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"Spongetown" Christiania as an urban living lab: Nature-based solutions for resilient, circular, symbiotic, and regenerative transitions in urban waters

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ABSTRACT

Rising sea levels and stormwater flooding threaten coastal ecosystems like wetlands, exacerbating urban sustainability challenges. Urban Living Labs and NBS propose decentralised, community-driven approaches emphasising *resilience, circularity, symbiosis*, and *regeneration*. This study examines Freetown Christiania, a pioneering community-led urban laboratory and countercultural enclave within Copenhagen's socio-technical-ecological systems, as they pursue SDGs within planetary boundaries. We analyse Christiania's urban *niche* using participatory observation and *sociotechnical* frameworks—including *Actor-network Theory*, the *Multi-Level Perspective*, and *Sociotechnical Imaginaries*. We investigate NBS innovations, such as reed bed systems, constructed wetlands, green roofs, and green-blue infrastructure, which exemplify Christiania's integrated urban water management—innovations reshaping Copenhagen's grey infrastructure path dependency, driven by Danish agendas and Sino-European sponge city partnerships.

Identifying key actors, drivers, barriers, and scenarios, our thematic analysis codes problems, interests, and strategies to articulate a proposal for expanding Christiania's NBS niches through urban planning and governance. Findings highlight Christiania's contributions to NBS in wastewater treatment, habitat preservation, biodiversity monitoring, and sustainability ideology. The *Freetown* bridges community-led innovations with municipal and international strategies, positioning itself as a potential pilot for further integrating socio-technical, techno-economic, socio-ecological, and institutional design approaches to urban and coastal sustainability.

We propose a replicable multi-criteria methodology for territorial transitions in Copenhagen, the Baltic, and globally. Based upon IUCN and DGNB standards, we outline criteria for urban NBS proposals developed with Christiania's Building Office and local stakeholders. These criteria inform scenario planning in our project, "Spongetown Christiania," forecasting trajectories and pathways for local governance of infrastructure, urban renewal and development.

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1. Introduction

1.1. Assumptions, research gap and goals

Urban negotiations between the Danish capital's municipality (Copenhagen's *Kommune*) and the community of *Fristaden* (or *Freetown*) Christiania express a clash of sustainable urban development standpoints [1]. During the last decades, a semi-coherent but contested *vocabulary*[1] has enriched the meaning of *sustainability*[2] [2] - a global trend with local-regional-national implications and manifestations. Not bound by a binary classification system (i.e. something is *sustainable* or not), gradients of quantitative and qualitative properties and indicators define the concepts' criteria and categories (i.e. that define how *sustainable* something is).

The thematic and conceptual analysis in the Glossary anchors our literature review to inform the project's theoretical framework. We based our inquiry on *Social-Ecological-Technical Systems* [3] (SETS - which we prefer to designate here as *Socio-Technical-Ecological Systems* (STES) [4]). We propose that the STES umbrella framework's common ground between *socio-ecological* and *socio-technical* fields has implications for *Science and Technology Studies*. Aiming to decipher how this *socio-ecological* reframing might affect the *Multi-level Perspective* (MLP) on *Sustainability Transitions* (ST) [5,6] and the *Actor-network* Theory (ANT) [7–9], we assume that if the MLP decodes the selection environments and evolution of *socio-technical systems* (STS) systems, those are *translatable* as experienceable and tangible *whole/living systems* in ANT's flat ontology[3]. These foundational assumptions enable us to delve into the *transitions* and *translations* of RCSR *sustainability paradigms*[4]. In the methodology section, we clarify how this hybrid ANT-MLP framework was grounded in Christiania's urban development.

1.2. Grounding the problem in case-study design

Integration attempts increasingly suggest that we should consider for *sociotechnical transitions* both systemic-evolutionary and functionalist-structuralist understandings (*Sociotechnical Transitions*, MLP, *Transition Management* (TM), Strategic *Niche* Management (SNM)) as well as material-semiotics and constructivism[5] (Social Construction of Technology, ANT, MoT, *Sociotechnical* Imaginaries (STI), and even SNM) alike). As the theoretical debates try to mend (or deepen) the gaps between entrenched schools of thought, our case study of Christiania and the "Spongetown Christiania" project provide an opportunity to examine these overlapping theoretical frameworks' practical implementation and effectiveness in real-world contexts. Authors who developed *sociotechnical* approaches to understanding urban systems provide essential examples of how to ground these theories in the making of Urban Living Labs (ULL) for NBS and RCSR *transitions*.

Shedding light on MLP-ANT integration, [10] opposes [11] assertions that ANT's "*micro-focus, flat ontology and complexifying epistemology*" hinders its capacity for engaging with MLP (and other *sociotechnical transitions* evolutionary perspectives such as SNM and TM). Maassen argues that "*rather than somehow* 'nesting' *ANT at the* 'niche-level'", we can use the integration of ANT to "*interrogate the character of* 'niches' *and* 'regimes' *before deploying them as analytical units*". Despite this problematic conceptual background, we will assume to be intuitive that Christiania, within this study's scope, acts as a *niche*

[1] In our *Supplementary Material* document [3], on Appendix D, we explore a Glossary of *concepts* (signalled henceforth in *italics)* linked with *socio-technical* and *socio-ecological* processes of *change*, sustainability science, and methodologies originating from these converging schools of thought [62]. We sought to ground these theories in our *Spongetown* Christiania strategic urban planning proposition spanning research, design, implementation, and management domains of *practice* [123].

[2] A robust new definition of *Sustainability* is necessary to reframe oversimplifying notions and represent conceptual diversity of this "*ideological field intertwined with multiple theoretical models in philosophy"* (for our full definition, see the relevant Glossary entry). We believe that different *sustainabilities* represent an amalgamation of concerns, imaginaries, and methodologies underpinned by the *Resilience, Circularity, Symbiosis, and Regeneration* (RCSR) paradigmatic principles. Our chosen conceptualisation emphasises a poly-epistemological, holistic, and heuristic approach aimed at generating *transition* and *translation* processes towards ecological integrity, social equity, and economic viability – acknowledging the *wickedness* of these problems through their *volatility, uncertainty, complexity,* and *ambiguity* (VUCA). Through the lenses of RCSR, we prioritise adaptability to biospheric and climatic change, efficient and effective cyclical resource management, post-anthropocentrism, and positive, just, beautiful, and culturally adequate outcomes, aiming to ensure that human societies, lifeforms, and ecosystems may survive and thrive within Earth's carrying capacity.

[3] The integration of ANT and MLP is crucial in our approach, structuring a nuanced understanding of *translations* of urban STs. ANT is an experience and practice-based constructivist conceptualisation of *whole systems.* Its concept of *nature cultures* [119], *for* instance, reflects this holistic stance. ANT highlights the importance of individual and collective *agency* in effecting change, acknowledging the power of *non-human* and even *non-living* elements of social reality [175]. MLP offers a systemic view of *socio-technical co-evolution*, identifying *pathways* [175,176] through which NBS innovations find trajectories towards *mainstreaming* or *obsolescence*[177]. A dual approach holds the promise of articulating all social "*motors of change*," encompassing teleological, dialectic, evolutionary, and life cycle [178] - perspectives on *sociotechnical* and socio-ecological change that may be understood as oppositional or complementary.

[4] *Resilience* is the capacity of urban systems to adapt, transform, and recover from changes, stresses, and shocks, emphasising initiative-taking and preventive strategies for long-term sustainability teleology. *Circularity* focuses on designing closed-loop, C*radle-to-*C*radle* (C2C) systems that eliminate waste by reusing and recycling materials, promoting resource efficiency, and reducing environmental footprints and societal harm. *Symbiosis* applies principles from natural ecosystems to create cooperative, bio-inspired systems where outputs from one process become inputs for another, fostering harmony between human, living and environmental systems. *Regeneration* extends beyond sustainability by designing systems with net-positive outcomes, actively restoring ecosystems and creating conditions where life can thrive. Refer to the Glossary and its References (Appendices D and E) for an explanation of the origins of the RCSR sustainability paradigms identified during our research and relevant works for those concepts' evolution.

[5] In *Science and Technology Studies*, authors have argued for the necessity of reconciling existing *transition* frameworks such as MLP [179], TM [180], and SNM [10] with constructivist ANT and post-ANT-inspired methodologies. Indeed, these may be within the most relevant *sociotechnical* approaches to frame relationships between technology and society, especially in connection with MLP, as hypothesised by [61], in which these theories were the top choices of the study's respondents. The conceptual framing of *sociotechnical transitions* and *translations* stems from various philosophical paradigms in sociology and organisational development [128]. Within STS, these larger sociological theories differ in their takes regarding the perception of concepts such as *agency* and *change* [147] (nuanced sociological subjects), framing the major lines of scepticism over the possibility of theoretical integration or synthesis.

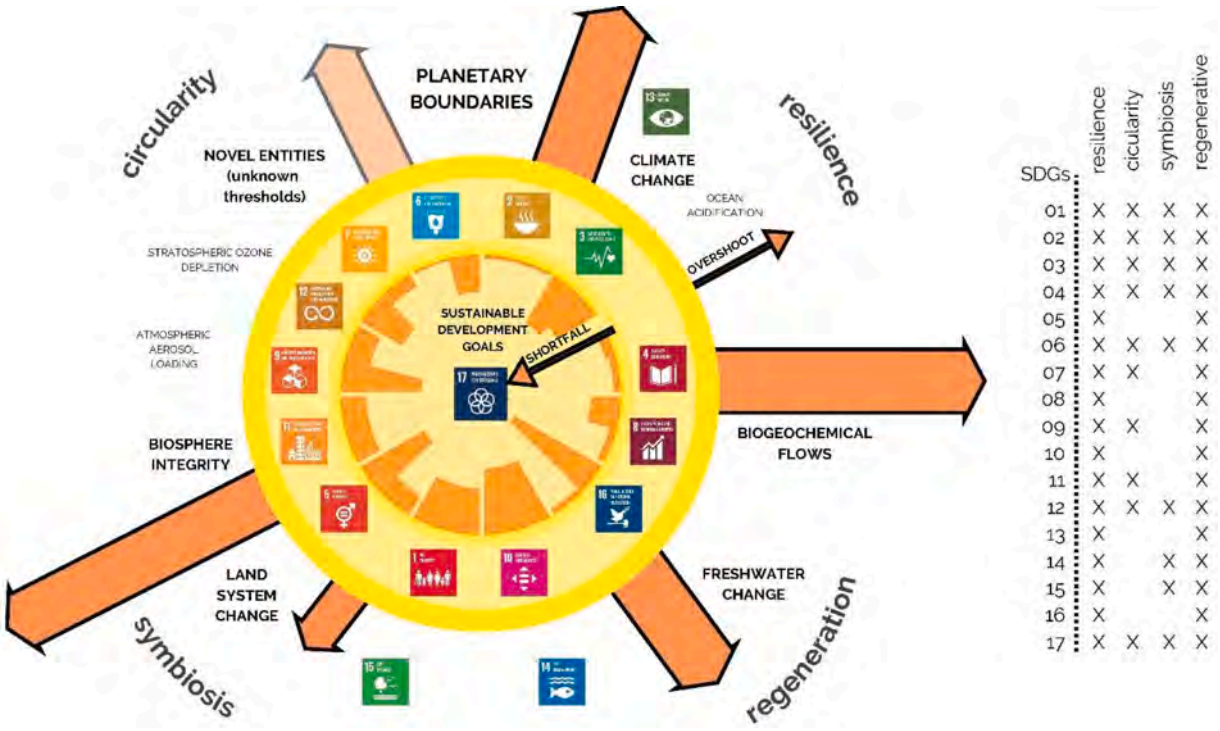

Fig. 1. The Doughnut for the Anthropocene [23] Framework for framing Sustainability teleology, defined by two thresholds: Planetary Boundaries [17] and Societal Foundations. (and related SDGs [20]). Between PBs and SDGs lies the safe and just space for Humanity - the domain for planetary stewardship [18]. Here we surmise Doughnut SDG-PB teleology and track the translation of RCSR paradigms into SDGs. In Appendix B, we analyse DGNB-DK through this lens.

in Copenhagen's urban *regime*[6].

Our Spongetown *actor-network* aims to ground these theoretical discussions by demonstrating ANT's multi-level application potential [12] within the historic,systemic and evolutionary insights of the *transition* frameworks. Here, we argue, MLP could structure the systemic understanding of *multi-level actor-networks* over time and the inherent *translation trajectories* of perceived *matters of fact, value, care* and *concern*. We believe such an approach can lead to more comprehensive results by rooting ANT's micro-spatial-temporality in a systemic and historical understanding of multiple co-evolving *sociotechnical* perspectives. In this study, we will aim this theoretical framework at the study of urban systems and the Water, Energy, Food and Ecosystems (WEFE) nexus.

However, conceptualising cross-level organisations and *actors*' agencies within *multi-level* networks might hinder MLP's hierarchical stratification capacity. Categorisations such as alternative, subaltern niches vs. *incumbent regimes*, or even mavericks within *niches* (which would exist under the conventional MLP micro-level) presented by [13] already alert us to this matter.

1.3. Research questions

Building on these assumptions, the theoretical research question emerges as:

1) *Can material-semiotic/constructivist approaches (ANT, SNM, STI) and evolutionary/systemic frameworks (MLP, SNM, TM) of socio-technical studies be used to analyse translations and guide STES transitions toward urban sustainability in Christiania?*

A reflexive thematic analysis methodology [14] grounded the theoretical enquiry to practice, further specifying our scope, through the following question:

2) *How can we ground the STES theoretical integration within a study of Christiania's transition trajectories using reflexive thematic analysis and multi-criteria urban analysis methods?*

The theoretical framework and proposed methodology were then guided towards the investigation of our Christiania NBS ULL transition agenda:

3) *In what ways can Christiania pursue Integrated Urban Water Management (IUWM) and transition its WEFE infrastructure toward RCSR sustainability paradigms, steering drivers and barriers in STES in Copenhagen and beyond?*

Copenhagen's urban STES positioning steers Christiania's *Lokalplan*. The Danish capital is adapting to the *wicked* [15,16] and urgent challenges of the *Anthropocene*. Shared interest in respecting *planetary*

[6] Alternative *sociotechnical* systems with a greater thematic span than one specific industrial sector (i.e. urban *niches* and their multi-purpose infrastructure) require a *regime* framing that is dubious at best and indecipherable at worst. As an example, our place-community (Christiania) could be framed as a local *niche* component of the vaster municipal urban *regime* or, by opposition, to be its own subaltern/alternative *proto-regime* from the *perspective* of a specific built environment operation in its territory - such as the renovation of a particular local building. Internationally, considering its uniqueness in lifespan within intentional communities, Christiania could be regarded as not even a *niche* but a radical maverick leader in urban decentralisation in a European capital city, keeping it low-density and rich in ecosystems. Similarly, Christiania's RBS pioneer decentralised implementation was a *maverick*-level change in Copenhagen (and international) wastewater and urban *practices* in the 1970s (as the scientific consensus on the merits of the technology and regulations on best *practices* were still being crafted). Under this understanding, only by the late 1980s would RBS become a form of the decentralised wastewater *Constructed wetlands*' *niche*, as regulations became fully fledged, validating an alternative proto-*regime*. It would take another 20 years before CWs became a Best Management *Practice* within the NBS/Sponge City scope, paving the way towards *landscape*-level changes and the promise of being fully integrated into future *regime*-change trajectories.

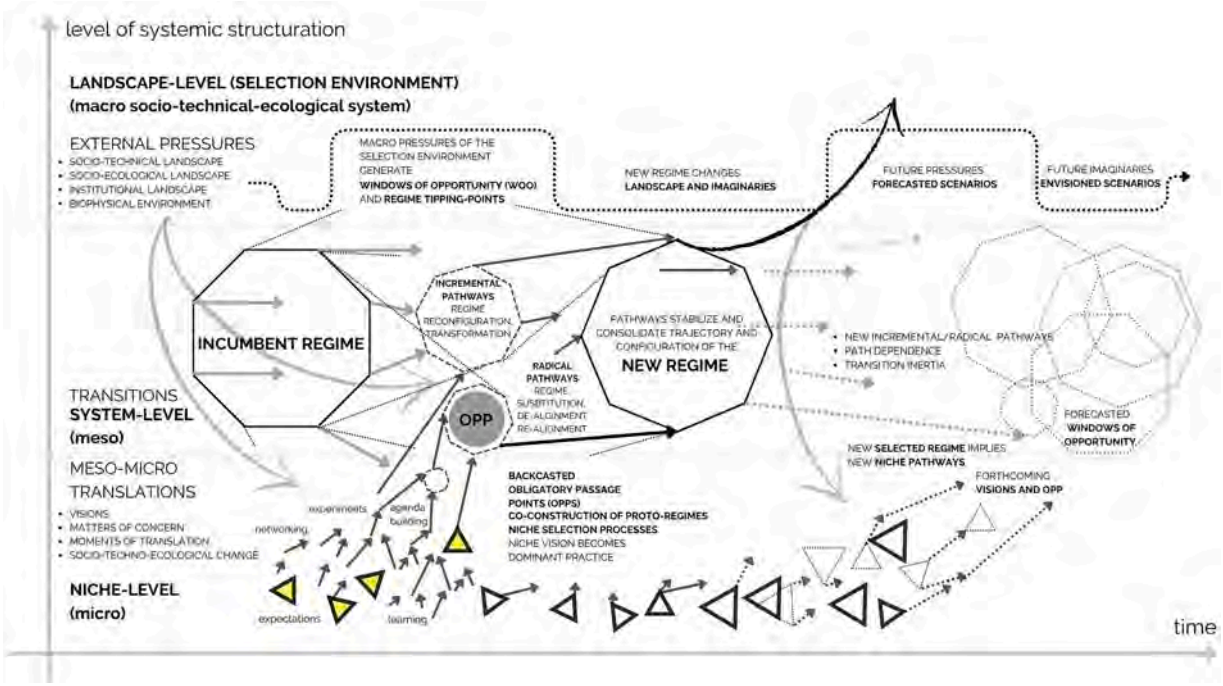

Fig. 2. Our MLP-ANT-TM-SNM-STI integration framework draws on Geels & Schot's multi-level structure [45] to understand translations and TPs of SNM, [46] and TM [47]. ANT contributes to the multi-level translations through MoT[48] which interact with STI concepts [49].

boundaries (PBs) [17,18] is compromised by diverse understandings of how *planetary commons* [19] are to be protected and how *stewardship* translates to SDGs [20] in urban planning *practice* and regulating institutions [21,22]. We endorse the merits of the emergent *doughnut vision* [23] for *sustainability*'s teleology (Fig. 1): finding the common, just, safe, meaningful and beautiful space for humanity's development between societal foundations, ecological ceilings and environmental limits. Our case study, decyphers how these *transitions* are *translated* through standards like DGNB-DK [24] and the IUCN Global Standard for NBS [25] within the Danish built environment and how they may impact Christiania.

Freetown Christiania's *Constructed Wetlands* (CWs) and *Reed-Bed Systems* (RBS) created in the 1970s a pioneer NBS *niche* within the urban *regime* of Copenhagen's municipality [26,27]. Christiania's alternative systems, emblematic of the community's early adoption of *Green-Blue Infrastructure* (GBI)[28], stand as precursor practical experiments of contemporary *Sustainable Urban Drainage Systems* (SUDS) [29], *Water Sensitive Urban Design* (WSUD) and IUWM or even WEFE nexus concepts [30]. Herein lies a local contrast with Copenhagen's *regime path dependence* on *grey infrastructure* [31] for urban water chemical treatment [32]. As an informal ULL, Christiania operationalised RCSR paradigms within its unique urban water management genesis. We assume that the *Freetown*'s alternative technological inclinations provided a tangible countercultural NBS *niche* to Copenhagen's *regime* positioning in the STES *landscape*. We study if and how the community's governance and organisations can *breakthrough* and overcome *lock-ins* at the social, institutional, economic and technical levels regarding urban ST and further *expand* the *niche* for NBS. Together, we prospect *boundary objects* and *interessement devices* between Copenhagen and Christiania STES, decoding their agendas and seeking *Windows of Opportunity* (WoOs) for materialising potential *Obligatory Passage Points* (OPPs) towards furthering RCSR *transitions* between Copenhagen and Christiania [5,33].

Early-on experiences in NBS for urban water STs in Christiania were riddled with *wickedness* [34–37]. As a radically alternative *maverick* effort within a conflictual urban negotiation with the *incumbent* (and literal) *regime*, Christiania stands as an *actor-network* of unofficial explorers of NBS's Life cycles and *Ecosystem Services* (ES) [38], with a pioneering take on the local urban WEFE systems [39]. Their endorsement of the *Sponge City* agenda during this project exemplifies their continuous openness to IUWM *transitions* and international cooperation. On the other hand, Copenhagen's historical *landscape* of economic institutionalism, capitalist welfare state policies, and *neoliberal* global-market tendencies [40] contrasts with Christiania's community/place-based development [41], *decentralisation* ethos [42], alternative governance and market models, such as *degrowth* [43], consensus democracy [42], and localised trade systems [44] which challenges the prevailing *green growth* development model of the Danish economy[7] and the UN's SDGs.

