive control combined with loosely defined NbS criteria reinforced institutional visibility and implementation opportunity as dominant recognition filters.

4.2. Recognition: how vulnerability and legitimate publics are constructed

Recognition processes (the second stage of the cascade) filtered which territories, populations, and forms of knowledge became institutionally legible as priorities for NbS intervention. These filters operated differently in each city, conditioned by the procedural arrangements described above.

In São Paulo, recognition processes associated with NbS are formally underpinned by maps, indicators, and technical diagnoses of socio-environmental vulnerability; however, these references rarely translate into binding criteria for decisions regarding where interventions are implemented. Vulnerability is institutionally constructed through technical categories that simplify complex territorial realities, operating more as discursive forms of legitimation than as practical guides for action.

The interviews reveal a recurring epistemic conflict, in which local knowledge and social perceptions of risk are marginalized or reinterpreted as barriers to implementation, while technical-scientific expertise remains the primary legitimate form of knowledge (Interview 1, public manager, São Paulo). Although sporadic attempts at participation and co-production of diagnosis occur, they depend on the discretion of specific departments or *subprefeituras* and do not constitute an institutionalized practice. Thus, the recognition of vulnerability in São Paulo

operates in a fragmented, selective, and weakly influential manner over decision-making, generating unstable categories of "legitimate publics" that are disconnected from formal diagnoses (Interview 2, research institution, São Paulo; PanClima, 2021). This directly conditions the distributive patterns analyzed in the subsequent stage of the cascade. In practice, this dynamic weakens the institutional visibility of peripheral populations exposed to overlapping socio-environmental risks, while local and experiential forms of knowledge tend to be subordinated to technical and hydrological criteria, and in some cases, reframed as implementation barriers, during decision-making processes.

In Campinas, recognition processes are more explicitly structured and institutionalized, with socio-environmental vulnerability incorporated as a formal criterion for territorial prioritization. The construction of vulnerability relies on multiscale diagnoses and maps that combine climatic, hydrological, and socioeconomic indicators, developed under the coordination of SECLIMAS and GT Campinas, with support from international technical networks (Interview 23, NGO/international cooperation, Campinas; Campinas NbS Municipal Strategy, 2022). These instruments provide greater institutional visibility to territories exposed to climate risks associated with social disadvantages, legitimizing technical-scientific expertise as the main reference for defining priority publics.

However, recognition remains anchored in what is measurable and mappable, which may simplify complex territorial realities and marginalize vulnerabilities less captured by official indicators. Although more structured participatory experiences exist, they operate predominantly in a consultative manner and within previously defined technical parameters, limiting the substantive incorporation of local knowledge into the diagnostic process (Interview 24, research institution, Campinas). Although recognition processes are more institutionally structured, participation remains concentrated among recurrent institutional actors, with limited incorporation of situated community knowledge into the definition of priorities and intervention strategies.

Both cities benefit from international technical cooperation and produce vulnerability diagnostics; what differs is what happens to those diagnostics within each institutional structure. In São Paulo, fragmentation across secretariats and administrative silos prevents coordinated translation of vulnerability criteria into implementation decisions: budget windows, political visibility, and sub-municipal discretion consistently override centrally produced diagnostics. In Campinas, intersectoral coordination structures provide greater institutional continuity between planning and implementation, even if allocation decisions remain conditioned by financing opportunities and administrative readiness, even if allocation decisions remain conditioned by financing opportunities and administrative readiness. The distinction is institutional capacity to act on what diagnostics reveal.

São José dos Campos exhibits recognition processes marked by a pronounced disconnection between institutional discourse and operational decision criteria. The city presents a proliferation of plans, programs, and narratives that mobilize terms such as resilience, climate adaptation, and NbS, often geared toward obtaining certifications, environmental awards, and institutional communication strategies (Interview 5, private sector, São José dos Campos; Interview 9, research institution, São José dos Campos).