Through MoT, STI, and *Transition Pathways* (TP) Analysis, we sought to operationalise ANT and MLPs as practical tools to describe our case study. Our *participatory scenario envisioning* (STI) combines bottom-up *co-design* of *niche management strategies* (SNM) and top-down *pathway steering* (TM) (Fig. 2). This *multi-level* participatory process should *empower* the *niches* of Christiania's community and *nurture* its *transition agenda*, enabling it to strategise its forthcoming urban plan, mediating negotiations accross multiple levels and fields. Focusing on early MoT of *problematisation* (to which MLP offers an invaluable macro-evolutionary lens), *interessement* and *enrolment*, our *translation* work navigates the intricacies of *gentrification*, centralisation, and social justice issues, proposing urban planning as a *boundary object* and *interessement device*

[7] After the infamous 2011 Stormwater Event uncovered the hidden costs of climate adaptation inaction, Copenhagen's urban planning, governance and markets started incremental steps towards WSUD, GBI and NBS [181], despite the difficulties inherent to a very large network of *stranded assets* and inherent *path dependency* [29,107]. Simultaneously, changes have been happening at the European level that mainstreamed most of the timeless NBS present in Christiania as contemporary best *practices* at the forefront of international urban sustainability agendas, in pilot organisations such as UNALAB, BIODIVERSA+ and formal institutional support of the European Investment Bank and the European Commission [145,171]. However, Freetown's unique positioning as an early-on NBS adopter has not yet been integrated (let alone endorsed or acknowledged) into the broader municipal urban planning *trajectory*, which tends to be more incremental and at odds with radical change scenarios.

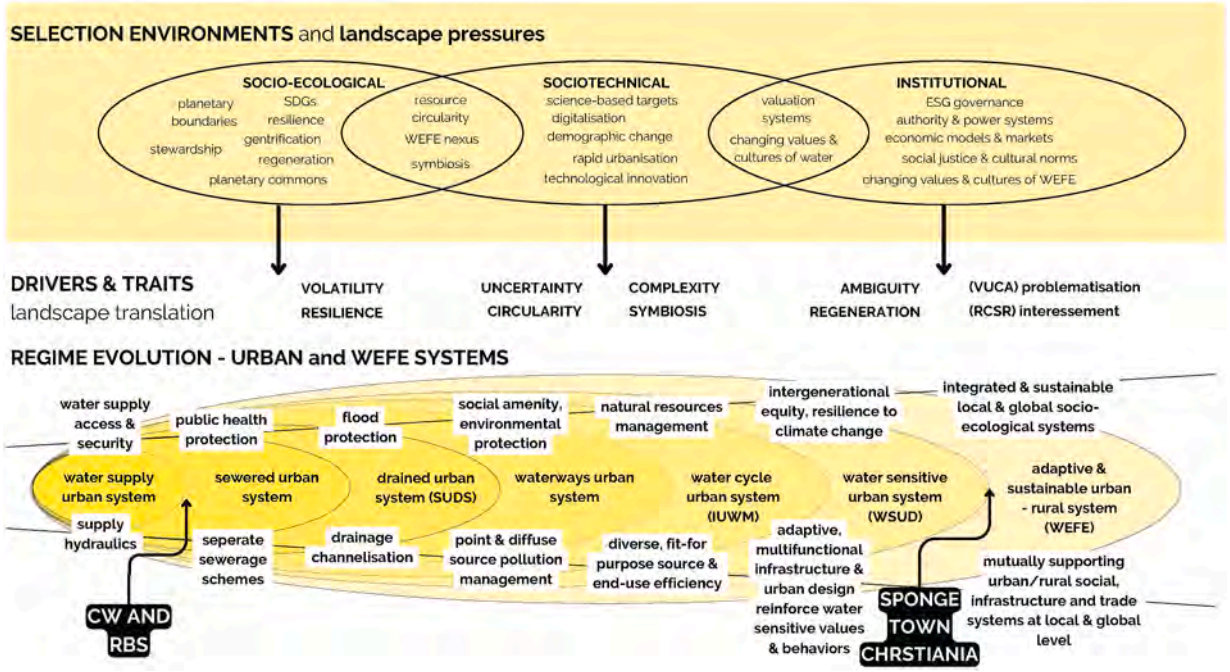

Fig. 3. Main selection environments, evolution drivers and traits to be selected within WEFE systems. The regime evolution of urban water systems is documented by [30], which we used to frame our conceptualisation of WEFE transitions, pathways, strategic scenarios, and visions.

for RCSR *transitions*.

This approach seeks to reconcile ANT's relational insights on the symmetry of experienced meaning and perceived *agency* with MLP's structural embeddedness of *change* and overarching systemic evolution. By balancing these two holistic standpoints perceptions of *sociotechnical* change with differentiated focuses, our research contributes to the discourse on sustainable urban futures, *envisioning pathways* stemming from the complex interplay between meso/micro-level actionable reality and macro-level systemic environment.

2. Integrative social, technical and ecological approaches to sustainability *Transitions*

2.1. Resilient, circular, symbiotic and regenerative urban transitions

2.1.1. Sustainability translations of nature-based concepts

NBS for pursuing ES for SDGs is a testament to the growing place-based *planetary stewardship* agenda. Further *translations* of these concepts take place at the *landscape level* through the establishment of many ESG directives regulating governance and markets at the international and European levels [50] and PB-backed proposals to limit growth, like the *Doughnut Economy*[8]. Both initiatives provide frameworks for governance and market *economisation* of current *sustainability externalities* [51] *linked with green growth* development models by interlocking PBs and *societal boundaries* on *socio-economic systems* [52].

The negative *externalities* that rapid urbanisation and climate change wrought on the WEFE of Earth Systems, as explored by [53,54], reveal the interconnectedness of these vital resource cycles and flows with the *trajectories* of urban waste systems STs [55]. Such global problems are deemed solvable through NBS ULL for urban WEFE-nexus-compliant GBI decentralisation [39,56,57]. Proponents of *eco-localism* [41] and *regenerative design and development*, [58], frame the value of *decentralisation* as a *pathway* to place-based development [59] through *Socio--ecological Systems* (SES) [60] and STS [61] combined fields of studies [4, 62,63].

The discourse shift towards *regeneration* and local *resilience* emphasises the relevance of *decentralised* infrastructure in pursuing *sustainability*. However, *degrowth* and *decentralisation* still seldom gain traction in most international urban *regimes*, as urban density and scale rapidly augment worldwide. We illustrate these broad selection environment pressures in current *landscape perspectives* and *envisioned scenarios* in Fig. 3.

Foreshadowing emergent *bio-inspired* trends in STES *thinking* [64,65], *Biomimicry* (BM) was articulated by [66] as a method that takes inspiration from nature to solve complex challenges, valuing and improving our relationship with nature towards sustainability. As made explicit in *"Biomimicry for X"*, the BM classification framework by [67], BM and *Bio-inspired Design (BID)* methodologies encompass aesthetic, ethical and epistemological diversity – which inadvertently diffuses the role that these approaches have in NBS and RCSR *transitions* [68–70].

The LCA *circularity* model *translation* to economics (*lifecycle* costs), for instance[9], echoes along the principles of BM and BiD methods in urban planning [71], proposing emulating and integrating natural cycles and ecosystems in response to the *externality* crisis of capitalist [72]

[8] In 2023, the *Doughnut* Economics model was translated into "A *Doughnut* for Urban Development" [21,22] by the cooperation of Real Estate and AEC (Architecture, Engineering, Construction) companies and organisations in Denmark, signalling the local *translation* of international *landscape* shifts. Because of this *translation* attempt, the DGNB Planet classification was created in Denmark.

[9] *Life Cycle Assessment* (LCA) is a methodology that stems from the *Circularity* paradigm. It is structural to the notions of *Bio-Economy* (BE) and *Circular Economy* (CE), explored by [182,71]. These concepts offer economic frameworks that dovetail with these ecological principles. BE focuses on the sustainable production and conversion of biological resources akin to natural processes. At the same time, CE champions a closed-loop system, reducing the need for new materials and minimising waste.

economisation and *valuation* processes[10]. Sceptics of green growth and PB complementarity have sprung an array of alternative models such as *Doughnut Economy, Degrowth, Sharing Economy, Ecological Economy,* and *Sharing Economy* [73,74], advocating for post-growth and post-capital policies.

Despite their troublesome socio-economic implications, ES and LCA are viewed as the bleeding edge of applied sustainability research in urbanism and NBS in the built environment [68,75,76]. Combining the approaches should shift us from a mere damage mitigation, net zero, and *circular lifecycle* problematisation towards a *resilient, symbiotic* [77] and *regenerative* approach for net-positive urban design and development [78]. The conceptualisations of urban systems as *urban ecologies* [79], *metabolisms* [80], and *symbiotic relationships* align closely with NBS emergence [71]. *Bio-inspiration* [75] has led ecological urbanism proponents to view cities as *living systems* [41], emphasising going beyond optimisation of resource and energy flows by promoting *symbiotic* meaningful relationships of *stewardship* [81,82] between urban communities and their home environments[11].

Underscoring the importance of a balanced transdisciplinary integration for sustainability projects, [83] review several design methodologies and their contributions for a potential STES framework for the design of RCSR transitions. Our thematic analysis asserts the need these authors diagnose for systemic *transition* design to be nourished by knowledge stemming from complementary ecological, social, and technical domains, understood by different epistemological, ontological, heuristic and ethical backgrounds.

2.2. Integrated urban water management - transitioning from grey infrastructure to the sponge city concept

Within the *landscape* of urban WEFE *transitions* [55], NBS are catalysts for RCSR *systemic change* . In this realm, a tangible STES shift occurs: from centralised engineered *grey infrastructure* [84] to the ecologically attuned systems of NBS for GBI [28,85,86][12].NBS and *living systems*' design must account for ES synergies and inter-systemic connectivity [62,87,88]. The *Sponge City Concept* (SCC) synthesises the coastal *translations* of NBS, GBI and ES in urban environments [89–91]. Worldwide, various regions have adapted the SCC [92], reflecting diverse TPs and *scenarios* [30] connected with *multi-level dynamics* between *incumbent grey* and alternative *green, blue, brown, and multi-coloured* [93] infrastructural systems. Tapping the demand for social benefits of the SCC's ES, NBS elements increment natural or semi-natural systems presence in urban areas, providing foundational assets such as air and water quality regulation, pollution filtration, prevention of soil erosion, flood risk reduction, biodiversity and eco-systemic bridging [57,94].

The SCC fuses these transformative *multicoloured* infrastructure NBS and SUDS as critical components to address environmental change events across multiple urban regimes. As documented by [95,96], SUDS integrate natural *green* and *blue* elements into planning pluvial drainage and wastewater infrastructures, intending to blur the dichotomies between built infrastructure and natural environments. *Sponge cities* employ SUDS and GBI not merely as functional elements—integrating grey transportation and treatment systems with local urban ecosystems—but also as vehicles for decentralisation via inter-local management [84,97,98]. In Fig. 3, we highlight these global *trajectories,* finding *pathways* beyond *grey-centralised* systems that structure our MLP analysis of Christiania's potential for implementing regional, national and international RCSR agendas for urban water management.

The WEFE Nexus exemplifies the c*ircularity paradigm*'s *translation* within the global territorial governance of STs [99] At the urban level, the SCC and WSUD envision cities functioning like *living systems*, resonating with *symbiotic* (*bio-inspired* and *biomimetic*) NBS agendas [100]. These trajectories transcend conventional water drainage, effluent treatment and urban growth [101] to encompass a broader spectrum of principles of urban development and WEFE management for territorial STES *resilience* and *regeneration*.

IUWM unifies aspects of urban systems commonly addressed mainly by *grey infrastructure* [102], emphasising the interconnectedness of water, materials, energy and nutrient flows, in urban and coastal conservation and weaving these elements into cohesive WEFE infrastructures for urban systems planning. Authors in *Sponge City* literature claim the SCC to be a specific design example of IUWM *translation* [103,104], focused on absorption, infiltration, and retention as water resource management strategies. They contribute to climate-change adaptation, through stormwater runoff drainage, sea-level rise management, and biodiversity promotion. These concepts showcase a novel *proto-regime* in the AEC sector. They mark a radical *regime* shift in which the *niche expansion* of NBS and GBI continues changing urban *regimes* in association with *landscape* drivers at the regional-to-planetary levels.

An MLP on the STs of Urban WEFE Systems, as delineated by [105], offers an analytical framework that could describe the evolution of RCSR paradigms as they meet the built environment planning sector [106] and the broader macro-territorial WEFE industrial infrastructure, and its institutional systems . Constructivist and systemic-evolutionary perspectives have been used to map *transition trajectories* and interactions between *incumbent* socio-technical-ecological configurations in Denmark by [107], echoing *landscape* level and related *regime transition* and *translation* developments [108]. The combined explanatory power of these perspectives may further clarify the dynamics of STES's changes and the spectrum of sustainability micro-innovations and macro-evolutions within urban WEFE management systems (Fig. 4).

2.3. "Spongetown": The multi-level management of Christiania as an urban living laboratory for translating NBS in Copenhagen's RCSR transitions

People know Christiania, a semi-autonomous neighbourhood and

[10] Engineering and scientific approaches to NBS still struggle with Life cycle and ES integration [38,76] and are faced with the daunting task of pacifying these services within *incumbent* markets and governance as a new NBS technological paradigm unfolds [75] at odds with conventional *anthropocentric economic valuation* concepts. ES illustrates nature's indispensable role in human well-being, encompassing *provisioning, regulatory, supporting, and cultural services*. These *services* (or *disservices*) may form the new bedrock of informed and sustainable urban planning for broader ecosystem integration and *Stewardship*. Still, trade-offs between them and the assessment of impact are typically economised. Bio-inspired NBS approaches to RCSR urban *transitions*, such as Urban Biomimicry for design processes, hold a lot of promise but require Life cycle and ES integration [66,68,71], which are still at odds with *incumbent* typical anthropocentric and *capitalist* economic systems of *valuation*.

[11] [89] (among many authors in this literature) presented NBS not merely as urban ecological add-ons but as pivotal elements in urban *cultural change* towards *sustainability*, beyond traditional notions of carbon neutrality and economic *circularity,* focusing instead on broader RCSR (i.e. boosting urban systems integration of biodiversity), and acting as tools for *transition* towards "*ecological civilisations*" (an ambition acknowledged by the Chinese government as the purpose of their SCC regional watershed *translation*). We extrapolated our *sustainability paradigms* from [71] symbiotic [67,183] and *regenerative* [184] frameworks for Circular Cities, adding the *Resilience* concept from SES thinking [185,101].

[12] [57] and [95] emphasise NBS as cost-effective, resource-efficient solutions inspired by nature, aiming for systemic interventions and local adaptation [133] specifically highlights the role of CWs as NBS in decentralised wastewater treatment as a *practice* that could restore wetlands' protagonism in today's cities [155,186]. Similar calls for action rally urban planners around other GBI for coastal ecosystems, from riparian areas to shorelines and coasts, as our attention turns even towards uncharted territories, striving to replenish key marine ecosystems such as kelp forests, seagrass meadows, and reefs in connection with coastal urban planning [25,187,188].

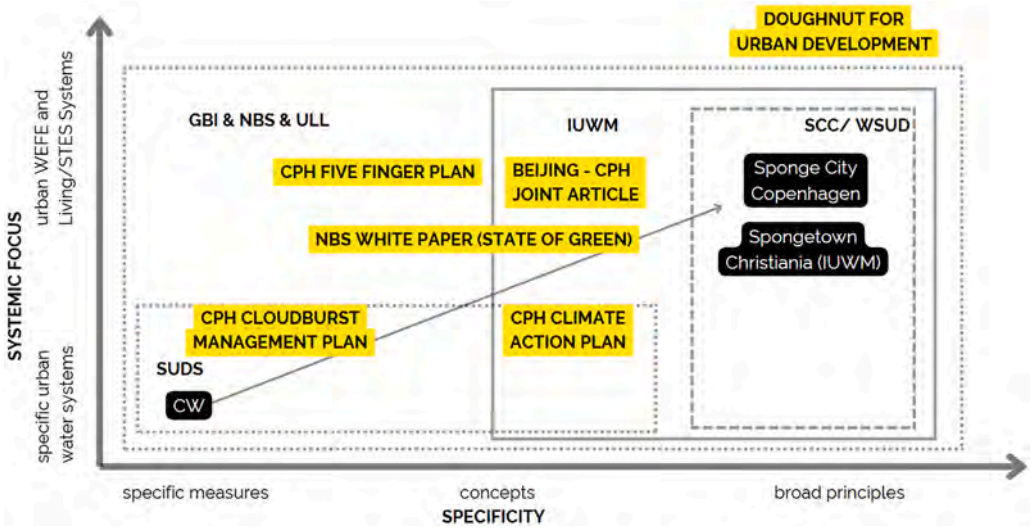

Fig. 4. Systemic Focus and Specificity of WEFE concepts, framework adapted from [108] and adapted to our work to map measures undertaken at the regime level towards urban WEFE transition in Copenhagen.

intentional community in Copenhagen, for the alternative lifestyles, its vibrant counterculture, their participatory approach to sustainable urban living, and even the consensus-democracy governance of its local institutions [36]. Since its early military base days of popular "*squat*" occupation during the 1970s, VUCA factors in Christiania's *wicked* urban genesis caused problems for the community. The neighbourhood's illegal status, contested governance, and political stances stirred much of the *multipartisan wickedness* in the unique trajectory of this neighboorhood, influencing the city at large [1,35,37,44].

Copenhagen municipality's inability to provide an effective urban planning response to Christiania's informal emergence generated unmet needs. Rising demand became fertile ground for pioneering experiments adopting the alternative systems described in the previous section. CWs, composting toilets, green roofs, urban farming in Christiania proves the capacity for NBS to promote *decentralisation* in willing communities with strong sustainability ethos [43,109]. Mutual non-compliance of institutions and regulations created ambiguity and ambivalence in the urban management of a territory contested between a *regime* and a *niche* disputing construction standards and proprietary structure. These effects were necessary collateral damage for the greater good of local autonomy and *regime laissez-faire* coexistence for decades.

Danish courts decided Christiania's future *trajectories* in 2011—almost 40 years after its founding—when the state claimed rights over the land, but offered the community the option to have it sold back to its association's fund [1,110]. The ruling marked the start of negotiations of other sort - now aiming to address the legal and regulatory challenges that have hindered Christiania's integration into the mainstream urban planning and governance initiatives in Copenhagen [111]. The is situation to be mended by unfolding plans and regulations leading to a much antecipated forthcoming *Lokalplan* after many postponed and outwardly rejected attempts.

Locals and sympathisers claim an official external endorsement of Christiania and its devotion to radical, grassroots sustainability is overdue as a matter of *recognitional justice*[13], according to various research papers that have studied this small, rather unique and revolutionary neighbourhood [36]. As of 2025, Freetown was still renegotiating (see Table 1. for a complete overview) its legalisation and institutionalisation terms. Further inclusion in the city's infrastructures and urban strategy becomes even more necessary because of the looming threat of climate change impacts (Fig. 5) especially stormwater surges, violent rainfall and rising seawater and groundwater [112], which have caused considerable damage to the city's and neighbourhood's infrastructure and urban assets in the recent past, integrating concerns of multiple parties.

3. Methodology

3.1. Research and case-study design assumptions

In this study, it is further assumed that overlapping concepts from different STS schools of thought — such as MoT (ANT), TPs (MLP), *niche management strategies* (SNM), *visions* (STI), *transition arenas and adaptive governance* (TM) — may bridge between material-semiotic and systemic-evolutionary studies of the *sociotechnical*.

For instance, MoT in ANT, which includes *problematisation, interessement, enrolment*, and *mobilisation*, aligns with TM/MLP's emphasis on *transition pathways* by describing how agency is stabilised in network relationships, changing actors and constructing and enacting *systemic transition* across multiple *actor-networks*. Similarly, *niche* management strategies (SNM) and *niche-regime* interactions (MLP) explore how *actors shield, nurture, aggregate*, and *scale* innovations to *expand niches* and challenge dominant socio-technical *regimes*, through different *pathways*.

Sociotechnical visions anchor perception of the future in this integration by embedding fantasies, goals, ideographs, and symbolic cues into the *translation* of *transition* processes, connecting the relational dynamics of material-semiotic approaches with the long-term *systemic change* emphasised by evolutionary frameworks. Likewise, *adaptive governance* (TM) advocates *visioning* (*forecasting*) as a relevant participatory tool to be used within *transition* arenas and towards *backcasting* OPPs (Fig. 2), facilitating the alignment of diverse *actors* across scales and maintaining flexibility in response to changing scenarios, teleologies and *imaginaries*.

3.2. Grounding theoretical hypotheses

While rooted in distinct theoretical foundations and perspectives, the overlaps of STS conceptualisations highlight commonalities in their explanatory focus on the processes and mechanisms of STES's

[13] Alternative systems and infrastructure built by Christiania's pioneers are now wrapped up under the umbrella term of NBS as the mainstreamed bleeding edge of EU's urban research, investment, and political endeavours. Christiania's *niches* are pioneering examples in Copenhagen of current internationally acclaimed best *practices*, of the NBS for GBI [189] that Copenhagen strives to implement [190].

Table 1
Timeline of Events across the AEC & Sustainability Landscape, Freetown Christiania Urban Niche, and Copenhagen Urban Governance Regime.

Year/Event Level	AEC & Sustainability Landscape	Freetown Christiania Urban Niche	Copenhagen Governance and Planning Regime
1967–1971		Christiania is occupied; squat projects begin	Danish Armed Forces vacate military site; initial police resistance fails
1971			Initial police resistance is unsuccessful because of the high popularity of the squat project
1972		Common Meeting and First Institutions are Developed with Local Pioneer Communities	Temporary Agreements between State and Squatters
1973			Authorities push to normalise Christiania and organise a competition for a public project for the area
1974		Christiania finds its way towards representation in the municipality through the Women's List	
1975		**Christiania becomes a matter of concern at the National level in Denmark**	
1976	Danish Energy Agency founded in response to the energy crisis	Legal Action from Christiania due to the State's breach of past promises	The Ministry of Defence places a court case for the expulsion of Christiania's Squatters
1980	IUCN, WNF, UNEP co-author World Conservation Strategy		
1981		**Nature-based Solutions Projects begin in Christiania as Pioneer Urban Sustainability Experiments (RBS, CWs, Greens Roofs and Walls…)**	The Ministry of Environment commissions Møller & Grønborg to develop a Local Plan
1985	Danish nuclear phase-out plan and wind programme started		
1986		Christiania releases the "Voilá Report" affirming capacity for Self-Organisation	
1987	Brundtland Report "Our Common Future"		
1987		**Special Committee for negotiations between Christiania and Public Authorities**	
1988		**Municipality's plans for progressive normalization of Christiania face local resistance and uncertainty**	
1989		Inhabitants express distrust over the plan. Concerns over the disruption of Christiania's rurality arise.	Christiania's Law enshrines local autonomy, but territory is to be divided into rural and urban areas
1990		Declaration of Affection by Christiania invites outsiders to experience life in the Freetown	Copenhagen Finger Plan is established
1991	World's first offshore wind farm in Vindeby	**Christiania's Green Plan is published;** Technical Maintenance Office is Instituted	
1992			Authorities push for a local tax on Christiania's inhabitants, and an **agreement is reached**
1994		Substance abuse grows and prohibition laws escalate the issues in Christiania	
1996			Previous Lokalplan is revisited with Christiania's participation
1997		Christiania's own currency "Løn" is established with the worth of 50 DKK	
2001			Stricter Governmental attitudes towards Christiania return to national government
2004		Christiania eliminates the Green Light District's drug trade visibility to gain bargaining power	The Ministry of Defence loses jurisdiction over Christiania's territory; the Culture Ministry gains oversight over the land
2004-2005	**Copenhagen Municipality attempts to approve a plan for the construction of 30.000 sqm. in Christiania. Vandkunsten Architects collaborate with Christiania to develop the "Christiania Is Not For Sale" alternative project and plan.**		
2005		Knud Foldschack represents Christiania's legal interests and concerns	The Culture Ministry's Agency publishes documents on ownership modes as an offer to Christiania
2006		Christiania rejects the offer and proceeds with a claim for prescriptive rights to the land	Various offers to Christiania's formalization as territorial owners through transaction processes
2007	DGNB system established in Germany; State of Green Collaborative Non-profit AEC Hub is founded for the Danich AEC Sector's Sustainability Transition	Christiania accepts a landownership offer after negotiations	
2008	IUCN launches Global Nature-based Solutions Initiative	Christiania is pressed to make a final decision	New local plan for Christiania is attempted
2009	COP 15 Conference in Denmark		Copenhagen 2025 Climate Plan Copenhagen Green Roof Mandate
2010	Green Building Council Denmark is Established; Danish Nature Agency is founded		
2011	**Copenhagen's Cloudburst event kickstarts environmental agendas and empowers organisations towards climate adaptation and sustainability policies.**		
			Copenhagen Climate Adaptation Plan is drafted
2012	Copenhagen-Beijing Sister Cities Collaboration	**Ongoing agreement for 15.000 sqm is reached, fulfilling Christiania's Law of 2004. Internal institutions and self-organisation capacity recognised by state, but further normalisation attempts ensue.**	

(*continued on next page*)

Table 1 (*continued*)

Year/Event Level	AEC & Sustainability Landscape	Freetown Christiania Urban Niche	Copenhagen Governance and Planning Regime
2012-2013	DGNB-DK system is adopted by Danish Green Building Council nationally		Copenhagen Cloudburst Management Plan; Copenhagen Green Mobility Plan
2016		Gang violence escalates around Pusher Street; drug trade stalls closed	Police raids of Christiania's Pusher Street/ Green Light District begin
2018	Strategic Sector Cooperation celebrated between Beijing and Copenhagen		Building Regulations (BR-18); Copenhagen Circularity Strategy
2019	National Strategy for Sustainable Construction and Approval of a Voluntary Scheme for Sustainability Assessment		Copenhagen Municipality Plan (KK19); Lynetteholmen Urban Plan
2021			Copenhagen Climate Plan 2021-2025
2022	Public Chenese-Danish workshops on Sponge Cities; Joint Sister Cities Report on Sponge Cities at International World Water Congress	Pusher Street stalls are closed following murders related to black market escalations	
2023			Copenhagen Biodiversity Strategy "Place for Nature"
2024		Escalating gang violence builds a tighter agenda between the municipality and the inhabiting community towards drug trade abolition	Copenhagen Storm Surge Report
2025	**Pusher street and green light district are closed by the local community with municipality support supervision and police enforcement; urban negotiations resume planning, coupled with the ongoing urban renewal projects and building renovations.**		

transitions. Thematic commonalities and interdisciplinary conceptual patterns are at the root of our methodological choice for *thematic analysis* to drive our *theoretical grounding* endeavours in Christiania. We present the results of our thematic analysis of the literature, tested through case-study grounding, in a glossary of concepts in Appendices D and E. The complexity of the grounding process, the field of research, and the case itself led us to neither set aside quantitative approaches to thematic analysis or structured processes for coding, nor to consider them central to our study. We use inductive and deductive processes, subjectively anchoring our participants in standpoints of the relevant literature and vice versa – our participants being fairly well acquainted with urban sustainability [14,113].

The research posits hypotheses that explore the potential for integrating these frameworks, the role of Christiania in assessing this integration, and the implications of their combined application:

- **Theoretical Complementarity Hypothesis** Material-semiotic constructivist approaches (e.g., ANT, STI) and systemic-evolutionary frameworks (e.g., MLP, TM, SNM) are complementary, offering distinct yet not unreconcilable perspectives on STs and *sociotechnical* reality. Their integration enhances the analysis of relational dynamics and systemic trajectories, bridging micro and macro-level processes.
- **Conceptual Bridging Hypothesis** Shared concepts—*translation, transition* pathways, *sociotechnical* visions, *niche* aggregation, and participatory governance—may bridge theoretical integration. Assessing these concepts within an actual *transition* experiment in Christiania will reveal whether material-semiotic and systemic-evolutionary approaches can align effectively. If not, it will reveal to what extent their operative concepts overlap and if they are redundant, complementary or contradictory.
- **Incompatibility Hypothesis:** Despite their theoretical potential for complementarity, these frameworks' ontological and epistemological differences—such as ANT's flat ontology versus MLP's hierarchical structuring—may create irreconcilable tensions that hinder their integration or of specific concepts from different theories.
- **Christiania as a Testbed Hypothesis:** Christiania's governance model and experimental *practices* in NBS and ULL provide a unique context for evaluating the feasibility of integrating approaches to urban STs and *translations*. The study tests whether these frameworks can converge in theory and practice by analysing Christiania's *niche*-level dynamics and interactions with Copenhagen's urban *regime* and relevant organisations.
- **Scaling and Transferability Hypothesis:** Grounding this hybrid framework in Christiania tests its assumptions and may demonstrate its applicability as a transferable model for STs in other urban contexts. Christiania's *practices* offer insights into how localised *actor-network* stabilisation can influence *systemic change*, providing a blueprint for similar initiatives globally.

3.3. Materials and data collection

This study employed a reflexive thematic analysis (RTA)[14] as its primary analytical framework, and infused with elements of constructivist grounded theory (CGT) [114,115] and interpretative phenomenology (IPA) [116,117]. This hybrid approach gathered and co-produced knowledge on urban *transitions* by connecting individual and collective meaning-making with systems-level *change*, enabling us to interrogate the interplay between theoretical concepts, lived experiences, and participatory design artefacts within a real-world STES. Our research began with an extensive literature review, focusing on key *sustainability paradigms*, STES-thinking, as well as NBS- and STES-related design schools, particularly *sociotechnical, socio-ecological*, and *bio--inspired* approaches, alongside *Multi-Criteria Decision-Making* (MCDM) [118] methodologies relevant to infrastructure and urban water STs. These theoretical domains informed our analytical direction and grounded the iterations of a project-specific glossary of terms, which reflected empirical *matters of concern* and supported the iterative refinement of project assumptions and theoretical frames.

The glossary played a pivotal role throughout, initially populated by themes from the literature review and early coding iterations and subsequently shaped by field engagement and literature revisiting. As a *boundary object*, it enabled a reflexive co-construction process, where we introduced glossary terms to interviewees and workshop participants, inviting collaborative refinement. This helped develop precise, non-redundant terminology and fostered a shared language between researchers and participants, embedding the theoretical scaffolding within the case study context. This iterative exchange led to mutual immersion between researchers and participants in the language of STES *transitions*. We operationalised a grounded theory approach to integrate STS and SES concepts, drawing on ANT, MLP, TM, and SNM to explore sustainable *transitions* and *translate* concepts like NBS, GBI, SCC, IUWM, and RCSR through MoT, TPs, *Niche* Management Strategies, and *Socio-technical Visions* across social, technical, and ecological realms.

Fieldwork followed an observant participation method guided by ethnographic immersion. Primary data collection (Appendix A -

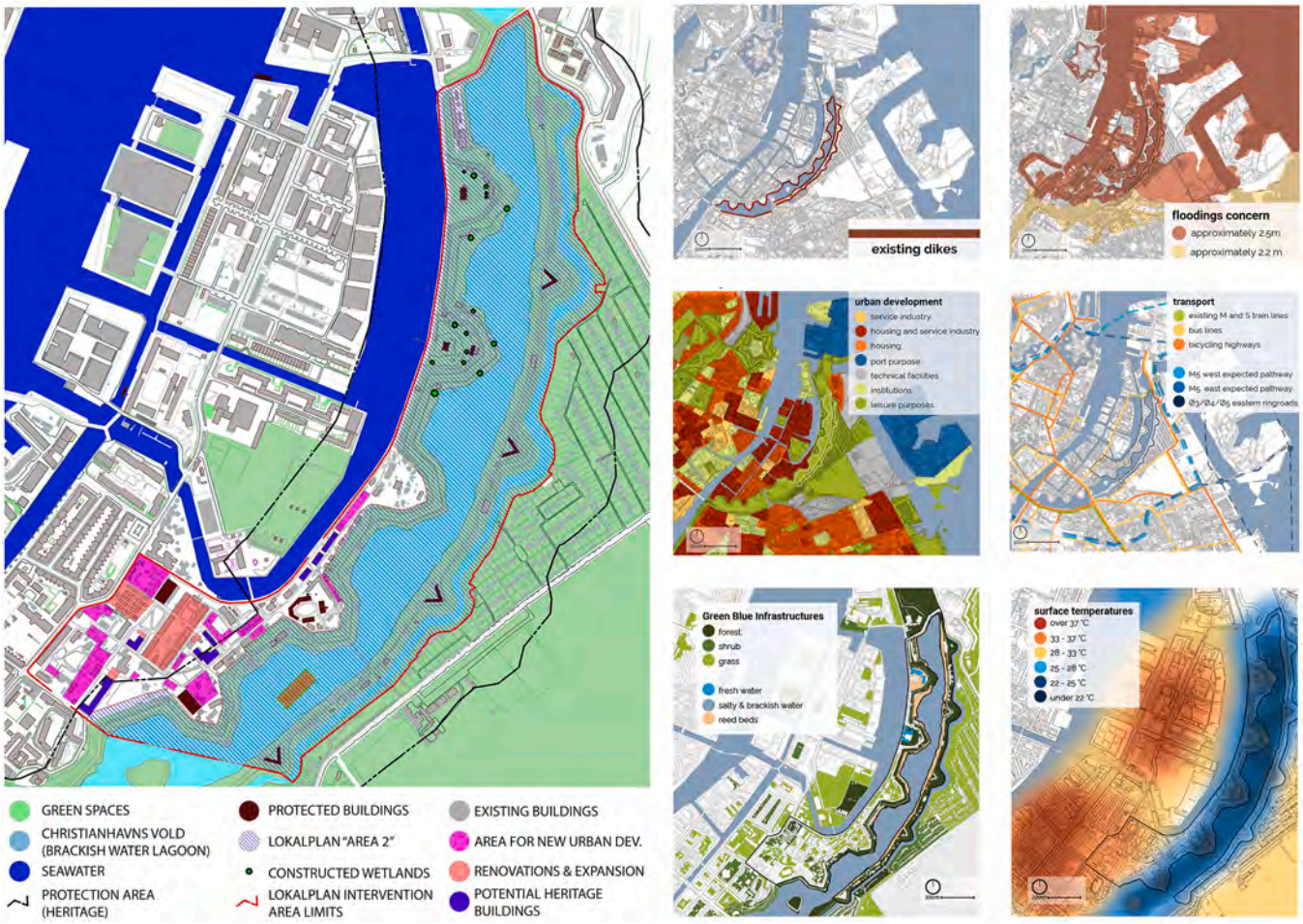

Fig. 5. Based upon data from the 2008 Christiania's *Lokalplan* and municipality data we mapped the main territorial boundaries and urban sustainability prevalent themes deemed relevant for Spongetown Christiania's management area as an ULL and urban planning device and updated its urban analysis with current urban sustainability agendas. A broader and more detailed analysis can be consulted on Appendix B[3].

Fieldwork) included fifteen semi-structured interviews with residents, designers, engineers, public servants, and researchers involved in Christiania's community projects. Participants were identified through snowball sampling based on their roles and networks. We transcribed interviews, lasting 45–90 minutes, from audio recordings and documented them through descriptive field notes. All data were anonymised according to GDPR protocols, referring to participants by role-based descriptors. Additional material included project reports, urban planning drafts, internal communications, working maps, community notices, and design briefs, primarily sourced from Christiania's *Byggekontor*, BACESS A/S, the municipality of Copenhagen, and Danish or European governmental agencies (Appendix B – Urban Analysis; Fig. 5). These documents were coded alongside interview data and literature, serving as empirical sources and as triangulation points for conceptual reflection.

Production analysis focused on evaluating artefacts of community engagement, such as sketches, annotated maps, technical drawings, and workshop outputs expressing ideas for NBS and IUWM interventions. Researchers performed a semiotic analysis of these materials to interpret how the community visualised and communicated STIs. Structured workshops and co-design activities were iterative, interactive sessions employing serious games (questionnaire bowl, wheel of change), scenario building, visioning, and participatory mapping. Techniques from co-design and participatory planning methodologies brought diverse stakeholders into shared *imaginaries* of transformation. Field notes and photographic records from these activities were coded, anonymised, and thematically integrated. A survey questionnaire was distributed to 20 stakeholders, combining closed Likert-scale items with open-ended questions to assess perceptions of NBS performance, IUWM applicability, governance capacity, and understanding of RCSR principles. Researchers purposively selected participants based on their project involvement, pseudonymising responses solely for publication.

These data allowed us to develop a *multi-level actor* mapping and a timeline of *transition* events, consolidated into diagrams and schematics by visualising *multi-level* interactions and relationships. These tools served dual purposes: aiding our analysis of *socio-technical* and *socio-ecological* domains and acting as participatory *boundary objects* in workshops and project presentations, stabilising meaning and aligning stakeholder perspectives across technical and narrative aspects.

We applied RTA iteratively and recursively to reflect the developing nature of the project, with pattern detection and meaning-making following phenomenological immersion. The process began with familiarisation, involving repeated readings of field notes, transcripts, and documents, accompanied by memo-writing and literature review. Initial inductive coding was enriched with theoretical constructs from ANT, MLP, SNM, TM, and *Sociotechnical* Imaginaries (STI), leading to the grouping and refining of coded experiences around glossary terms and emergent categories. Iterative revisions of theme boundaries and coherence, informed by feedback loops with stakeholders, followed theme development. Theme coding and definition integrated stakeholder-derived expressions with literature-consistent terminology, while narrative construction embedded themes in interpretive passages grounded in field interactions and glossary terms. Throughout this process, we maintained analytical memos documenting decisions,

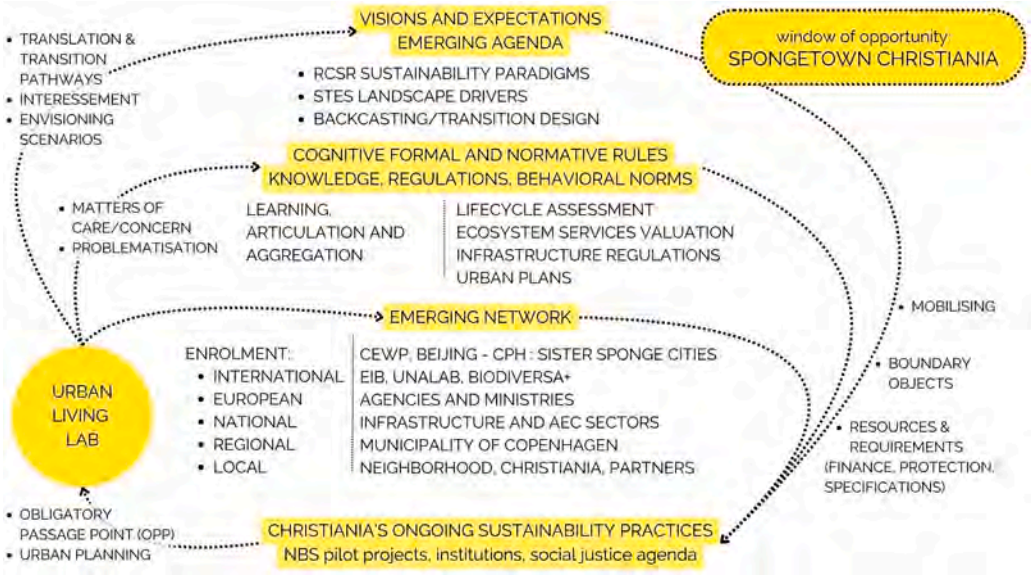

Fig. 6. Multi-level framing of three niche processes identified by SNM (expectations, networking, and learning). adapted to *Spongetown Christiania*, from [46].

coding evolutions, glossary refinements, and participant reflections, serving as a reflexive audit trail that captured how meaning was generated across theoretical and empirical dimensions along two different semester reports within our Sustainable Design Engineering MSc. and a thesis with Aalborg University – Copenhagen. We compiled the most relevant results of this process in our Supplementary Material document [3].

Stakeholder presentations and feedback sessions validated the results and provisional designs, fostering co-responsibility for *transition* pathways and aligning the Spongetown strategy with the local agenda and institutional context. This culminated in the proposal of a design and policy roadmap, incorporating insights from our hybrid analysis into the emerging urban plan. Based on research findings, we formulated policy and regulatory considerations to support IUWM and NBS implementation through frameworks such as IUCN-DGNB and developed a strategy for NBS and GBI within Christiania's urban agenda, aligning with the forthcoming *Lokalplan*. A customised IUCN-DGNB criteria set formed the basis of the strategy; we refined this set into strategic visions and selected scenarios using *a Strengths-Weaknesses-Opportunities-Threats* (SWOT) Analysis across *Political, Environmental, Social, Technological, Economic and Legal* (PESTEL) domains (see Appendix B).

4. Analysis and results

We developed a *multi-level translation* [11,119] (Figs. 2, 6) approach to *transitions* based on ANT, MoT, TM, SNM and STI (Fig 7, Fig. 8), through which we made use of the MLP to overcome the barriers and tap the drivers of mainstreaming NBS adoption and RCSR *translations* and *transitions* between Copenhagen, Christiania and the larger international context. We pursued with the *actors* enrolled in this project the *vision* of creating an *obligatory passage point* (OPP) [120] to inscribe our *Spongetown Concept* into the forthcoming Urban Plan. ULLs can be framed as *constellations* of urban *niches* [121,122] for the design and development of urban experiments for STs – in this case, for the *translation* of the SCC in Christiania, by making use of partner *niches*, *incumbent* agendas and RCSR *sustainability landscape* pressures in urban WEFE systems [41, 123–127].

Through STS and SES frameworks [4,62], we structured a *multi-level* management approach between forecasting *landscape* drivers, *regime* adaptation scenarios and *niche*-oriented *transition* strategies by focusing on the local *niches*' perceptions of *landscape* pressures and *regime* structure through our interviews regarding *sociotechnical, socio-ecological* and *institutional* aspects. We used *translation* tactics to generate systemic WoOs with our participant stakeholders, focusing on the RCSR aspects of sustainability and their STES ramifications (A.4; A.7; A.8; A.10; A.11; A.12; A.13; A.14; A.15; A.16; A.17).