Consequently, problems, territories, and publics tend to be recognized as legitimate when interventions align with immediate technical feasibility, institutional visibility, or specific implementation opportunities. Interviews described rare and episodic experiences of participation and co-production, occurring mainly in isolated projects mediated by universities, while the majority of interventions are conceived and implemented devoid of co-creation with the affected communities (Interview 5, private sector, São José dos Campos). As a result, institutional recognition remains oriented toward administratively visible projects and technical implementation opportunities, while community-level understandings of territorial vulnerability exert limited influence over project definition and prioritization.

These recognition dynamics subsequently conditioned distributive outcomes. In São Paulo, selective recognition reinforced NbS concentration in technically feasible and politically visible areas rather than in high-vulnerability territories. In Campinas, integrated vulnerability diagnostics enabled more targeted allocation patterns, although implementation limitations weakened distributive stability over time. In São José dos Campos, abstract recognition criteria and visibility-oriented priorities produced fragmented and largely symbolic distributive patterns.

4.3. Distributive outcomes in NBS allocation

Distributive outcomes (the final stage of the cascade) materialized the cumulative effects of the preceding procedural and recognition mechanisms. The spatial patterns of NbS allocation observed in each city reflected how earlier institutional choices had constrained which territories were recognized as eligible and which vulnerabilities were rendered invisible.

São Paulo exhibits distributive NbS outcomes that are fragmented and dissociated from formal diagnoses of socio-environmental vulnerability. Despite the existence of maps, plans, and instruments that identify priority areas based on climatic, hydrological, and social criteria, these references do not translate into binding parameters for the final selection of intervention sites. NbS allocation is predominantly guided by immediate technical feasibility, residual resource availability, budgetary windows, and political visibility, often mediated by local dynamics and specific sectoral interests (Interview 1, public manager, São Paulo; Interview 2, research institution, São Paulo).

Consequently, interventions concentrate in areas where execution is simpler and institutional returns are more immediate, while territories with higher socio-environmental vulnerability remain underserved or receive sporadic, discontinuous, and small-scale actions. Even when integrated diagnoses are produced, they are frequently overridden by administrative opportunity at the moment of final decision (Interview 16, public manager, São Paulo). This distributive pattern limits the redistributive potential of NbS and reinforces existing spatial inequality, contributing to the reproduction of distributive injustices.

Campinas demonstrates a more consistent effort to direct interventions toward areas identified as environmentally vulnerable, anchored in technical diagnoses and prioritization criteria. However, the benefits produced tend to be partial or unstable due to limitations in the implementation and maintenance phases. Technical execution failures were identified, such as inadequate planting practices and operational weaknesses, undermining the long-term ecological functionality of the solutions (Interview 24, research institution, Campinas). As a result, distributive effects become conditioned by the institutional capacity for continuous execution, producing unequal or temporary gains (Interview 18, public manager, Campinas). This pattern reveals a disconnect between planning and the effective delivery of benefits, limiting the transformative potential of NbS and exposing the limits of distributive justice in practice.

São José dos Campos exhibits distributive outcomes marked by limited territorial implementation, lack of scale, and the absence of a consistent allocation pattern oriented toward socio-environmental vulnerability. The few interventions identified take on an experimental, isolated, and fragmented character, consisting of small-scale typologies in locations defined by visibility, opportunity, or technical feasibility (Interview 11, private sector, São José dos Campos; Interview 15, public manager, São José dos Campos). Lacking systematic alignment with territories that concentrate higher exposure to climate risks, there is neither spatial redistribution of NbS benefits nor a reduction of intra-urban socio-environmental inequalities. This distributive pattern is not merely the result of isolated operational limitations but rather emerges from an institutional arrangement in which closed, technically driven decision-making arenas, combined with abstract recognition mechanisms, interrupt the justice production cascade before it can

translate into effective distributive outcomes on the ground.