Grounding our theoretical framework in lived experience, we explored the ULL framework as an opportunity for evolutionary, cyclical, teleological and dialectical processes of *change* [128,129] to be perceived and unfold in urban planning practice. Through concepts such as *scenarios, visions, ideographs, cues and fantasies* of STI [49], we negotiated *translations* of this conceptual framework within our hybrid TM and SNM approach to *transition* steering and *niche* management of Christiania's built environment and WEFE infrastructure.

Dominating regulations, management systems, technology paradigms, conventional problem-solving and cultural barriers support the *incumbent regime* of centralised wastewater treatment. Contrasting with the broader *landscape* context, Christiania's *niche* operations and imaginaries need alternative approaches to its management, considering its role in broader *transitions*. Christiania has repeatedly demonstrated its forward-thinking approach to social and environmental issues [35,130]. The STES *change* management framework, depicted in Fig 7, visually represents our analysis, highlighting the interplay of *imaginaries, translations,* and *transitions* within the *niche, regime*, and *landscape* levels. In Fig 6, we *ground* that approach to MLP to our case-study *transition* analysis, assumptions and forecasted relevant scenario for further research.

4.1. RCSR transitions in a changing landscape: Innovative decentralised NBS vs. grey-centralised path dependency

Decoding the *translation moments* of RCSR paradigms in ongoing ST drivers in the *landscape* [131] is key to understanding the behaviour of urban *niches* like Christiania and *regime* components in Copenhagen and Denmark [27]. In Christiania, we witness a *transition* from grey-centralised *Wastewater treatment plants* (WWTP) to decentralised NBS through CWs finding their place in the community's *protective space*. This generated a local *proto-regime* with potential replicability throughout the region, resonating with many other emergent bio-based technologies and NBS in general.

Our Analysis section starts with the history, stories, and discourse underlying problematisations and interests that led to the community's

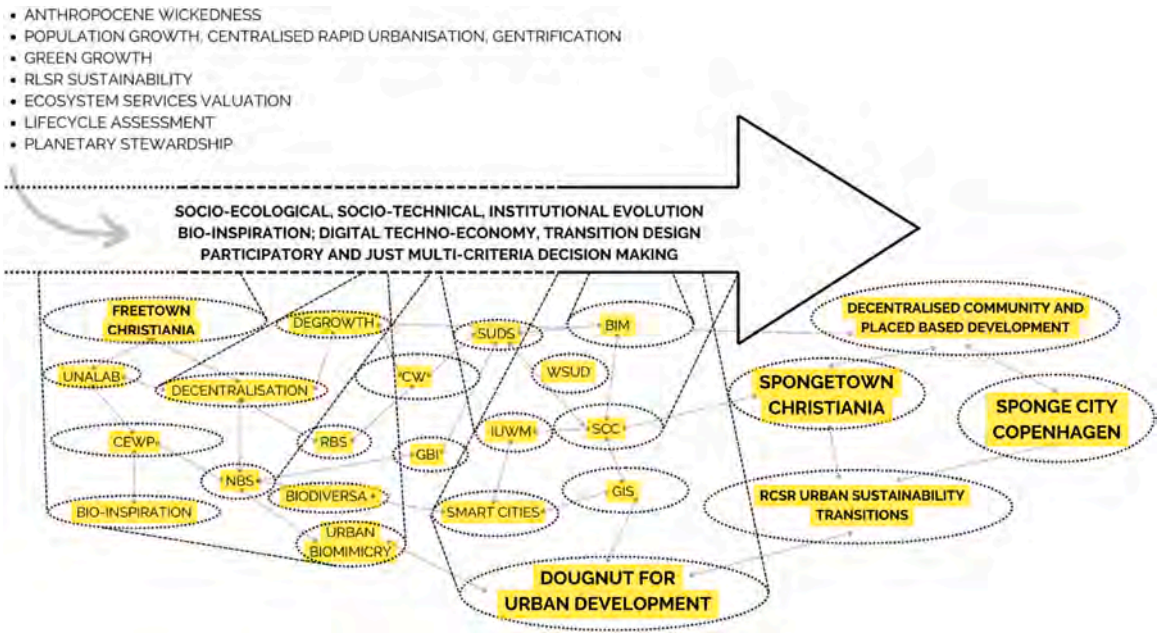

Fig. 7. Actor-network, pathways and trajectories stabilisation in *Spongetown Christiania*, adapted from [46].

Fig. 8. *Spongetown Christiania* as an emerging common agenda aggregating interests and integrating targets. Resulting from the thematic analysis of interactions with multiple local network members and regional/national governance actors relevant to Christiania's urban transitions.

adoption of BACESS A/S Rootzone Technology *Reed-Bed Systems* (RBS) among many other NBS for GBI. In our Discussion and Design section, we review the current network state and our ongoing *nurturing knot-working* [132] endeavours, which are reassessed through an ANT/MLP-framed *systemic* and *evolutionary* understanding of multiple *sociotechnical* dialectical and teleological constructions of *change* over time and how they materialise in Christiania and Copenhagen through the development of an ever-growing WEFE nexus and STES *imaginary* and *visions*, illustrated by Fig. 4.

4.1.1. Incumbent, grey-centralised waste and water systems: collection, piping, pumping, centralising and distribution of sewage and water through chemical treatment plants

Centralised management systems collect, transport, and treat wastewater and water resources at industrial facilities, then discharge treated effluents into water bodies. *Grey infrastructure*, such as pipes,

pumps, and treatment plants for filtration, biological disinfection, and chemical treatment, has been the traditional backbone of these systems [133,134].

The historical evolution of urban water and sewage systems, rooted in the separation of human excreta from society, stems from health hazards and social stigmas (perceived by locals A4, A7)[14]. This led to the development of centralised treatment plants. Modern sanitation is linked to modernity, improved living standards, and urban health, as evidenced by recent urbanisation and industrialisation[15], regardless of widely known sustainability issues [16]. Despite the international acknowledgement of serious externalities, WWTPs still largely keep the cultural trust built upon their perceived advantages.

As Copenhagen's urban *regime* subscribes to the *Doughnut Economy,* NBS and the SCC (even if at odds with *Green Growth* [135] agendas) [24,136], Christiania manifests the potential to become a ULL for these RCSR *transitions* [137,138]. Christiania's unique *sociotechnical* and *socioecological* positioning in a changing *regime* and *landscape* denotes the behaviour of a territory (Fig. 5) and community, which stands as an urban *niche* [27] (Table 1; Fig. 5). Its alternative governance, market and radical commitment to sustainability are countercultural pioneers within the Copenhagen *regime* and the broader *landscape.*

SNM [45,46,124,139,140] teaches us to activate existing NBS *niches* in Christiania by *shielding* and *nurturing* [141] them, while TM [47,125,141,142] focuses on *translating* the SCC and RCSR paradigms locally, steering top-down influences and *backcasting* OPPs [92,100,136]. The Christiania *niche* resonates with the full scope of RCSR *paradigmatic principles* for urban development [75]. Its experience as a consensus democracy favours participatory approaches to urban design, framing a place-based opportunity in Copenhagen for alternative urban WEFE systems *expansion* and of the urban *niche* for NBS in Copenhagen [121,137,143] or even *upscaling* of the niches present there as a whole *constellation* (green roofs, red beds, constructed wetlands, green walls, edible gardens, hyperaccumulators, bioswales, building with biomaterials, etc.).

NBS could, however, negatively impact Christiania for IUWM if a top-down, engineering-dominated mindset disregards the co-evolutionary, co-creative potential of engaging with local networks of human, *non-human* and *non-living agency* [7,69,144]. Expressed *socio--economic matters of concern* about NBS adoption are still reliant on Science and Engineering aspects of the design process - where *the lock-ins* related to *stranded assets* and the ability to assess and measure cost-benefit dynamics to pursue investment [145] have proven to be a critical barrier for other ULLs for NBS. Indeed, the life cycles of urban product-service systems are complex and uncertain, especially in an NBS case, due to the need to account for ES in LCA [146], requiring careful pondering and accounting of multiple global and local f*actor*s and including participatory *networks* of *decision-influencing actants* [38,71].

4.1.2. Incremental transitions, path dependency, inertia and the drivers for radical alternative niches in Christiania

Conventional WWTP incrementalism falls short of addressing SDGs, indicating the need for a radical shift towards RCSR alternatives that reimagine the relationship between urban WEFE infrastructure systems, ecosystems and natural environmental cycles [147]. Prevailing responses to these sustainability challenges often have involved innovations within the existing grey systems, focusing on enhancing efficiency, reducing energy and chemical inputs (decoupling), and minimising emissions [148]. Grey systems' structural embeddedness in urban infrastructure establishes high levels of *path dependency* and *transition inertia* [61], that are reinforced by dominant values, norms, beliefs and *practices*. Overcoming *inertia* requires long-term, multi--sectorial solution development, monitoring, and combinations of top-down and bottom-up efforts for systemic public-private, non-governmental, and non-profit organisational collaborations.

Urban *symbiosis* through WEFE and GBI eco-connectivity may enable urban systems' RCSR decentralisation shifts [97], allowing local resource management. The community of Christiania shares this opinion (A.3; A.4; A.8; A.12; A.14) that decentralised NBS fosters community engagement and awareness [27,149,150]. Interviewees also reported that their experience with NBS suggests slower, less environmentally damaging, and less financially costly implementation over time compared to centralised grey systems, as supported by relevant literature [42,151].

Adoption of NBS, such as CWs, creates an interest in establishing regulatory pathways for ES *valuation and economisation,* overcoming these widespread socio-economic *lock-ins* (as highlighted in events A.7 and A.8). *Transition* to integrated WEFE nature-based infrastructure requires not only technological innovation but also *systemic changes* in institutional frameworks in Copenhagen underlying governance, markets, and societal values (A.4, A.14) towards *green-blue-grey* or even *multicoloured* systems [93]. Integrating ESA-LCA [38,76] may be essential (if not a crucial barrier to overcome) to better Christiania's negotiating position at Copenhagen's municipality table.

4.1.3. Integrating political economy and market dynamics in Christiania's NBS

Economisation, as discussed by [51,152], highlights the processes through which NBS valuation translates its pricing. LCA and ES assessments are still being *problematised* into valuation systems [153,154], challenging existing market frameworks that have historically *externalised* and showed little interest in ES accounting [155]. The international markets' and governments' struggle to tap the value of NBS and their ES ([95–97] underscores the importance of state interventions and *Public-Private Partnerships* (PPPs) (A.14) in redefining economic systemic boundaries and pressuring profit motives to care for people and planet [145,156]. Overcoming dual market and governance *transition inertia* and *path dependency* often has required a collaborative PPP approach

[14] Engineering fields have traditionally governed sanitation, water resource management and wastewater management in connection with human health sciences [84,133,191]. Engineering institutions have designed and developed infrastructures to avoid human waste-related impacts on health and environmental water hazards, but also intentionally separate the population from contact with excreta and toxic pollutants for human and environmental health. Cultural Influences on societal perception of human excreta and biological waste as essentially negative and the desire for separation have shaped urban infrastructure and reflect broader dichotomies such as nature/society [192] and body/mind [193]. This has resulted in systems emphasising control over nature and detachment from biological processes, prioritising technical solutions over ecological integration and sterilising health risks related to pathogens.

[15] Safety of alternative plant-based sanitation technology was an expressed matter of concern regarding Christiania's CW in interview A.10. These doubts were clarified further in the process in interview A.7 and event A.11.

[16] Urban water systems in industrialised nations face sustainability challenges, exacerbating PBs overshoots, including biodiversity loss, climate change, eutrophication, and ocean acidification. United Nations [194] reports that 80% of wastewater globally is discharged without treatment, posing severe environmental and health risks. Wastewater is growing within WEFE problematisation as an "untapped resource" [195] for ES and infrastructural *symbiosis*. Despite their global underperformance in addressing societal needs, the energy demand of conventional grey systems, which account for 4% of global electricity consumption and 8% of global GHG emissions, underscores the unsustainable nature of current *practices* [196]. Rapid urbanisation intensifies drivers for alternatives, with [22] projecting an urban population increase of 2.5 billion by 2050. This demand-side growth strains existing infrastructure that fails to meet its targets for mitigating the impact on water quality and availability [22,197]. Climate change forecasts droughts, floods, and sea-level rise-related imbalances of hydrological cycles to increase in intensity and frequency, exceeding the capacity of the sewers and generating dangerous overflows and hazardous discharges. Climatic changes in hydraulic loads will also impact treatment efficiency, leading to a significant deterioration of the effectiveness of urban waste and water systems or irreversible damage and even critical failure in providing the required services [86].

[156]. These allow for synchronised *top-down* and *bottom-up mobilisations* – a reality acknowledged by key local *actors*, well aware of the vulnerability their *niche* faces in the environmental *landscape* - and of the *regime*-level pressures for Christiania's normalisation (A.15, A.17).

The following subsection discusses symptomatic RCSR *translations* taking root despite cultural, political, and economic *inertia*. These concepts signify positive momentum for WEFE infrastructure *transitions*, as exemplified by the EU NBS Agenda [50,145,157] and *Sister Cities* such as Beijing and Copenhagen promoting the SCC [136,158].

4.2. Regime change: Sponge City Copenhagen between break-through and lock-in

4.2.1. Sustainability paradigms, international partnerships and IUWM transitions in a sino-european context

4.2.1.1. Global action, policy and international cooperation. LCA and ESA find their way internationally through the SDG agenda, and integration proposals arise in novel ISO norms currently under development. The global movement towards sustainable urban development has seen significant contributions from China and the European Union. China's national Sponge City initiative is an example of the LCA-ESA concepts' *translation* agendas to national urban governance, with cities like Beijing and Shenzhen pioneering IUWM strategies and tens of others following suit.

The European Union is an important partner in this research and governance collaboration, explicitly teaming up with the Chinese infrastructural agenda in the *China-Europe Water Platform* (CEWP).

4.2.1.2. European union's role in Nature-based Urban Transitions. European governance and financial institutions promoting the European Green Deal, craft ESG directives and fund Horizon Europe projects, emphasising NBS and GBI as central components of urban planning and climate adaptation strategies [159], underscoring the importance of these solutions and strategies for urban RCSR *transitions*.

In the EU Urban Water *transition* framework, BIODIVERSA+ and UNALAB coordinate research for NBS and ULLs, while the European Investment Bank may provide valuable resources for investing in Christiania under this framework of urban development (A.15, A.17). The EU has been pivotal in promoting NBS, ES, and ULLs through legislative frameworks and funding mechanisms. The *Water Framework Directive* (WFD) and the *Urban Wastewater Treatment Directive* (UWTD) are key regulatory frameworks supporting the implementation of NBS, GBI, the SCC, WSUD and IUWM concepts and design principles across member states, encouraging cities to adopt SDGs and *practices* for *stewardship* of the *commons* within PBs.

4.2.2. Regime trajectory changes and niche expansions in Copenhagen's urban planning and Denmark's AEC sector

4.2.2.1. A Doughnut for the Built Environment: strategic policies and plans. Strategic *transition* plans guide Copenhagen's approach to IUWM. The *Copenhagen Cloudburst Management Plan* introduced the management of extreme rainfall events through integrated GBI and SUDS. The *Climate Adaptation Plan* aims to make Copenhagen carbon-neutral by 2025, emphasising sustainable urban development towards climate adaptation. It proposes that WSUD resolve multiple sustainability issues, from mitigating the urban heat island effect to biodiversity *regeneration* and sea-level rise adaptation. Building regulations enforce limited LCA nationally, but lag to define legal criteria for ES., The DGNB-DK certification system for built environmental sustainability, however actively creates pathways for it.

The Finger Plan adapted its green belt strategies for sustainable urban development, using GBI zoning measures for long-standing use. It has recently strengthened a new component of coastal protection named *the Bracelet* – a nature-based coastal barrier system for wave breaking and sea-level management, including projects in Nordhavn, Sydhavn, Amager and Lynetteholm. For Christiania's urban development, key *regime* players are the municipality, the Culture Ministry and the Environmental Protection *Agency* (A.12, A.14), which represent the major stakeholders that share ownership over the assets in the territory of Christiania with the local inhabitants, as highlighted by interviews (A.4, A.12, A.14) and mapped in Fig. 6.

4.2.2.2. Niche Innovations between Christiania and BACESS. Christiania's RBS, CWs and GBI represent a grassroots approach to NBS, showcasing how community-driven projects (A.4, A.5, A.7, A.11 A.13) can contribute to the city's broader sustainability and specific water management goals. *Actors* in our project network like (A.4, A.7, A.11, A.12, A.13, A.14, A.15, A.16) were instrumental as they actively contribute to this day to the RBS and CWs design, construction and maintenance in Christiania. BACESS's technological solutions illustrate the potential of private sector innovation in supporting urban sustainability when the public sector opens a WoO for decentralised solutions, even with a small-scale public sector *niche* like Christiania.

4.2.2.3. Niche-Regime interactions: multi-level pathways of STES Change. The interaction between *niche* innovations in Christiania and BACESS and Copenhagen's urban water management *regime* highlights the dynamic relationship between localised projects and international urban sustainability *landscapes*. These interactions highlight the potential of *niche* innovations to influence the municipality's agenda and become integrated into it as *boundary objects* and *interessement devices*.

- The success of *niche* innovations in influencing the broader *regime* is contingent upon a supportive regulatory context as discussed in (A.4, A.7, A.11), with *actors* from Christiania's Building Office and caretakers of local wetlands and RBS (A.7, A.13, A.15, A:16), and responsible for the design of the Christiania's 1991 *Green Plan* and with members of the *Frie Natur* association (A.14, A,17) which protects biodiversity in Copenhagen with a focus on the island of Amager, in the areas of Christianshavn and Christiana).
- The partnership between Christiania's Building Office and BACESS A/S (A.11, A.15), namely between (A.4) and (A.7) *actors*, municipal and national authorities, illustrates the importance of collaboration across different stakeholders linked with varying levels of *agency* and role expertise. This collaborative approach aligns the neighbourhood's *niche* innovations with the city's sustainability goals and national regulations, enabling broader impact through scaling up.
- Further collaboration with *regime actors* like Københavns Kommune, DGNB, and IUCN may unlock critical pathways for boundary objects to arise in negotiations that further empower Christiania's NBS by rendering the community a protected space. Complementarity with place-based approaches at the *regime*-level in partnership with NBS and ULL initiatives in Horizon Europe may create *multi-level* momentum in numerous organisations around Christiania towards ESA-LCA research. Our latest interviews with Christiania's Byggekontor pointed firmly towards the community's interest in this collaborative agenda, also pointing greater favourability towards the European project than had been the case in the community's countercultural inclinations.

4.3. Strategic management of Christiania's niche amidst Copenhagen's transition trajectories

Christiania is well-equipped to become an official ULL for NBS in Copenhagen (A.12, A.14, A.15, A.17), with the particularity of its leading CW experimentation within the municipal SCC framework, especially for its wastewater treatment GBI. Their RBS for wastewater management aligns and already goes further (A.4, A.10, A.13, A.16)

than Copenhagen's incremental takes on wastewater infrastructure agendas [121,160]. Christiania's collaborative efforts towards supporting our research revealed during this process not only their particular sensitivity towards *landscape*-level *matters of concern* [161,162] but also their willingness and *agency* to influence Copenhagen's urban future even beyond their settlement and local interests, pressing for *tipping points* [163] in regional urban *transitions* and pursuing connected *regime*-change WoO [33].

4.3.1. Christiania's role in advancing NBS, GBI, and the SCC

Christiania demonstrates a rare convergence of NBS infrastructure for WEFE systems, place-based *stewardship*, and unique cultural affinity with RCSR sustainability. Among the most ecologically significant areas in Copenhagen, it features multiple protected habitats including ponds, wet meadows, and forest patches that support key species such as *Rana temporaria, Lissotriton vulgaris*, and a variety of mosses, birds, and aquatic invertebrates. The neighbourhood provides year-round ecological services: shading from mature canopies (e.g., oak and hawthorn), amphibian migration corridors, pollinator habitats, and stormwater buffering. Cumulative human-nature interaction, not central planning, produced these benefits – reinforcing network *resilience* through co-creative collaboration between the Gardener's Group, local businesses, and inhabitants, rather than conventional top-down centralised *landscape* planning.

Christiania already embodies Copenhagen's Biodiversity Strategy 2050 targets, with over 10% freshwater coverage, habitat connectivity, and food-producing vegetation networks. *Actor*s such as A.4 and A.13 alerted us of their detailed observations about seasonal and historic shifts in pond water quality, salinity levels, sedimentation, nutrients and reedbed health, showcasing a decentralised native knowledge network that we only begun to untangle. As an NBS prototype, Christiania aligns with SCC ambitions and surpasses Copenhagen's current IUWM deployments. The CWs alone, adapted over time with community input, treat household wastewater, enable habitat preservation, and engage residents in adaptive maintenance cycles – they are unique in Copenhagen, treating blackwaters and greywaters locally.

4.3.2. BACESS A/S and Christiania's informal PPP

Reciprocal learning, rather than conventional supplier-consumer dynamics, shaped the relationship between BACESS A/S and Christiania - in a relationship that resembles a micro-scale public-private partnership. According to A.7 and A.11, Christiania's residents played a direct role in identifying the location, orientation, and operational constraints of RBS systems, particularly in areas affected by soil quality, usage patterns, and water volume fluctuations. Users modified the original system design plans through these engagements to match the realities of everyday life, seasonal flow, and to formalise roles, responsibilities, and maintenance routines.

Residents frequently offered feedback on usability and maintenance issues (A.11), while BACESS adapted system simplification strategies to reduce misuse and improve robustness over time. On interview A.4 it was noted that such co-design processes allowed the systems to be absorbed into community routines, extending the value of the infrastructure beyond its technical performance, but also providing venues for maintenance fine-tuning and a sense of ownership. The decades-long partnership also avoided conflicts common in mainstream infrastructure projects by embedding user trust and *agency* from the start. BACESS's experience in Christiania has since served as a reference model for adapting CW design to dense, low-formality urban sites.

4.3.3. Institutional and regulatory framing of RBS and CW

Denmark's regulatory and political *landscape* significantly influences the implementation of RBS, CW and NBS within Copenhagen's *regime*, the market framing of economic systemic boundaries, and connected *overflows*. Guidelines established by the Danish Environmental Protection Agency for Rootzone Technology and willow-based CWs outline the performance expectations and design requirements for these systems [164] but do not explicitly account for a broader ES framing, as documented in (A.4, A.7, A.13, A.16). Christiania has the potential as a ULL to develop and experiment with internal frameworks to build these processes outside of conventional institutional boundaries, experimenting with concepts such as *Sharing Economy* and *Doughnut Economy* internally, and using its findings for widespread adoption of *sufficient statistics* for *valuation* and *economisation* such as *pricing* for *pacifying* the service at the broader *regime* and *landscape* levels.

4.3.4. Leveraging International and Local Multi-Level Dynamics for Niche Management within broader Transitions

The TM perspective of Christiania's urban *niche* persuades us to inform and steer *niche* initiatives by navigating *regime* TPs like Copenhagen's collaboration with Beijing on the SCC (A.17). This partnership leverages global insights on the SCC and IUWM systems, aiming to refine and scale CW and broader NBS applications at local scales towards global synergy steering [100,102,136]. As noted by A.13 and A.15, local *actor*s are open to engaging with these frameworks strategically, especially in collaborations with researchers and visiting urban *transition* teams. Their NBS bioremediation work near Mælkebøtten, mitigating soil contamination, could serve as a proof-of-concept for future EU-aligned local brownfield restoration. The interest among residents in contributing to Horizon-linked projects—without sacrificing autonomy—suggests potential for trans-local collaboration that strengthens *niche*-level *agency*, but also *regime* change opportunities.

Overall, the growing sentiment in the community that future threats transcend their scope and capacity for effective intervention paves the way for TM tactics to become increasingly relevant to Christiania's urban *niche* management.

4.3.5. Niche-regime state of affairs and implications

The dynamic interaction between Christiania's *niche* innovations and Copenhagen's urban water management *regime* highlights the potential for localised solutions as *regime tipping points* in the *landscape*, by reinforcing *feedback loops* (Fig. 6; Table 1). These interactions suggest *pathways* for integrating innovative water management *practices* into Christiania's urban planning, but also the potential for the city to learn from a plethora of alternative approaches present in the neighbourhood, from RBS to CWs and NBS for *multi-coloured* infrastructure.

However, the *regime* still lacks mechanisms to integrate meaningfully the informal *sociotechnical* system logic escaping its bureaucracy. For example, Christiania's mitigation strategies address soil contamination around Krudthuset and Mælkebøtten (A.4, A.14). Infrastructural neglect allowed the site's contamination, stemming from decades-old military industrial activities, to persist while the community's damage mitigation efforts went unrecognised. The contradiction highlights the asymmetry between local *agency* and central policy validation, as well as socially discriminatory *regime practices* denounced by the local community.

The ongoing *Lokalplan* negotiation reflects these conflicts. Although people have cited Christiania's contributions to Copenhagen's culture and *landscape*, its STES remain underrepresented in zoning logic, land-use analysis, and sustainability strategies. *Actor*s such as A.11 suggested the development of valuation infrastructures — like *stewardship* credits or participatory certification — that would help reframe Christiania's systems from informal experiments to institutional benchmarks. This would not only improve *regime* responsiveness but also support Christiania's role as an experimental *actor*.

Transition potential is highly *wicked*, including all TPs, such as *reproduction processes, de-alignment/re-alignment, technological substitution, reconfiguration,* and *hybrid pathways*. Multiple parties steer these *trajectories,* adjusting to VUCA factors as STES conditions change and clash with RCSR paradigms in urban governance and planning *practices,* as a novel cycle of regime-niche interactions begins.

4.3.6. Strategic implications for niche management and transition steering

The exploration of NBS and CW in Christiania, facilitated by BACESS and supported by regulatory frameworks, exemplifies an actionable approach to urban water management innovation. These initiatives illustrate the importance of *niche shielding* in fostering sustainable urban *transitions*. Indeed, local *actors* in Christiania are knowledgeable and responsible for implementing, maintaining, *expanding* and reviewing local NBS *practices*, a condition of community embeddedness deemed necessary for most successful NBS and ULL projects. Our ongoing collaboration intends to leverage the presented WoO in our MLP towards future *niche expansion*, unlocking relevant expectations as they present themselves through engagement with municipal, national, and European organisations and international collaborations (Fig. 6). High customisability to user needs and provisioning of learning venues for knowledge and agenda sharing are key for NBS businesses in Christiania and in general. This could prove unmanageable when attending to local expectations and implementing highly bureaucratic standards such as DGNB, IUCN or methodologies as complex as ESA-LCA. The vast amount of information needed from Christiania's urban planning network's multiple members and connected STES, combined with highly complex criteria, might still present challenges, even with effective information sharing and communication.

5. Design and discussion

5.1. Strategy, tactics, decision-making and engagement

5.1.1. Niche management for expansion and empowerment

Strategically chartering these *trajectories* involved contributing to the *problematisation* of *niche shielding, interessement* and *enrolment* for *nurturing,* and *mobilising* towards *expansion* and *empowerment* (Fig. 7). Our work utilises urban planning as a key OPP and WoO*,* ensuring higher *trajectories* are contemplated and *translated* into *Spongetown's* SNM. The effectiveness and viability of CW and NBS in tackling urban water issues help to draw broader support within Copenhagen. As these innovations establish legitimacy, regulatory and policy frameworks adapt, supporting their wider application across the urban *regime* and slowly overcoming *lock-ins,* as illustrated in our *niche-landscape* trajectories charting towards Spongetown Christiania *breakthrough* in Fig 9.

5.1.2. Multi-level interactions with endogenous regime changes

Christiania's *niche* innovations intersect with Copenhagen's urban water management *regime* through processes of *substitution* and *emergent transformation*, facilitated by collaborative efforts, policy dialogues, and best practice sharing. International partnerships underscore the *regime*'s adaptive response to *niche* innovations, *transitioning* from traditional WWTP and *grey infrastructure* towards NBS. This foreshadows potential for novel trajectory pathways if Christiania adopts an ULL approach that caters to the Sino-European agenda as a suitable laboratory. *Rebound effects* from international *landscape* drivers could also act as crucial positive *feedback loops*, disrupting *lock-ins* from *path dependency* and *transition inertia*. Framing these *visions* was our main *niche nurturing* activity as project participants and our key contribution to *empowering* ongoing SNM activities.

5.1.3. Leveraging RCSR landscape drivers

The RCSR framework for Sustainability collects four concepts that we identified as major *ideographs* and *cues* in current conceptual discourse as *landscape* positive pressures being locally *translated*. The RCSR concepts are already present in major communications in governance and market *devices* in Copenhagen. Their meaning is fuelled by *fantasies* that trickle their *translation* potential into concepts like SDGs and *Doughnut Economics*. As practitioners, Christiania's role was instrumental in broadening our understanding of sustainability *imaginaries*; its counterculture's *fantasies* and *ideographies* helped shape our *vision* for its development as a unique case study for ambitious,

Fig. 9. Illustration articulating imaginaries from key stakeholders in our interviews regarding urban development possibilities and desires for Christiania's urban future – a product of envisioning exercises.

promising, and radical agendas in IUWM *transitions* — otherwise, we would likely have settled for a less ambitious agenda. *Problematising* global agendas, we strived to *empower* Christiania's *transitions* at the local while steering regional and international levels (Appendices A, B and C) into a Spongetown Strategy and Project – as RCSR takes root in Christiania, in its turn the community drew this inspiration from a plethora of international influences. It holds the promise of growing these proto-*regimes* beyond its territory, *expanding* those *niches* as a place of *utopianism*.

5.2. Negotiation spaces and transition pathways for the translation of a" Spongetown" ULL in Christiania

5.2.1. Actor-network, Boundary Objects, and Interessement Devices

The ongoing negotiation processes involve diverse *actors* and *actants*, including the Christiania community, scientists, managers, engineers, designers, implementers and users. The *agency* under this framing extends even to *non-living* entities like the CW and the ES they provide, as well as the living beings (*human* and *non-human)* that inhabit them; however, methodologies to render the latter actionable were found to be more sparsely mentioned or consensual in the literature of our thematic case-study oriented analysis. The *human/non-human, living/non-living* assembly emphasises ANT's symmetry principle in clarifying the understanding of the heterogeneity of entities within STES networks. Their *agency* and connected MoT*, matters of fact, value* and *concern* can be explored within SNM and TM processes as suggested in Fig. 8 towards OPPs – in our case, they define the boundaries of an urban plan.

The following *interessement devices* played essential roles in *multi-level translations* for navigating *scenario envisioning* and steering the *transition* experiments and co-creation of *imaginaries* and perceived OPPs also framed negotiation spaces in our study:

- Investment, Legal Frameworks and Agreements: Essential for formalising engagement, these devices help align the diverse *actors*' roles with the project's objectives, highlighting the socio-political intricacies of environmental governance.

- Participation Venues, Educational Programs and Learning Opportunities: These are critical tools for aligning community interests with environmental sustainability, emphasising the role of knowledge dissemination in *actor-network* alignment. The proposed IUCN-DGNB MCDM framework in Appendix B allows Christiania to compile, organise, and analyse the considerable ammount of knowledge required across multiple WEFE sectors.
- Demonstration Projects, Networking and Articulating Expectations: Showcasing the tangible benefits of NBS, serving as practical examples of the ULL's potential impact, attracting support and engagement from a broad range of stakeholders. The community has a long tradition of hosting and fostering these kinds of activities without support from outsiders. It is, therefore, worthy of being considered for public and private investment within the community's profit control measures.

5.2.2. Proposed Passage Points for Spongetown ULL

The RCSR paradigms for the ULL were important *imaginaries* towards *urban* agenda *problematisation* and *actor enrolment* clarification [165], facilitating collaboration across *agency* domains and providing a shared *envisioned* space for innovation and experimentation in our network. We *envisioned Spongetown* as a hub that embodies the community's aspirations towards sustainable urban living and *stewardship* enactment of the core tenets of their countercultural lifestyle, which is arguably becoming mainstreamed in some regards (Table 1; Fig. 8; A.21). The urban plan is a key OPP that can enshrine a concrete *trajectory* for ongoing urban negotiations, experiments, and agenda alignment with the municipality (Fig. 8). It also reignites interest in the community's aspirations and collective identity renewal.

The SCC, likewise, acts as a *boundary object*, offering a unifying framework for sustainable water management and criteria for defining our ULL's teleology – a technical concept with roots in both ES and life cycle *circularity*. This concept facilitates engagement across disciplinary fields, aligning with the ANT perspective on the adaptability and robustness of boundary objects to maintain coherence across different contexts – for instance, between organisations like IUCN, DGNB, Copenhagen municipality and the European Commission. Spongetown resonates with the messaging of *Bevar Christiania* inspiring community *resilience* and tapping the perceived need to reinvent the *genius loci.* The recent eradication of gang violence rekindled the hope that a new episode in this place's story may unfold.

5.2.3. Drivers for ES Valuation Spongetown Translation Moments

Economic Valuation of ES proves *wicked* in monetising the indirect (*externalised*) benefits provided by CW, such as climate regulation and biodiversity. The ANT perspective suggests that integrating new *actor*s or rewiring their networks could navigate these barriers, enabling a more comprehensive incorporation of economic and managerial concerns [132,165,166] into niche-level efforts, and reducing *externalisation* risks of regime activities [152], while our MLP-SNM provides the systemic framing and understanding of the *institutional evolution* that underlies *valuation systems*, and why externalities exist in the first place [5]. Both approaches to *problematisation* and analysis of the present situation can be solution-oriented, and are not mutually exclusive, but have diametrically oppositional focus. We believe that a balanced usage of both perspectives is necessary for a strategic outlook that understands its assumptions and the need to revise them, which is all too true when commenting on the financial value of solutions under a widely criticised economic *landscape of capitalist regime*s.

Christiania's distinctive legal and governance *landscape* poses specific challenges and opportunities in navigating legal and governance structures, which could provide a unique blend of *lock-in/break-through* scenarios in ES valuation. Utilising the ULL as a *boundary object* can help bridge Freetown's *radical pathways* to sustainability and underlying *visions* with incremental political agendas, fostering collaboration and mutual understanding of the underlying *value* in ES *economisation,* by leveraging European support to bypass regional interests and narrow municipality problematisations.

5.3. Managing transitions, translations and niches: a symbiotic, regenerative and circular design process for a Spongetown Lokalplan

Our *Spongetown Lokalplan* concept represents a strategic initiative to embed NBS and GBI within its urban fabric, aiming to align with Copenhagen's *Finger Plan* and its novel *Bracelet*. This municipal plan prioritised the enhancement of green wedges, stormwater management, biodiversity conservation, and climate change adaptation through sustainable urban interventions. Christiania's unique position, nestled within the Christianshavn neighbourhood near Copenhagen's coastal area, offers a distinctive opportunity to implement these sustainability concepts effectively at the palm of the plan. However, the endeavour to integrate CW for ES into Christiania's *landscape* unveils a complex scenario of negotiation spaces and TPs, fraught with both opportunities and challenges connected with LCA-ESA valuation and PB framing.

Vulnerabilities to storm surges (up to 7.4 m) and projected sea-level rise (4.4 m) [167] provided recurring triggers for network realignment. *Regenerative* design proposals resulted from residents and institutions translating these pressures, voiced through their *concerns* and *caretaking*. Contaminated zones like Krudthuset and Sølyst (A.5, A.14) became reconfigured as remediation *interessement* hotspots, potentially *enrolling* fungi, hyper-accumulators, and sediment-filtering wetlands as non-human *actant*s in future-oriented healing *assemblages*.

Brackish rainwater reservoirs spawned iterative *interessement* as infrastructural *boundary objects*, linking freshwater, marine, and community places (Figs. 5; 8; 10). Floating wetlands and mussel reefs further reinforced the inter-scalar linkages between local care and regional adaptation. These interventions not only enhanced enrolment among new stakeholders (e.g. marine scientists, biodiversity advocates) but also kept the socio-technical system open to future *translation*. Likewise, multi-functional seawalls, kelp forests, and seagrass meadows reoriented hard infrastructure into living, polysemic *actant*s. They simultaneously address climate *resilience*, ecological restoration, and carbon capture, making them effective *interessement devices* across governance scales.

Proposed mobility infrastructures—such as bridges connecting Christiania to Amager and Refshaleøen — should extend the laboratory's reach while upholding the community's (and the city's) soft mobility strategies. These proposals were not static; they operated as devices for negotiating urban identity, scale, , rhythm and accessibility. Introducing experimental *landscape* proposals reinforced the plan's role in (de)stabilising *transition* dynamics. These negotiation spaces, envisioned as open to adaptive experimentation, facilitate back-and-forth movement between *enrolment* and *mobilisation*. Their value lay less in fixed outcomes than in their capacity to forecast future relationships between *actor*s, infrastructures, and living beings and places.

5.3.1. Boundary objects for urban sustainability transitions

The ULL and SCC transcend traditional disciplinary divides and enable innovation. These concepts facilitate collaborative engagement and embody the project's sustainability goals, which are crucial for the

Fig. 10. A design-scenario experiment for Spongetown Christiania. We assumed a high public investment in redesigning Christiania's wetlands for coastal resilience. Considering predicted storm surge effects (Appendix C), we suggested the creation of a wave-breaking wall that doubles as an urban bridge structure protecting the lakes as a freshwater biome against flooding, while connecting Indre By and Christianshavn. The proposal includes a low blueprint, moderate-density urban development. Floating landscape architecture is envisioned to provide for long-term nature-based activities.

co-construction of knowledge and development of material-semiotic networks for overcoming typical NBS's barriers [168,169]. Urban planning as a boundary object works especially well in negotiations and envisioning expectations (Figs. 9, 10), however, it demands the taxing creation and comparison of many credible scenarios through trans-disciplinary MCDM [170] (Figs. 7, 10).

5.3.2. *Valuation, economisation and social justice concerns*

Regarding social justice, the lack of recognition for Christiania's pioneering sustainability efforts, especially in broader urban water management discussions, alongside the disengagement of Christiania's Building Office from strategic municipal issues, poses significant challenges to achieving cohesive urban multi-level *breakthrough* in our case study. Low endogenous *sociotechnical* resources for scientific analysis of the valuation of current ES in Christiania, could inhibit the community from analysing their *stewardship* of local ecosystems and to gather arguments to address *distributional justice* issues.

The community adheres to the usage of "*slow technology*" (A.4, A.11, A.15, A.17) in opposition to mechatronic and digital technology – which they defend through *degrowth* conceptualisations of *ecological, sharing welfare*, that could be disregarded as nostalgic or naif. However, this stance also echoes co-related lack of significant capital investments and central power structures' interest in the *niche*'s alternative projects and revolutionary ethos. Ostracisation impairs ambitions of technological development and could cause diminished community know-how and interest from the get-go but conversely boost drivers for decentralisation. A place-based approach to hybridising "*high*" and "*slow*" technology may provide the most interesting and adaptive TPs for *niche* management [41].

Christiania's territorial management, property structure, and authority over different expertise frame *procedural* justice as a complex institutional issue, riddled with significant inter-organisational siloism, animosity, and ambiguity. Native techno-scepticism further entrenches the local community, which already suffers a generalised under-

appreciation of the *breakthrough* potential that may be dormant in the NBS on its grounds, alongside its institutional and organisational structure (A.15, A.17),

The complexities of *sufficient statistics* that can lead to *economising* and *commodifying* ES through *pricing* [171,51,166] and navigating Christiania's unique legal framework may also inhibit the *Spongetown's* ambitions. The unavailability of ISO norms for ESA-LCA integration and the international backpedalling on these issues by political forces means Christiania cannot disregard negative scenarios, justifying its healthy scepticism over the recognition of their *stewardship* of ES.

Christiania's economic semi-autonomy may be key in experimental projects for alternative ES and NBS valuation systems. Its native culture aligns with broader societal *transitions* away from the typical environmental externalities of *laissez-faire* capitalism present in the *regime*. Instead of capitulating to *incumbent* economic institutionalism or neoliberal policies, Christiania's capacity for planning sharing and ecological economics could better enable ESA-LCA performance, given the community's explicit preference for *Keynesian, Marxist, doughnut*, and *degrowth* economic approaches.

Against the backdrop of growing interest in NBS, participants flagged the risk of instrumentalisation [172] — where its valuation might serve as a proxy for *gentrification* through liberalisation of local land assets [130,173] (A.17). To counteract this, our proposal integrated participatory certification, anti-displacement mechanisms, and negotiated land-use agreements as stabilising devices. These contrasts pose complex *reconfiguration* TPs for the Copenhagen *regime* as sustainability *change* drivers impact the problems of *economisation* models worldwide in adaptation to PBs and limits to growth. Societal challenges in the *landscape* emerge from the foundational assumptions of economic theories, the institutional *inertia* of entrenched power structures, and property *regimes* governing material and financial assets in Christiania.

5.4. NBS, GBI and RCSR sponge cities - a sociotechnical imaginary for an IUWM experiment in copenhagen

5.4.1. Vision and aspirations for NBS and GBI mobilisation through ES valuation

Spongetown Christiania's *vision* is to create RCSR urban *transitions* toward NBS for IUWM by *mobilising* systemic strategies into *practice* via experiments [17]. Inspired by the principles outlined in its *vision*, we *backcasted scenarios* for integrating NBS and GBI into the fabric of Copenhagen as a Sponge City. Our *multi-level* strategy aims to transform urban *landscapes* towards ecosystemic mimicry that not only withstands climate adversities but also enhances biodiversity and community well-being, RCSR principles for harmony with nature and *translating* locally broader *landscape transitions* by leveraging potential partnerships with *transition*-prone *actors* in the *regime*.