4.4. Connecting stages: from institutional design to distributive injustice

Across the three cases, the cascade operated through distinct institutional configurations, but the directional logic held: procedural arrangements constrained recognition filters, which in turn shaped distributive outcomes before implementation occurred. What varied was the stage at which the chain was interrupted or distorted. In São Paulo, the cascade is traceable to a specific procedural arrangement, where the fragmentation of agenda-setting authority across sub-municipal units, operating independently, stripped vulnerability diagnostics of any binding force over implementation decisions. Sub-prefectures set their own priorities based on budget availability and political opportunity, effectively excluding socio-environmental vulnerability as a functional recognition criterion at the time of site selection. The distributive outcome (NbS concentrated in technically manageable, politically visible locations) was not a failure of recognition knowledge, which existed; it was the result of a procedural structure that prevented that knowledge from reaching the allocation stage.

In Campinas, the formalization of an intersectoral arena (GT Campinas), coordinated by SECLIMAS and supported by WRI Brasil, enabled integrated vulnerability criteria to enter recognition processes as planning references. What the procedural arrangement could not control was the implementation stage, conditioned by technical readiness and external financing cycles. The cascade was interrupted between recognition and distribution, producing gains that were more targeted than in the other cases but remained partial and unstable.

In São José dos Campos, the cascade was closed before recognition could function as a meaningful filter. Executive concentration of decision-making, combined with deliberately vague NbS criteria across planning instruments, meant that no territorial definition of vulnerability was ever operationalized as a selection criterion. Recognition became oriented by institutional visibility, with certifications, sustainability rankings, and award-eligible projects rather than by exposure to risk. The distributive pattern that followed, characterized by symbolic and experimental interventions without spatial correspondence to vulnerability, was determined upstream, by a procedural configuration that had already established visibility, not vulnerability, as the governing logic (See Table 1).

5. Discussion

The case studies demonstrated that distributive injustices associated with Nature-based Solutions do not emerge solely at the final stage of public policy, nor exclusively from implementation failures. Rather, they are produced upstream through specific combinations of procedural arrangements and institutional recognition mechanisms. These configurations structure who participates in decision-making, which territories and publics are considered legitimate, and which criteria guide the spatial allocation of solutions. By treating environmental justice as a causal chain, the Justice Production Cascade Framework shifts the analytical focus from the late-stage assessment of distributive effects to an understanding of the institutional processes that actively shape territorial outcomes.

This study extends environmental justice scholarship in three ways. First, it advances beyond frameworks that treat the three dimensions [8, 16] by proposing an explicit sequential mechanism through which each institutionally conditions the next. Second, it complements NbS governance research documenting tokenistic participation and exclusionary dynamics [12,13] by reconstructing the institutional chain connecting them. Third, it extends the Global South literature [4,7] by specifying how governance fragmentation produces distributive injustice, not directly, but by preventing vulnerability knowledge from acquiring binding force at the moment of allocation.

Campinas revealed that even when upstream procedural and

Table 1

Institutional pathways that connect procedural design, recognition filters, and distributive outcomes.

City	Stage 1- Procedural configuration	Stage 2 - Recognition filter	Decision trigger / justification	Stage 3 - Distributive outcome
São Paulo	Fragmented arenas with shifting decision nodes at sub-municipal level; agenda control shaped by budget windows and local political priorities	Vulnerability framed through technical categories with weak binding power; selective incorporation of diagnostics	Immediate technical feasibility, political visibility, and administrative opportunity	NbS concentrated in implementable areas; weak alignment with socio-environmental vulnerability; fragmented and uneven distribution
Campinas	Formalized intersectoral arenas coordinated by environmental authorities; early definition of priorities and criteria	Vulnerability constructed through integrated socio-environmental diagnostics; recognition anchored in measurable indicators	Territorial prioritization combined with technical executability and project readiness	More targeted allocation toward vulnerable areas, but distributive benefits remain unstable due to implementation and maintenance constraints
São José dos Campos	Centralized and closed decision arenas; early agenda control by technical and executive bodies	Recognition mediated by abstract sustainability narratives and institutional visibility rather than territorial vulnerability	Visibility, opportunity, and symbolic alignment with institutional discourse	Minimal territorial materialization; experimental and symbolic interventions with no systematic distributive pattern

recognition stages function as designed, the cascade can stall at the recognition-distribution interface due to financing cycles and administrative contingencies outside any planning arrangement's scope. This specifies a practical implication, where the binding force of vulnerability criteria must extend into implementation, not only upstream.