5.4.2. Urban planning and governance scenarios, multi-level management considerations and multi-criteria decision forecast

Christiania's *transition* does not reduce to a binary between normalisation and autonomy pathways. Rather, it unfolds across a diverse trajectory field over a *landscape* of urban infrastructure governance and spatial scenarios, shaped by the interplay between internal and external network, regime selection agenda and environmental pressures. We analysed these trajectories, structured through a combined SWOT–PESTEL framework (Appendix B), illuminate both the community's strengths, weaknesses and adaptive capacities (or *inertias* and *path dependencies*) to the systemic forces that shape its exposure to risk or opportunity. Together, they formed the strategic groundwork for multi-criteria and *multi-level* planning decisions.

At one end of the spectrum lie scenarios of environmental erosion, social displacement and economic exclusion. Politically, delegitimisation and elite capture describe dynamics in which external *actors* override or fragment Christiania's internal governance, undermining its direct democracy. In the legal domain, unilateral enforcement emerges from overlapping or conflicting regulatory *regimes*, leading to planning paralysis, demolition threats, or institutional *lock-ins*. Unchecked contamination, canopy clearance, and infill construction degrade and fragment ecological areas, compromising biotopes and wetland ecologies. Communities face threats from unchecked rising seawater and groundwater levels, while storm barrier design ignores their interests. Preference for WWTP solutions and technocentric NBS further triggers social discontent. Exclusion and incompatibility arise from imposed systems that fail to align with local capacities and interests. Economically and socially, the scenario of *gentrification* and cultural erasure sees speculative forces displacing existing residents, undermining the *commons*-based institutions that define Christiania's cultural identity. *Reproduction* and *transformation* pathways look like the lesser of evils, while Christianites struggle to fend off *purposive transitions* aimed at their *proto-regime* and negotiate damaging attempts at *reconfiguration* coming from multiple *regime* sectors.

In contrast, scenarios of RCSR *transition* foreground Christiania's potential as a living laboratory for sustainability. The ecological preservation scenario reinforces biodiversity corridors and protects critical habitats. Transformation *transition* pathways take this further, with *regime* sponsorship empowering endogenous GBI to restore polluted soils and groundwater systems. Sponge city integration embeds Christiania within Copenhagen's climate *resilience* framework, re-aligning with local WEFE systemic adaptation agenda. Socially, community-led development and inclusive *transition* prioritise accessibility through novel soft mobility infrastructure, coastal renewal, and social equity through spatial design. Technological strategies and low-tech *stewardship*, make way for transparent and accessible real-time digital environmental monitoring and infrastructure renewal – showcasing internal *niche* openness for substitution pathways for the greater good. Economically, *commons*-based *circularity* and ES valuation enable local self-reliance and open pathways to *stewardship*-based funding, based upon carbon sequestration and other net-positive impact accounting – showcasing the depths of *landscape* change in *regime* re-alignment. Legally, customary autonomy offers recognition of Christiania's *sui generis* governance within a stabilising framework.

Hybrid scenarios of negotiated compromise emerge between these poles. Gradual formalisation and regulatory integration provide phased alignment with statutory frameworks, but may constrain self-governance. *Green growth* investment *mobilises* funding for sustainable retrofits at the risk of market intrusion. Legal pluralism and technological retrofit compromises offer more flexible solutions, balancing internal norms with formal requirements. Compromise scenarios, while not resolving fundamental tensions, may offer stabilising mechanisms in a complex and changing institutional context. As middle-of-the-road pathways between idealistic and catastrophist expectations, perhaps they are the most likely to come to pass – in fact, they might already be present by combining aspects of utopian and dystopian scenarios.

5.4.3. Translating RCSR urban transitions, NBS WEFE imaginaries and the spongetown vision for Christiania

Spongetown Christiania as a ULL may come to represent a landmark approach to urban sustainability, blending NBS, *multicoloured*

[17] Central to achieving this vision is the strategic mobilisation of NBS and GBI infrastructure, enrolling *actors*, and mobilising a whole living network. CWs, green roofs and edible gardens perform essential ES in Christiania's ecosystems and *sociotechnical* networks and are inhabited by a rich living community of unacknowledged non-human *actors*. As detailed by [133,87], these wetlands hold a potential for integrating natural processes into urban design, offering solutions for water management, food production, carbon sequestration, biodiversity enhancement, and recreational, leisurely places. Recent approaches showcase the untapped potential of urban areas to contribute positively to climate and biodiversity through CW'S ES, aligning with RCSR *transitions* and learning from their historical development.

infrastructure, and RCSR principles in urban management, planning, and designing. Its model addresses ecological challenges while advocating for and experimenting with a reimagined market and policy *landscape* that co-exists with a post-growth prosperity paradigm in development.

By locally rendering tangible global agendas, we strived to turn *imaginaries* into *visions* and actionable in teleology for MCDM. In our Supplementary Material document, we have presented the project's latest proposals for urban planning and governance (Appendix C).

6. Conclusions and recommendations

Overcoming *transition inertia* in Christiania's and other urban WEFE NBS *niches* requires engaging a range of *actors* from the AEC public and private sectors, such as urban designers, engineers, and policy-makers, from top-down, bottom-up or even lateral positioning. Our hybrid STS framework data collection may have sacrificed perceptions of *landscape-to-regime translations* by not engaging directly with those *regime actors* or inviting them to interact with the *niche* sooner. This was, however, a strategic option deemed necessary because of insufficient *niche* maturing, agenda misalignments and dispersed *problematisation* regarding *regime transitions* in Freetown. A focus on *shielding* became necessary for articulating expectations, learning, and *mobilising* a newly *empowered network* at the *niche* level. Poorly articulated *problematisations*, lack of *interessement devices*, and pre-enrolled *actors* in addressing STES challenges could downgrade the *niche*'s perceived value in current urban negotiations and was therefore avoided altogether and supplemented alternatively by official documentation representing *regime* and *landscape*-level organisations, problematisations, agenda, roles, and projects. Limitations of time, funding, and disciplinary scope prevented the adequate enrolment of the many relevant actors that comprise the *regime*. Appendices B and C contain supporting ethnographic and spatial analysis data.

To address RQ1, we adopted an integrative framework combining material-semiotic and systemic-evolutionary perspectives of STs. From this design-for-RCSR-ST framework, we derived the SCC, *translating* it into our ULL *transition* strategy and applying it as an experimental *transition* design model in Christiania's Spongetown *Lokalplan*. We explored conceptual *transition* design, as well as forecasting pathways and scenarios for *shielding, nurturing*, and *expanding* the *niche*. This empowered a strategic shared *vision* and tangible common agenda for the urban development of Christiania and Copenhagen — an interessement device that gained bottom-up traction and enrolled us in the forthcoming next phase of community mobilisation toward the ULL pilot project (A.15, A.17). Our approach aimed to configure an institutional setting favourable to plural urban governance while tactically leveraging ambiguity to maximising flexibility in the management of expectations and agenda aligments.

To address RQ2, we grounded our framework in a structured design methodology and proposed three interrelated design approach sets, operationalised within the RCSR STs framework. These sets *translated* theory into practical scenario-building tools and MCDM approaches, tuned to the spatial, social, and institutional specificities of Christiania:

- Socio-ecological and BiD approaches apply principles, strategies and processes of BM, Permaculture, and *Regenerative* Design and Development to create co-evolutionary, symbiotic NBS. These strive to synergise with natural ecosystems' life cycles, processes, and patterns towards RCSR design for SDGs within PBs, pursuing *planetary stewardship* of the *commons*.
- Socio-technical design approaches, such as ANT, TM, MLP, SNM, DfST, and Participatory Co-Design, are to be applied considering the social, organisational, institutional, and cultural dimensions of the systemic design of urban STs, accounting for *pathways, imaginaries, and, multi-level translations*. They apply to break through from *lock-ins* and *inertia* by leveraging bottom-up and top-down, radical, and incremental change factors and navigating environmental, institutional and STES systemic selection environments towards the evolution of sustainable innovations and connected agendas.
- Techno-economical design approaches, including Agile, Parametric, Generative, and Digital Design [174] methods, using advanced processes, enabling real-time LCA and ESA integration, through BIM and GIS to optimise the design and operation of urban WEFE management systems. In integration with STES, information-intensive and sophisticated digital tools may prove key to make the market case for ES valuation by generating knowledge on the value of Christiania's ecological and urban assets. Still, they imply high investment, social capital and the usage of robust interdisciplinary effective and time-efficient *problematisation* for MCDM approaches [118].

These design heuristics have collectively enabled Christiania to pursue IUWM and *transition* its WEFE systems toward RCSR sustainability paradigms in the past and hold great promise for their future (RQ3). They can enable MCDM and scenario fine-tuning and modelling aligned with DGNB-IUCN indicators (Appendices B and C), to render them *translatable* to *actors* in the Danish-European AEC *regimes*. Optimised they can navigate pathways in real-time for a *transitioning* Christiania and its WEFE systems to enable activities aligned with broader RCSR sustainability strategies. Literature and field practice confirm that these design approaches have strong transformative potential and warrant further exploration and integration. Though tensions persist between competing schools of thought, we found complementarity between *socio-ecological* and *socio-technical* approaches. Their cross-polination yields a practical and nuanced vocabulary for *mobilising* sustainability concepts into action. We invite critical testing of this framework's overlaps, assumptions, and limits and call for continued hybridisation of STS and SES models to further contextualise emerging urban *transition* processes.

The lab-hub of Christiania's NBS could act as a strategic interface between research, governance, and experimentation — bridging academic STES theory and high-end disciplinary *practices* to a living place and willing, deserving community. Considering the growing demand for LCA, ESA, ESG, and related assessments—and recognising their institutional and technical complexity—Christiania must remain radically adaptable. This community serves as both an experimental agent and a proven testing ground for decentralised responses to global challenges as sustainability tools and planning frameworks are developed. Its example shows that adaptability must extend beyond spatial design to governance, legal instruments, and knowledge systems — supporting diverse *actors* in co-creating value, navigating VUCA, and shaping RCSR change. Christiania persists as a hallmark of how urban sustainability experiments can defy and inspire the status quo amid accelerating global *wickedness*.

NBS Impacts and Implications:

Environmental Impact

This study demonstrates how Christiania's experimental Green-Blue Infrastructure (GBI) and Nature-Based Solutions (NBS) contribute to ecosystem resilience by addressing stormwater flooding and mitigating climate-induced vulnerabilities. By operationalising resilient, circular, symbiotic and regenerative (RCSR) paradigms, the research provides a model for embedding ecological stewardship into urban planning, fostering systemic alignment with planetary boundaries and SDGs.

Economic Impact

The proposed pathways for integrating the valuation of ecosystem service assessments (ESA) and lifecycle assessments (LCA) enable resource-efficient urban transitions and pathways towards the valuation of natural capital within urban environment design and planning operations. These strategies highlight the potential of hybrid socio-technical-ecological systems (STES) methodologies to align techno-economic innovation with sustainability goals, promoting cost-effective decentralised urban water solutions that benefit both public and private stakeholders. Our proposed strategy for institutional and organisational, methodological integration renders valuation of IUCN-DGNB indicators more tangible for post-growth models of the built environment.

Social Impact

By utilising participatory governance and co-design methodologies, this research empowers communities to bridge grassroots initiatives with top-down municipal planning. Hybridisation of socio-ecological systems (SES) and socio-technical systems (STS) generates frameworks for ensuring also the fair inclusion of marginalised (niche) voices in sustainability transitions. These are expected to foster innovation, collaboration, and shared responsibility for systemic transformations. Our research exemplifies in practice how such communities can create, manage, design and leverage regime and landscape pressures that enable niche practices and visions to become translatable in wider institutional transitions connected to RCSR paradigms.

CRediT authorship contribution statement

Manuel Higgs Morgado: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Despoina Vasiliki Vastardi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Flore-Eva Baudot Almeida:** Writing – original draft, Visualization, Methodology, Investigation, Funding acquisition, Formal analysis. **Hanaa Dahy:** 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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Data availability

Data will be made available on request.

References

[1] A. Coppola, A. Vanolo, Normalising autonomous spaces: ongoing transformations in Christiania, Copenhagen, Urban Stud. 52 (2015) 1152–1168, https://doi.org/10.1177/0042098014532852.
[2] J.E. Moore, A. Mascarenhas, J. Bain, S.E. Straus, Developing a comprehensive definition of sustainability, Implement. Sci. 12 (2017) 110, https://doi.org/10.1186/s13012-017-0637-1.
[3] M. Higgs Morgado, D.V. Vastardi, F.E. Baudotand, H. Dahy, Spongetown Christiania as an Urban Living Lab: Nature-based Solutions for Resilient, Circular, Symbiotic and Regenerative Transitions in Urban Water, Nature-based Sol. (2025), https://doi.org/10.5281/zenodo.15288624.
[4] H. Ahlborg, I. Ruiz-Mercado, S. Molander, O. Masera, Bringing technology into social-ecological Systems research—Motivations for a socio-technical-ecological systems approach, Sustainability. 11 (2019) 2009, https://doi.org/10.3390/su11072009.
[5] F.W. Geels, Micro-foundations of the multi-level perspective on socio-technical transitions: developing a multi-dimensional model of agency through crossovers between social constructivism, evolutionary economics and neo-institutional theory, Technol. Forecast. Soc. Change 152 (2020) 119894, https://doi.org/10.1016/j.techfore.2019.119894.
[6] F.W. Geels, Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective, Curr. Opin. Environ. Sustain. 39 (2019) 187–201, https://doi.org/10.1016/j.cosust.2019.06.009.
[7] A. Dwiartama, C. Rosin, Exploring agency beyond humans: the compatibility of Actor-Network Theory (ANT) and resilience thinking, Ecol. Soc. 19 (2014). https://www.jstor.org/stable/26269633. accessed February 21, 2024.
[8] M. Michael, Actor-network theory: trials, trails and translations. Actor-Network Theory: Trials, Trails and Translations, SAGE Publications Ltd, 2017, pp. 10–27, https://doi.org/10.4135/9781473983045, 55 City Road.
[9] H.A. Perkins, Ecologies of actor-networks and (non)social labor within the urban political economies of nature, Geoforum. 38 (2007) 1152–1162, https://doi.org/10.1016/j.geoforum.2007.01.007.
[10] A. Maassen, Heterogeneity of lock-In and the role of strategic technological interventions in urban infrastructural transformations, Eur. Plan. Stud. 20 (2012) 441–460, https://doi.org/10.1080/09654313.2012.651807.
[11] F.W. Geels, Ontologies, socio-technical transitions (to sustainability), and the multi-level perspective, Res. Policy. 39 (2010) 495–510, https://doi.org/10.1016/j.respol.2010.01.022.
[12] Y.A. Fatimah, Z.H. Prasojo, S.W. Smith, N.E.B. Rahman, D.A. Wardle, K.Y. Chong, A. Saad, J.S.H. Lee, Multi-level actor-network: Case of Peatland programs in a Riau Village, Indonesia (1974–2020), Geoforum. 145 (2023) 103829, https://doi.org/10.1016/j.geoforum.2023.103829.
[13] T. Birtchnell, T. Harada, G. Waitt, On the verge of change: maverick innovation with mobility scooters, Environ. Innov. Soc. Transit. 27 (2018) 118–128, https://doi.org/10.1016/j.eist.2017.11.002.

[14] H. Morgan, Understanding Thematic Analysis and the Debates Involving Its Use, TQR, 2022, https://doi.org/10.46743/2160-3715/2022.5912.
[15] A. Tietjen, G. Jørgensen, Translating a wicked problem: A strategic planning approach to rural shrinkage in Denmark, Landsc. Urban. Plan. 154 (2016) 29–43, https://doi.org/10.1016/j.landurbplan.2016.01.009.
[16] L. Zu, Wicked problems and sustainability challenges in the era of VUCA, in: The Elgar Companion to Corporate Social Responsibility and the Sustainable Development Goals, Edward Elgar Publishing, 2023, pp. 9–26. https://www.elgaronline.com/edcollchap/book/9781803927367/book-part-9781803927367-10.xml. accessed February 10, 2024.
[17] K. Richardson, W. Steffen, W. Lucht, J. Bendtsen, S.E. Cornell, J.F. Donges, M. Drüke, I. Fetzer, G. Bala, W. von Bloh, G. Feulner, S. Fiedler, D. Gerten, T. Gleeson, M. Hofmann, W. Huiskamp, M. Kummu, C. Mohan, D. Nogués-Bravo, S. Petri, M. Porkka, S. Rahmstorf, S. Schaphoff, K. Thonicke, A. Tobian, V. Virkki, L. Wang-Erlandsson, L. Weber, J. Rockström, Earth beyond six of nine planetary boundaries, Sci. Adv. 9 (2023) eadh2458, https://doi.org/10.1126/sciadv.adh2458.
[18] W. Steffen, K. Richardson, J. Rockström, S.E. Cornell, I. Fetzer, E.M. Bennett, R. Biggs, S.R. Carpenter, W. de Vries, C.A. de Wit, C. Folke, D. Gerten, J. Heinke, G.M. Mace, L.M. Persson, V. Ramanathan, B. Reyers, S. Sörlin, Planetary boundaries: guiding human development on a changing planet, Science (1979) 347 (2015) 1259855, https://doi.org/10.1126/science.1259855.
[19] J. Rockström, L. Kotzé, S. Milutinović, F. Biermann, V. Brovkin, J. Donges, J. Ebbesson, D. French, J. Gupta, R. Kim, T. Lenton, D. Lenzi, N. Nakicenovic, B. Neumann, F. Schuppert, R. Winkelmann, K. Bosselmann, C. Folke, W. Lucht, D. Schlosberg, K. Richardson, W. Steffen, The planetary commons: A new paradigm for safeguarding Earth-regulating systems in the Anthropocene, Proc. Natl. Acad. Sci. 121 (2024), https://doi.org/10.1073/pnas.2301531121 e2301531121.
[20] UN, Transforming our World: The 2030 Agenda for Sustainable Development, (2015). https://www.unfpa.org/resources/transforming-our-world-2030-agenda-sustainable-development (accessed February 9, 2024).
[21] M. Adamovic, W.K. Al-Zubari, A. Amani, A.I. Ameztoy, C. Bacigalupi, S. Barchiesi, B. Bisselink, K. Bodis, F. Bouraoui, S. Caucci, J. Dalton, R.A. De, H. Dudu, C. Dupont, K.J. El, A. Embid, N. Farajalla, B.C.R. Fernandez, E. Ferrari, L. Ferrini, Y. Filali-Meknassi, M.J. Franca, N. Ghaffour, V. Girardi, B. Grizzetti, C. Hannah, G.I. Hidalgo, O. Houmoller, A. Jaeger-Waldau, C.B. Jimenez, K. Kavvadias, I. Kougias, H. Laamrani, T.S. Lemessa, A. Liebaerts, A. Lipponen, J. Lorentzen, A. Makarigakis, M. Marence, L. Martin, E. Michalena, A. Mishra, R. H. Mohtar, G.M. Moner, M. Moreno-Abat, Z. Mpakama, M. Pastori, A. Pistocchi, M. Sartori, S. Schmeier, D. Schmidt-Vogt, J. Sehring, V. Smakhtin, S. Szabo, A. Takawira, M. Thiem, J.K. Tiruneh, S. Tsani, H.E.D. Van, K. Verbist, S. Xenarios, G. Zaragoza, Position Paper on Water, Energy, Food and Ecosystem (WEFE) Nexus and Sustainable development Goals (SDGs), JRC Publications Repository, 2019, https://doi.org/10.2760/5295.
[22] UN Habitat, Ayyoob, World Cities Report 2022: envisaging the future of cities, United Nations Human Settlements Programme (UN-Habitat), 2022.
[23] K. Raworth, A doughnut for the Anthropocene: humanity's compass in the 21st century, Lancet Planet, Health 1 (2017) e48–e49, https://doi.org/10.1016/S2542-5196(17)30028-1.
[24] H. Birgisdóttir, A. Bjørn, A. Branny, C. Clausen, A. Fanning, I. Fetzer, N. Francart, L. Grcheva, M. Heide, E. Lassen, J. Leonardsen, F. Moberg, R. Nørgaard, D. Pham, K.K. Rasmussen, K. Raworth, M. Ryberg, E. Sahan, Doughnut for Urban Development: A Manual, D. Dani-Hill-Hansen, K.G. Jensen (Eds.), The Danish Architectural Press, Copenhagen, 2023. ISBN: 978-87-7407-432-8, https://www.home.earth/doughnut.
[25] F. Châles, M. Bellanger, D. Bailly, L.X.C. Dutra, L. Pendleton, Using standards for coastal nature-based solutions in climate commitments: applying the IUCN Global Standard to the case of Pacific Small Island Developing States, Nat.-Based Solut. 3 (2023) 100034, https://doi.org/10.1016/j.nbsj.2022.100034.
[26] A. Smith, R. Raven, What is protective space? Reconsidering niches in transitions to sustainability, Res. Policy. 41 (2012) 1025–1036, https://doi.org/10.1016/j.respol.2011.12.012.
[27] M. Wolfram, Cities shaping grassroots niches for sustainability transitions: conceptual reflections and an exploratory case study, J. Clean. Prod. 173 (2018) 11–23, https://doi.org/10.1016/j.jclepro.2016.08.044.
[28] A. Alves, B. Gersonius, Z. Kapelan, Z. Vojinovic, A. Sanchez, Assessing the Co-benefits of green-blue-grey infrastructure for sustainable urban flood risk management, J. Environ. Manage 239 (2019) 244–254, https://doi.org/10.1016/j.jenvman.2019.03.036.
[29] H.M. Madsen, Innovation and Implementation Pathways for Urban Climate Change Adaptation, Technical University of Denmark, Kgs. Lyngby, Denmark, 2018. Available at: https://findit.dtu.dk/en/catalog/5bf53ac4d9001d013c3c340c.
[30] K. Daniell, J.-D. Rinaudo, N.W.W. Chan, C. Nauges, Q. Grafton, Understanding and managing urban water in transition, in: Q. Grafton, K.A. Daniell, C. Nauges, J.-D. Rinaudo, N.W.W. Chan (Eds.), Understanding and Managing Urban Water in Transition, Springer, 2015, pp. 1–30, https://doi.org/10.1007/978-94-017-9801-3_1.
[31] G. Jørgensen, O. Fryd, A.A. Lund, P.S. Andersen, L. Herslund, Nature-based climate adaptation projects, their governance and transitional potential-cases from Copenhagen, Front. Sustain. Cities. 4 (2022). https://www.frontiersin.org/articles/10.3389/frsc.2022.906960. accessed December 18, 2023.
[32] R. Brown, B. Rogers, L. Werbeloff, Moving toward Water Sensitive Cities, Cooperative Research Centre for Water Sensitive Cities, Melbourne, Australia, 2016.
[33] J. Graham-Nye, N. Florin, M. Retamal, Windows of opportunity: the power dynamics in the disposable nappy regime and opportunities for niche innovations, Clean. Responsible Consumpt. 12 (2024) 100169, https://doi.org/10.1016/j.clrc.2024.100169.
[34] R.P. Horton, Christiania: An Embarrassment of Green Riches for Copenhagen, Urban Gardens, 2009. https://www.urbangardensweb.com/2009/11/28/christiania-an-embarrassment-of-green-riches-for-copenhagen/. accessed January 23, 2024.
[35] S.F. Midtgaard, But suppose everyone did the same" — The Case of the Danish utopian Micro-Society of Christiania, J. Appl. Philos. 24 (2007) 299–315. https://www.jstor.org/stable/24355045. accessed March 16, 2024.
[36] A. Vanolo, Alternative Capitalism and Creative Economy: the Case of Christiania, Int. J. Urban. Reg. Res. 37 (2013) 1785–1798, https://doi.org/10.1111/j.1468-2427.2012.01167.x.
[37] P. Rannila, R. Virve, Property and carceral spaces in Christiania, Copenhagen, Urban Stud. 55 (2018) 2996–3011. https://journals-sagepub-com.zorac.aub.aau.dk/doi/full/10.1177/0042098017713447. accessed March 16, 2024.
[38] S.E. Taelman, L.V. De Luca Peña, N. Préat, T.M. Bachmann, K. Van der Biest, J. Maes, J. Dewulf, Integrating ecosystem services and life cycle assessment: a framework accounting for local and global (socio-)environmental impacts, Int. J. Life Cycle Assess. (2023), https://doi.org/10.1007/s11367-023-02216-3.
[39] P.N. Carvalho, D.C. Finger, F. Masi, G. Cipolletta, H.V. Oral, A. Tóth, M. Regelsberger, A. Exposito, Nature-based solutions addressing the water-energy-food nexus: review of theoretical concepts and urban case studies, J. Clean. Prod. 338 (2022) 130652, https://doi.org/10.1016/j.jclepro.2022.130652.
[40] O.K. Pedersen, The Danish Negotiated economy, Ethos. (2012) 19–25. http://www.cscollege.gov.sg/Knowledge/Ethos/Issue%2011%20August%202012/Pages/The%20Danish%20Negotiated%20Economy.aspx. accessed March 16, 2024.
[41] A. Peponi, P. Morgado, Transition to smart and regenerative urban places (SRUP): contributions to a new conceptual framework, Land. (Basel) 10 (2020) 2, https://doi.org/10.3390/land10010002.
[42] B. Hermelin, K. Trygg, Decentralised development policy: A comparative study on local development interventions through municipalities in Sweden, (2022). https://doi.org/10.1177/09697764211054773.
[43] N. Verco, Christiania – A poster child for degrowth?. in: A. Nelson, F. Schneider (Eds.), Housing for Degrowth: Principles, Models, Challenges and Opportunities, 1st ed Routledge, London, 2018, p. 10, https://doi.org/10.4324/9781315151205.
[44] A. Winter, Environmental sustainability? We don't have that here": Freetown Christiania as an unintentional eco-village, ACME: An Int. J. Crit. Geogr. 15 (2016) 129–149. https://acme-journal.org/index.php/acme/article/view/1122. accessed March 16, 2024.
[45] F.W. Geels, J. Schot, Typology of sociotechnical transition pathways, Res. Policy. 36 (2007) 399–417, https://doi.org/10.1016/j.respol.2007.01.003.
[46] F. Geels, R. Raven, Non-linearity and expectations in niche-development trajectories: ups and downs in Dutch biogas development (1973–2003), Technol. Anal. Strateg. Manage 18 (2006) 375–392, https://doi.org/10.1080/09537320600777143.
[47] R. Kemp, D. Loorbach, J. Rotmans, Transition management as a model for managing processes of co-evolution towards sustainable development, Int. J. Sustain. Dev. World Ecol. 14 (2007) 78–91, https://doi.org/10.1080/13504500709469709.
[48] M. Callon, Some Elements of a Sociology of Translation: Domestication of the Scallops and the Fishermen of St Brieuc Bay, Sociol. Rev. 32 (1_suppl) (1984) 196–233, https://doi.org/10.1111/j.1467-954X.1984.tb00113.x.
[49] B.K. Sovacool, N. Bergman, D. Hopkins, K.E. Jenkins, S. Hielscher, A. Goldthau, B. Brossmann, Imagining sustainable energy and mobility transitions: valence, temporality, and radicalism in 38 visions of a low-carbon future, Soc. Stud. Sci. 50 (2020) 642–679, https://doi.org/10.1177/0306312720915283.
[50] D.G. for C.Action, European Commission, The EU emissions trading system (EU ETS), Publications Office, LU, 2013. https://data.europa.eu/doi/10.2834/55480. accessed March 16, 2024.
[51] K. Çalışkan, M. Callon, Economization, part 1: shifting attention from the economy towards processes of economization, Econ. Soc. 38 (2009) 369–398, https://doi.org/10.1080/03085140903020580.
[52] J. Hickel, G. Kallis, Is green growth possible? New Polit. Econ. 25 (2020) 469–486, https://doi.org/10.1080/13563467.2019.1598964.
[53] P. Romero-Lankao, T. McPhearson, D.J. Davidson, The food-energy-water nexus and urban complexity, Nat. Clim. Change 7 (2017) 233–235, https://doi.org/10.1038/nclimate3260.
[54] UNESCO, European Comission, Implementing the water–Energy–Food–Ecosystems nexus and achieving the Sustainable Development Goals - UNESCO Bibliothèque Numérique, (2021). https://unesdoc.unesco.org/ark:/48223/pf0000379588 (accessed March 17, 2024).
[55] A. Valencia, W. Zhang, N.-B. Chang, Sustainability transitions of urban food-energy-water-waste infrastructure: A living laboratory approach for circular economy, Resour., Conserv. Recycl. 177 (2022) 105991, https://doi.org/10.1016/j.resconrec.2021.105991.
[56] G. Langergraber, J.A.C. Castellar, T.R. Andersen, M.-B. Andreucci, G. Baganz, G. Buttiglieri, A. Canet-Martí, P.N. Carvalho, D.C. Finger, B.T. Griessler, R. Junge, B. Megyesi, D. Milošević, H.V. Oral, D. Pearlmutter, R. Pineda-Martos, B. Pucher, E.D. van Hullebusch, N. Atanasova, Towards a cross-sectoral view of nature-based solutions for enabling circular cities, Water. (Basel) 13 (2021) 2352. https

://www.ucviden.dk/en/publications/towards-a-cross-sectoral-view-of-nature-based-solutions-for-enabl. accessed February 7, 2024.
[57] H.V. Oral, M. Radinja, A. Rizzo, K. Kearney, T.R. Andersen, P. Krzeminski, G. Buttiglieri, D. Ayral-Cinar, J. Comas, M. Gajewska, M. Hartl, D.C. Finger, J. K. Kazak, H. Mattila, P. Vieira, P. Piro, S.A. Palermo, M. Turco, B. Pirouz, A. Stefanakis, M. Regelsberger, N. Ursino, P.N. Carvalho, Management of urban waters with nature-based solutions in circular cities—Exemplified through seven urban circularity challenges, Water. (Basel) 13 (2021) 3334, https://doi.org/10.3390/w13233334.
[58] L.V. Gibbons, S.A. Cloutier, P.J. Coseo, A. Barakat, Regenerative development as an integrative paradigm and methodology for landscape sustainability, Sustainability. 10 (2018) 1910, https://doi.org/10.3390/su10061910.
[59] J.H. Köhler, C. Hohmann, E. Dütschke, Sustainability transitions in local communities: District heating, water systems and communal housing projects, Work. Paper Sustain. Innov. (2018). https://www.econstor.eu/handle/10419/179113. accessed February 1, 2024.
[60] E.C. Ellis, The Anthropocene condition: evolving through social–ecological transformations, Philosoph. Trans. R. Soc. B: Biol. Sci. 379 (2023) 20220255, https://doi.org/10.1098/rstb.2022.0255.
[61] B.K. Sovacool, D.J. Hess, Ordering theories: typologies and conceptual frameworks for sociotechnical change, Soc. Stud. Sci. 47 (2017) 703–750, https://doi.org/10.1177/0306312717709363.
[62] T. McPhearson, E.M. Cook, M. Berbés-Blázquez, C. Cheng, N.B. Grimm, E. Andersson, O. Barbosa, D.G. Chandler, H. Chang, M.V. Chester, D.L. Childers, S.R. Elser, N. Frantzeskaki, Z. Grabowski, P. Groffman, R.L. Hale, D.M. Iwaniec, N. Kabisch, C. Kennedy, S.A. Markolf, A.M. Matsler, L.E. McPhillips, T.R. Miller, T.A. Muñoz-Erickson, E. Rosi, T.G. Troxler, A social-ecological-technological systems framework for urban ecosystem services, One Earth. 5 (2022) 505–518, https://doi.org/10.1016/j.oneear.2022.04.007.
[63] M.V. Chester, T.R. Miller, T.A. Muñoz-Erickson, A.M. Helmrich, D.M. Iwaniec, T. McPhearson, E.M. Cook, N.B. Grimm, S.A. Markolf, Sensemaking for entangled urban social, ecological, and technological systems in the Anthropocene, Npj Urban Sustain. 3 (2023) 1–10, https://doi.org/10.1038/s42949-023-00120-1.
[64] O. Speck, D. Speck, R. Horn, J. Gantner, K.P. Sedlbauer, Biomimetic bio-inspired biomorph sustainable? An attempt to classify and clarify biology-derived technical developments, Bioinspir. Biomim. 12 (2017) 011004, https://doi.org/10.1088/1748-3190/12/1/011004.
[65] T. Speck, S. Poppinga, O. Speck, F. Tauber, Bio-inspired life-like motile materials systems: changing the boundaries between living and technical systems in the anthropocene, The Anthropocene Rev. 9 (2022) 237–256, https://doi.org/10.1177/20530196211039275.
[66] R.B. MacKinnon, J. Oomen, M. Pedersen Zari, Promises and presuppositions of biomimicry, Biomimetics. 5 (2020) 33, https://doi.org/10.3390/biomimetics5030033.
[67] L. Ilieva, I. Ursano, L. Traista, B. Hoffmann, H. Dahy, Biomimicry as a sustainable design methodology—Introducing the 'Biomimicry for sustainability' Framework, Biomimetics. 7 (2022) 37, https://doi.org/10.3390/biomimetics7020037.
[68] E. Blanco, M. Pedersen Zari, K. Raskin, P. Clergeau, Urban ecosystem-level biomimicry and regenerative design: linking ecosystem functioning and Urban built environments, Sustainability. 13 (2021) 404, https://doi.org/10.3390/su13010404.
[69] C. Herrmann-Pillath, S. Sarkki, T. Maran, K. Soini, J. Hiedanpää, Nature-based solutions as more-than-human art: Co-evolutionary and co-creative design approaches, Nat.-Based Solutions 4 (2023) 100081, https://doi.org/10.1016/j.nbsj.2023.100081.
[70] C. Maller, Re-orienting nature-based solutions with more-than-human thinking, Cities. 113 (2021) 103155, https://doi.org/10.1016/j.cities.2021.103155.
[71] E. Horn, G. Proksch, Symbiotic and regenerative sustainability frameworks: moving towards circular City implementation, Front. Built. Environ. 7 (2022). https://www.frontiersin.org/articles/10.3389/fbuil.2021.780478. accessed December 18, 2023.
[72] J.W. Moore, The Capitalocene, Part I: on the nature and origins of our ecological crisis, J. Peasant. Stud. 44 (2017) 594–630, https://doi.org/10.1080/03066150.2016.1235036.
[73] E. Hofferberth, Post-growth economics as a guide for systemic change: theoretical and methodological foundations, Ecol. Econ. 230 (2025) 108521, https://doi.org/10.1016/j.ecolecon.2025.108521.
[74] G. Feola, Capitalism in sustainability transitions research: time for a critical turn? Environ. Innov. Soc. Transit. 35 (2020) 241–250, https://doi.org/10.1016/j.eist.2019.02.005.
[75] A. Bianciardi, N. Becattini, G. Cascini, How would nature design and implement nature-based solutions? Nat.-Based Solutions 3 (2023) 100047 https://doi.org/10.1016/j.nbsj.2022.100047.
[76] K. Alshehri, M. Harbottle, D. Sapsford, A. Beames, P. Cleall, Integration of ecosystem services and life cycle assessment allows improved accounting of sustainability benefits of nature-based solutions for brownfield redevelopment, J. Clean. Prod. 413 (2023) 137352, https://doi.org/10.1016/j.jclepro.2023.137352.
[77] L. Fraccascia, I. Giannoccaro, V. Albino, Rethinking resilience in industrial symbiosis: conceptualization and measurements, Ecol. Econ. 137 (2017) 148–162, https://doi.org/10.1016/j.ecolecon.2017.02.026.
[78] K. Hecht, J. Appelman, M.Pedersen Zari, Buildings as living systems—Towards a tangible framework for ecosystem services design, in: B. Faircloth, M. Pedersen Zari, M.R. Thomsen, M. Tamke (Eds.), Design for Climate Adaptation, Springer International Publishing, Cham, 2023, pp. 297–306, https://doi.org/10.1007/978-3-031-36320-7_19.
[79] C.J. Tanner, F.R. Adler, N.B. Grimm, P.M. Groffman, S.A. Levin, J. Munshi-South, D.E. Pataki, M. Pavao-Zuckerman, W.G. Wilson, Urban ecology: advancing science and society, Front. Ecol. Environ. 12 (2014) 574–581, https://doi.org/10.1890/140019.
[80] C. Kennedy, J. Cuddihy, J. Engel-Yan, The changing metabolism of cities, J. Indust. Ecol. 11 (2007) 43–59, https://doi.org/10.1162/jie.2007.1107.
[81] T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P.J. Marcotullio, R.I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K.C. Seto, C. Wilkinson, M. Alberti, C. Folke, N. Frantzeskaki, D. Haase, M. Katti, H. Nagendra, J. Niemelä, S. T.A. Pickett, C.L. Redman, K. Tidball, Stewardship of the biosphere in the urban era, in: T. Elmqvist, M. Fragkias, J. Goodness, B. Güneralp, P.J. Marcotullio, R.I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K.C. Seto, C. Wilkinson (Eds.), Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities: A Global Assessment, Springer Netherlands, Dordrecht, 2013: pp. 719–746. https://doi.org/10.1007/978-94-007-7088-1_33.
[82] A.E. Smith, Stewardship design principles: learning from living systems (BIRDS) to codesign fast-forward futures, in: T. Thatchenkery, D.L. Cooperrider, M. Avital (Eds.), Positive Design and Appreciative Construction: From Sustainable Development to Sustainable Value, Emerald Group Publishing Limited, 2010, pp. 117–135, https://doi.org/10.1108/S1475-9152(2010)0000003011.
[83] F. Ceschin, I. Gaziulusoy, Evolution of design for sustainability: from product design to design for system innovations and transitions, Des. Stud. 47 (2016) 118–163, https://doi.org/10.1016/j.destud.2016.09.002.
[84] A.N. Angelakis, A.G. Capodaglio, E.G. Dialynas, Wastewater management: from ancient Greece to modern times and future, Water. (Basel) 15 (2022) 43, https://doi.org/10.3390/w15010043.
[85] L. Kapetas, R. Fenner, Integrating blue-green and grey infrastructure through an adaptation pathways approach to surface water flooding, Philosoph. Trans. R. Soc. A: Math., Phys. Eng. Sci. 378 (2020) 20190204, https://doi.org/10.1098/rsta.2019.0204.
[86] OECD, Nature-based solutions for adapting to water-related climate risks, 2020. https://doi.org/10.1787/2257873d-en.
[87] C.B. Agaton, P.M.C. Guila, Ecosystem services valuation of constructed wetland as a nature-based solution to wastewater treatment, Earth 4 (2023) 78–92, https://doi.org/10.3390/earth4010006.
[88] M.A. Aguilera, J. Tapia, C. Gallardo, P. Núñez, K. Varas-Belemmi, Loss of coastal ecosystem spatial connectivity and services by urbanization: natural-to-urban integration for bay management, J. Environ. Manage 276 (2020) 111297, https://doi.org/10.1016/j.jenvman.2020.111297.
[89] J. Wang, F. Xue, R. Jing, Q. Lu, Y. Huang, X. Sun, W. Zhu, Regenerating Sponge City to Sponge Watershed through an innovative framework for urban water resilience, Sustainability 13 (2021) 5358, https://doi.org/10.3390/su13105358.
[90] J. Ma, D. Liu, Z. Wang, Sponge City Construction and Urban Economic Sustainable Development: an ecological philosophical perspective, IJERPH 20 (2023) 1694, https://doi.org/10.3390/ijerph20031694.
[91] A. Zaręba, A. Krzemińska, M. Adynkiewicz-Piragas, K. Widawski, D. Van Der Horst, F. Grijalva, R. Monreal, Water oriented City—A '5 scales' System of blue and green infrastructure in sponge cities supporting the retention of the urban fabric, Water. (Basel) 14 (2022) 4070, https://doi.org/10.3390/w14244070.
[92] F. Xue, J. Wang, Y. Huang, R. Jing, Q. Lu, From sponge city to sponge watershed: addressing comprehensive water issues through an innovative framework, IOP Conf. Ser.: Earth Environ. Sci. 569 (2020) 012083, https://doi.org/10.1088/1755-1315/569/1/012083.
[93] P. Sagrelius, L. Lundy, G. Blecken, A. Rizzo, M. Viklander, Blue-green infrastructure for all seasons: the need for multicolored thinking, J. Sustain. Water. Built. Environ. 8 (2022), https://doi.org/10.1061/JSWBAY.0000997.
[94] S.M. Muñoz, J. Schoelynck, D. Tetzlaff, R. Debbaut, M. Warter, J. Staes, Assessing biodiversity and regulatory ecosystem services in urban water bodies which serve as aqua-nature-based solutions, Front. Environ. Sci. 11 (2024), https://doi.org/10.3389/fenvs.2023.1304347.
[95] M. Radinja, N. Atanasova, A.Zavodnik Lamovšek, The water-management aspect of blue-green infrastructure in cities, Urbani Izziv. 32 (2021) 98–110, https://doi.org/10.5379/urbani-izziv-en-2021-32-01-003.
[96] S. Ncube, S. Arthur, Influence of blue-green and grey infrastructure combinations on natural and Human-derived capital in urban drainage planning, Sustainability 13 (2021) 2571, https://doi.org/10.3390/su13052571.
[97] A. Capodaglio, Integrated, decentralized wastewater management for resource recovery in rural and peri-urban areas, Resources 6 (2017) 22, https://doi.org/10.3390/resources6020022.
[98] S. Štrbac, M. Kašanin-Grubin, L. Pezo, N. Stojić, B. Lončar, L. Ćurčić, M. Pucarević, Green infrastructure designed through nature-based solutions for sustainable urban development, Int. J. Environ. Res. Public Health 20 (2023) 1102, https://doi.org/10.3390/ijerph20021102.
[99] P. Zhang, L. Zhang, Y. Chang, M. Xu, Y. Hao, S. Liang, G. Liu, Z. Yang, C. Wang, Food-energy-water (FEW) nexus for urban sustainability: A comprehensive review, Resour., Conserv. Recycl. 142 (2019) 215–224, https://doi.org/10.1016/j.resconrec.2018.11.018.
[100] H. Wang, C. Mei, J. Liu, W. Shao, A new strategy for integrated urban water management in China: sponge city, Sci. China Technol. Sci. 61 (2018) 317–329, https://doi.org/10.1007/s11431-017-9170-5.
[101] I. Tien, Resilient by design: the case for increasing resilience of buildings and their linked food-energy-water systems, Elementa: Sci. Anthropocene 6 (2018) 18, https://doi.org/10.1525/elementa.142.
[102] E. Nieuwenhuis, E. Cuppen, J. Langeveld, H. de Bruijn, Towards the integrated management of urban water systems: conceptualizing integration and its