In urban contexts marked by institutional fragmentation, uneven state capacities, and strong socio-spatial inequalities, the integration of NbS depends on coordination across policy and planning instruments operating at multiple scales to avoid siloed governance and uneven territorial implementation [11]. In these environments, criteria presented as neutral or strictly technical are often produced within restricted decision-making arenas and sustained by datasets insufficiently sensitive to socio-spatial inequalities. This creates the risk of reinforcing injustice by legitimizing diagnoses and priorities that render certain territories and populations institutionally invisible [7].

The central problem revealed by the three cases is not the absence of vulnerability knowledge, which existed in São Paulo and Campinas, but the institutional conditions under which that knowledge acquires or loses binding force over allocation decisions. This reframing has a direct preventive implication: if injustice is produced upstream, it can also be interrupted upstream, by redesigning the procedural arenas and recognition criteria that govern the earliest stages of the policy cycle, before territorial trajectories stabilize. For researchers, the framework offers a diagnostic tool to identify where in the institutional chain the cascade is most vulnerable to distortion. For policymakers, it specifies the intervention points with the highest leverage, not implementation monitoring, but arena design, data governance, and the operationalization of vulnerability criteria as binding parameters.

Although grounded in Brazilian case studies, the mechanism identified is not exclusive to this context. Processes of symbolic participation, selective recognition, and territorial prioritization oriented by feasibility and visibility are also present in cities of the Global North [12, 15, 35, 38] but shaped by different institutional arrangements. The Brazilian cities analyzed in this study are therefore approached as situated urban contexts within broader Global South debates, rather than as representative of the Global South as a whole. By reconnecting institutional design and the distribution of benefits, we aim to contribute to a more critical and operational understanding of environmental justice in Nature-based Solutions policies.

6. Conclusion

Distributive injustice in NbS is not an implementation problem. It is an institutional design problem, produced upstream through procedural configurations and recognition mechanisms that stabilize unequal territorial trajectories before any material intervention occurs. We demonstrate that causal sequence empirically across three Brazilian cities and analytically through the Justice Production Cascade Framework. Distributive injustice in NbS is institutionally produced upstream in the policy cycle through institutional arrangements that shape

territorial prioritization before implementation occurs. By applying the Justice Production Cascade Framework to three Brazilian cities, we showed how decision-making arenas, knowledge filters, and institutional definitions of vulnerability interact to produce unequal distributive outcomes.

The study contributes to environmental justice and NbS scholarship by conceptualizing procedural, recognition, and distributive dimensions as sequentially interconnected mechanisms rather than parallel analytical categories. In doing so, it offers an analytical framework for examining how institutional design influences territorial allocation patterns in urban climate governance.

The findings should be interpreted within the scope of the study. The analysis focused on three municipalities located within a single Brazilian state and therefore reflects specific institutional and governance configurations. Although several mechanisms identified here resonate with broader debates on NbS governance and environmental justice, the Brazilian cases should not be interpreted as representative of the Global South as a whole. Rather, they constitute analytically situated urban contexts in which the institutional production of distributive injustice becomes particularly visible.

Future research could apply the framework comparatively across different urban and political contexts to examine how variations in governance arrangements, institutional capacities, and participatory structures influence the production of distributive outcomes in NbS policies. Redesigning how decision-making arenas are structured, how vulnerability is operationalized as a binding criterion, and how recognition filters are governed is not a normative aspiration; it is the technical precondition for NbS policies that do not reproduce the inequalities they claim to address.

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Data availability statement

Supplementart data will be available on request from any of the authors. This is in line with GDPR rules in the EU. All data have been 'cleaned' to preserve anonymity.

Declaration of generative AI

AI tools were used only for minor language editing under the full control and responsibility of the authors. All ideas, structure, arguments, and conclusions are entirely the authors' own.

CRediT authorship contribution statement

Luana Braz Villanova: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Bruno Peregrina Puga:** Writing – review & editing, Visualization, Validation, Supervision. **Marcus J. Collier:** Writing – review & editing, Visualization, Validation, Supervision.

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.

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Supplementary materials

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