uncertainties, J. Clean. Prod. 280 (2021) 124977, https://doi.org/10.1016/j.jclepro.2020.124977.
[103] T.T. Nguyen, H.H. Ngo, W. Guo, X.C. Wang, N. Ren, G. Li, J. Ding, H. Liang, Implementation of a specific urban water management - Sponge City, Sci. Total Environ. 652 (2019) 147–162, https://doi.org/10.1016/j.scitotenv.2018.10.168.
[104] C. Liang, X. Zhang, J. Xu, G. Pan, Y. Wang, An integrated framework to select resilient and sustainable sponge city design schemes for robust decision making, Ecol. Indic. 119 (2020) 106810, https://doi.org/10.1016/j.ecolind.2020.106810.
[105] A. Mitić-Radulović, K. Lalović, Multi-level perspective on sustainability transition towards nature-based solutions and Co-creation in Urban planning of Belgrade, Serbia, Sustainability 13 (2021) 7576, https://doi.org/10.3390/su13147576.
[106] T.H.F. Wong, B.C. Rogers, R.R. Brown, Transforming cities through water-sensitive principles and practices, One Earth. 3 (2020) 436–447, https://doi.org/10.1016/j.oneear.2020.09.012.
[107] H.M. Madsen, R. Brown, M. Elle, P.S. Mikkelsen, Social construction of stormwater control measures in Melbourne and Copenhagen: A discourse analysis of technological change, embedded meanings and potential mainstreaming, Technol. Forecast. Soc. Change 115 (2017) 198–209, https://doi.org/10.1016/j.techfore.2016.10.003.
[108] C. Zevenbergen, D. Fu, A. Pathirana, Sponge Cities: Emerging Approaches, Challenges and Opportunities, MDPI, 2018, https://doi.org/10.3390/books978-3-03897-273-0.
[109] H. Thörn, In between social engineering and gentrification: urban restructuring, social movements, and the place politics of open space, J. Urban. Aff. 34 (2012) 153–168, https://doi.org/10.1111/j.1467-9906.2012.00608.x.
[110] H. Jarvis, Against the 'tyranny' of single-family dwelling: insights from Christiania at 40, Gender, Place Cult. 20 (2013) 939–959, https://doi.org/10.1080/0966369X.2012.753583.
[111] A. Coppola, A. Vanolo, Christiania e il conflitto con le istituzioni danesi: alcune note sulla convergenza fra spazi dell'autonomia e spazi del neoliberismo, Riv. Geogr. Ital. 121 (2014) 241–258. https://dialnet.unirioja.es/servlet/articulo?codigo=5885614. accessed March 16, 2024.
[112] D.H. Lund, Governance innovations for climate change adaptation in urban Denmark, J. Environ. Policy Plann. 20 (2018) 632–644, https://doi.org/10.1080/1523908X.2018.1480361.
[113] C. Balestreri, E. Kurucz, T. McIlwraith, S. Jacobs, Local understandings and global challenges: exploring sense of place in sustainability transitions, E&S 28 (2023) art33, https://doi.org/10.5751/ES-13895-280133.
[114] A. Clarke, Situational Analysis: Grounded theory after the postmodern turn, SAGE Publications, Inc., United States of America, 2005, https://doi.org/10.4135/9781412985833, 2455 Teller Road, Thousand Oaks California 91320.
[115] K. Charmaz, Constructing Grounded Theory., 2nd ed., Introducing Qualitative Methods Series, SAGE Publications Ltd., London, 2014. ISBN: 9781446297223, http://digital.casalini.it/9781446297223.
[116] V. Braun, V. Clarke, One size fits all? What counts as quality practice in (reflexive) thematic analysis? Qual. Res. Psychol. 18 (2021) 328–352, https://doi.org/10.1080/14780887.2020.1769238.
[117] J.A. Smith, M. Larkin, P. Flowers, Interpretative Phenomenological Analysis: Theory, Method and Research, SAGE Publications Ltd, London, 2021, p. 100. ISBN: 9781529780796, http://digital.casalini.it/9781529780796.
[118] M. Marttunen, J. Lienert, V. Belton, Structuring problems for Multi-Criteria Decision Analysis in practice: A literature review of method combinations, Eur. J. Operat. Res. 263 (2017) 1–17, https://doi.org/10.1016/j.ejor.2017.04.041.
[119] B. Latour, Politics of Nature, Harvard University Press, 2004, https://doi.org/10.4159/9780674039964.
[120] K.G. Aka, Actor-network theory to understand, track and succeed in a sustainable innovation development process, J. Clean. Prod. 225 (2019) 524–540, https://doi.org/10.1016/j.jclepro.2019.03.351.
[121] D.H. Florez Ayala, A. Alberton, A. Ersoy, Urban Living Labs: pathways of sustainability transitions towards innovative City systems from a circular economy perspective, Sustainability 14 (2022) 9831, https://doi.org/10.3390/su14169831.
[122] T. von Wirth, N. Frantzeskaki, D. Loorbach, Urban living labs as inter-boundary spaces for sustainability transitions?. Handbook on Planning and Complexity Edward Elgar Publishing, 2020, pp. 237–257. https://china.elgaronline.com/edcollchap/edcoll/9781786439178/9781786439178.00017.xml. accessed March 17, 2024.
[123] N.C. Nagorny-Koring, T. Nochta, Managing urban transitions in theory and practice - the case of the Pioneer Cities and Transition Cities projects, J. Clean. Prod. 175 (2018) 60–69, https://doi.org/10.1016/j.jclepro.2017.11.072.
[124] J. Schot, F.W. Geels, Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy, Technol. Anal. Strateg. Manage 20 (2008) 537–554, https://doi.org/10.1080/09537320802292651.
[125] C. Roorda, J. Wittmayer, P. Henneman, F. van Steenbergen, N. Frantzeskaki, D. Loorbach, Transition Management, Erasmus University Rotterdam, Rotterdam, 2014. Available at: https://openresearch.amsterdam/nl/page/101168/transition-management-in-the-urban-context.
[126] A. Smith, Translating sustainabilities between green niches and socio-technical regimes, Technol. Anal. Strateg. Manage 19 (2007) 427–450, https://doi.org/10.1080/09537320701403334.
[127] M. Wolfram, N. Frantzeskaki, Cities and systemic change for sustainability: prevailing epistemologies and an emerging research agenda, Sustainability. 8 (2016) 144, https://doi.org/10.3390/su8020144.
[128] G. Burrell, G. Morgan, Sociological Paradigms and Organisational Analysis, 2019.
[129] J.M. Wittmayer, F. Avelino, F. van Steenbergen, D. Loorbach, Actor roles in transition: insights from sociological perspectives, Environ. Innov. Soc. Transit. 24 (2017) 45–56, https://doi.org/10.1016/j.eist.2016.10.003.
[130] N. Ntounis, E. Kanellopoulou, Normalising jurisdictional heterotopias through place branding: the cases of Christiania and Metelkova, Environ. Plan. a 49 (2017) 2223–2240, https://doi.org/10.1177/0308518X17725753.
[131] K. Hölscher, N. Frantzeskaki, Perspectives on urban transformation research: transformations in, of, and by cities, Urban. Transform. 3 (2021) 2, https://doi.org/10.1186/s42854-021-00019-z.
[132] K. Lindberg, B. Czarniawska, Knotting the action net, or organizing between organizations, Scandinavian J. Manage. 22 (2006) 292–306, https://doi.org/10.1016/j.scaman.2006.09.001.
[133] J. Vymazal, The historical development of constructed wetlands for wastewater treatment, Land. (Basel) 11 (2022) 174, https://doi.org/10.3390/land11020174.
[134] R.R. Brown, N. Keath, T.H.F. Wong, Urban water management in cities: historical, current and future regimes, Water Sci. Technol. 59 (2009) 847–855, https://doi.org/10.2166/wst.2009.029.
[135] E. Botta, Green Growth: A case study on the Danish and Chinese sectoral innovation systems, (2013). https://doi.org/10.2139/ssrn.2221201.
[136] L. Rasmussen, Beijing Copenhagen -Joint Article on Climate Adaptation and Sponge City, City of Copenhagen, Embassy of the Kingdom of Denmark, J. R., Beijing Municipal Institute of City Planning and Design, 2022. Available at: https://kina.um.dk/en/news/report-beijing-copenhagen-joint-article-on-climate-adaptation-and-sponge-city-launched.
[137] G.S. Ascione, F. Cuomo, N. Mariotti, L. Corazza, Urban Living Labs, Circular economy and nature-based solutions: ideation and testing of aNew Soilin the City of Turin using a multi-stakeholder perspective, Circ. Econ. Sust 1 (2021) 545–562, https://doi.org/10.1007/s43615-021-00011-6.
[138] E. Blanco, K. Raskin, P. Clergeau, Towards regenerative neighbourhoods: an international survey on urban strategies promoting the production of ecosystem services, Sustain. Cities. Soc. 80 (2022) 103784, https://doi.org/10.1016/j.scs.2022.103784.
[139] R. Kemp, J. Schot, R. Hoogma, Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management, Technol. Anal. Strateg. Manage 10 (1998) 175–198, https://doi.org/10.1080/09537329808524310.
[140] P. Giganti, P.M. Falcone, Strategic Niche Management for Sustainability: A systematic literature review, Sustainability. 14 (2022) 1680, https://doi.org/10.3390/su14031680.
[141] J. Stiles, Strategic niche management in transition pathways: telework advocacy as groundwork for an incremental transformation, Environ. Innov. Soc. Transit. 34 (2020) 139–150, https://doi.org/10.1016/j.eist.2019.12.001.
[142] E. Panetti, A. Parmentola, S.E. Wallis, M. Ferretti, What drives technology transitions? An integration of different approaches within transition studies, Technol. Anal. Strateg. Manage 30 (2018) 993–1014, https://doi.org/10.1080/09537325.2018.1433295.
[143] D. Chronéer, A. Ståhlbröst, A. Habibipour, Urban Living Labs: towards an integrated understanding of their key components, TIM Rev. 9 (2019) 50–62, https://doi.org/10.22215/timreview/1224.
[144] E. Sayes, Actor–Network theory and methodology: just what does it mean to say that nonhumans have agency? Soc. Stud. Sci. 44 (2014) 134–149, https://doi.org/10.1177/0306312713511867.
[145] E.I.B. EIB, Investing in nature-based solutions: state of play and way forward for public and private financial measures in Europe, Publications Office, LU, 2023. https://data.europa.eu/doi/10.2867/031133. accessed December 7, 2023.
[146] P. Larrey-Lassalle, S. Armand Decker, D. Perfido, S. Naneci, B. Rugani, Life cycle assessment applied to nature-based solutions: learnings, methodological challenges, and perspectives from a critical analysis of the literature, Land. (Basel) 11 (2022) 649, https://doi.org/10.3390/land11050649.
[147] J. Köhler, F.W. Geels, F. Kern, J. Markard, E. Onsongo, A. Wieczorek, F. Alkemade, F. Avelino, A. Bergek, F. Boons, L. Fünfschilling, D. Hess, G. Holtz, S. Hyysalo, K. Jenkins, P. Kivimaa, M. Martiskainen, A. McMeekin, M. S. Mühlemeier, B. Nykvist, B. Pel, R. Raven, H. Rohracher, B. Sandén, J. Schot, B. Sovacool, B. Turnheim, D. Welch, P. Wells, An agenda for sustainability transitions research: State of the art and future directions, Environ. Innov. Soc. Transit. 31 (2019) 1–32, https://doi.org/10.1016/j.eist.2019.01.004.
[148] C. Hyun, Z. Burt, Y. Crider, K.L. Nelson, C.S. Sharada Prasad, S.D.G. Rayasam, W. Tarpeh, I. Ray, Sanitation for low-income regions: A cross-disciplinary review, Annu Rev. Environ. Resour. 44 (2019) 287–318, https://doi.org/10.1146/annurev-environ-101718-033327.
[149] S. Axon, The socio-cultural dimensions of community-based sustainability: implications for transformational change, J. Clean. Prod. 266 (2020) 121933, https://doi.org/10.1016/j.jclepro.2020.121933.
[150] N. Frantzeskaki, A. Rok, Co-producing urban sustainability transitions knowledge with community, policy and science, Environ. Innov. Soc. Transit. 29 (2018) 47–51, https://doi.org/10.1016/j.eist.2018.08.001.
[151] H. Dadashpoor, Z. Yousefi, Centralization or decentralization? A review on the effects of information and communication technology on urban spatial structure, Cities. 78 (2018) 194–205, https://doi.org/10.1016/j.cities.2018.02.013.
[152] M. Callon, An essay on framing and overflowing: economic externalities revisited by sociology, Sociol. Rev. 46 (1998) 244–269, https://doi.org/10.1111/j.1467-954X.1998.tb03477.x.
[153] A. Rödl, A. Arlati, A general procedure to identify indicators for evaluation and monitoring of nature-based solution projects, Ambio 51 (2022) 2278–2293, https://doi.org/10.1007/s13280-022-01740-0.

[154] B. Sowińska-Świerkosz, J. García, A new evaluation framework for nature-based solutions (NBS) projects based on the application of performance questions and indicators approach, Sci. Total Environ. 787 (2021) 147615, https://doi.org/10.1016/j.scitotenv.2021.147615.
[155] R. Giblett, Cities and Wetlands: The Return of the Repressed in Nature and Culture, 1st ed., Bloomsbury Publishing Plc, 2016 https://doi.org/10.5040/9781474269858.
[156] M. Mazzucato, in: Rev. (Ed.), The Entrepreneurial State: Debunking Public vs Private Sector Myths, Revised ed., Penguin Books, London, 2018, p. 288. ISBN: 9780141986104.
[157] D.G. for R. and Innovation, European Comission, Harnessing the power of collaboration for nature-based solutions: new ideas and insights for local decision makers, Publications Office, LU, 2023. https://data.europa.eu/doi/10.2777/954370. accessed December 18, 2023.
[158] L. Liu, O. Fryd, S. Zhang, Blue-green infrastructure for sustainable urban stormwater management—Lessons from six municipality-led pilot projects in Beijing and Copenhagen, Water. (Basel) 11 (2019) 2024, https://doi.org/10.3390/w11102024.
[159] S. Chen, F.H.M. van de Ven, C. Zevenbergen, S. Verbeeck, Q. Ye, W. Zhang, L. Wei, Revisiting China's Sponge City planning approach: lessons from a case study on Qinhuai District, Nanjing, Front. Environ. Sci. 9 (2021), https://doi.org/10.3389/fenvs.2021.748231.
[160] S. Bødker, C. Dindler, O.S. Iversen, Tying knots: participatory infrastructuring at work, Comput Support. Coop Work 26 (2017) 245–273, https://doi.org/10.1007/s10606-017-9268-y.
[161] S. Gherardi, Has practice theory run out of steam? Revue d'Anthropologie des Connaissances 11 (2) (2017) https://doi.org/10.3917/rac.035.0166 bk-bu.
[162] B. Latour, Why has critique run out of steam? From matters of fact to matters of concern, Crit. Inq. 30 (2004) 225–248, https://doi.org/10.1086/421123.
[163] F.W. Geels, M. Ayoub, A socio-technical transition perspective on positive tipping points in climate change mitigation: analysing seven interacting feedback loops in offshore wind and electric vehicles acceleration, Technol. Forecast. Soc. Change 193 (2023) 122639, https://doi.org/10.1016/j.techfore.2023.122639.
[164] H. Brix, C.A. Arias, The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: new Danish guidelines, Ecol. Eng. 25 (2005) 491–500, https://doi.org/10.1016/j.ecoleng.2005.07.009.
[165] P.R. Hansen, C. Clausen, Management concepts and the navigation of interessement devices: the key role of interessement devices in the creation of agency and the enablement of organizational change, J. Change Manage. 17 (2017) 344–366, https://doi.org/10.1080/14697017.2017.1286515.
[166] L. Doganova, P. Karnøe, The innovator's struggle to assemble environmental concerns to economic worth: Report to Grundfos New Business, March 2012, Grundfos New Business, 2012. Available at: https://vbn.aau.dk/en/publications/the-innovators-struggle-to-assemble-environmental-concerns-to-eco.
[167] Kystdirektoratet, Danmarks Meteorologiske Institut, Delundersøgelse af sikringsniveauer for stormflodssikring af København - Arbejdsgruppe Sikringsniveauer, (2024). https://sundogbaelt.dk/media/vvvnvszx/hovedrapport.pdf.
[168] S. Sarabi, Q. Han, A.G.L. Romme, B. De Vries, R. Valkenburg, E. Den Ouden, S. Zalokar, L. Wendling, Barriers to the adoption of urban living labs for NBS implementation: A systemic perspective, Sustainability. 13 (2021) 13276, https://doi.org/10.3390/su132313276.
[169] S. Sarabi, Enhancing the uptake of nature-based solutions in urban settings: an information systems approach, 2022. https://doi.org/10.13140/RG.2.2.17819.54560.
[170] S.L. Jiménez-Ariza, C.V. Rey, J.P. Rodríguez, M. Guzmán-Ramírez, Multi-criteria decision analysis inputs for planning the implementation of nature-based solutions in urban contexts, insumos a partir de análisis Multicriterio para La Implementación de Soluciones Basadas en La, Naturaleza En Contextos Urbanos 18 (2023), https://doi.org/10.5821/ace.18.52.11871.
[171] D.G. for R. and Innovation, European Comission, The vital role of nature-based solutions in a nature positive economy, Publications Office, LU, 2022. https://data.europa.eu/doi/10.2777/307761. accessed January 11, 2024.
[172] J.A. Maantay, A.R. Maroko, Brownfields to greenfields: environmental justice versus environmental gentrification, Int. J. Environ. Res. Public Health 15 (2018) 2233, https://doi.org/10.3390/ijerph15102233.
[173] C. Amouroux, Normalizing Christiania: project clean sweep and the normalization plan in Copenhagen, City Soc. 21 (2009) 108–132, https://doi.org/10.1111/j.1548-744X.2009.01017.x.
[174] B. Daniotti, M. Gianinetto, S. Della Torre (Eds.), Digital Transformation of the Design, Construction and Management Processes of the Built Environment, Springer International Publishing, Cham, 2020, https://doi.org/10.1007/978-3-030-33570-0.
[175] K.M.A. Chan, D.R. Boyd, R.K. Gould, J. Jetzkowitz, J. Liu, B. Muraca, R. Naidoo, P. Olmsted, T. Satterfield, O. Selomane, G.G. Singh, R. Sumaila, H.T. Ngo, A. K. Boedhihartono, J. Agard, A.P.D. de Aguiar, D. Armenteras, L. Balint, C. Barrington-Leigh, W.W.L. Cheung, S. Díaz, J. Driscoll, K. Esler, H. Eyster, E. J. Gregr, S. Hashimoto, G.C. Hernández Pedraza, T. Hickler, M. Kok, T. Lazarova, A.A.A. Mohamed, M. Murray-Hudson, P. O'Farrell, I. Palomo, A.K. Saysel, R. Seppelt, J. Settele, B. Strassburg, D. Xue, E.S. Brondízio, Levers and leverage points for pathways to sustainability, People Nat. 2 (2020) 693–717, https://doi.org/10.1002/pan3.10124.
[176] F.W. Geels, F. Kern, G. Fuchs, N. Hinderer, G. Kungl, J. Mylan, M. Neukirch, S. Wassermann, The enactment of socio-technical transition pathways: A reformulated typology and a comparative multi-level analysis of the German and UK low-carbon electricity transitions (1990–2014), Res. Policy. 45 (2016) 896–913, https://doi.org/10.1016/j.respol.2016.01.015.
[177] C. Adams, N. Frantzeskaki, M. Moglia, Mainstreaming nature-based solutions in cities: A systematic literature review and a proposal for facilitating urban transitions, Land, Use Policy. 130 (2023) 106661, https://doi.org/10.1016/j.landusepol.2023.106661.
[178] A.H. van de Ven, M.S. Poole, Explaining development and change in organizations, Acad. Manage. Rev. 20 (3) (1995) 510–540, https://doi.org/10.2307/258786.
[179] G. Prayag, L.K. Ozanne, R. Martin-Neuninger, P. Fieger, Integrating MLP and 'after ANT' to understand perceptions and responses of regime actors to Airbnb, Curr. Issues Tour. 25 (2022) 3150–3167, https://doi.org/10.1080/13683500.2020.1768226.
[180] F. Nevens, N. Frantzeskaki, L. Gorissen, D. Loorbach, Urban Transition Labs: co-creating transformative action for sustainable cities, J. Clean. Prod. 50 (2013) 111–122, https://doi.org/10.1016/j.jclepro.2012.12.001.
[181] H.J.D. Sørup, O. Fryd, L. Liu, K. Arnbjerg-Nielsen, M.B. Jensen, An SDG-based framework for assessing urban stormwater management systems, Blue-Green Syst. 1 (2019) 102–118, https://doi.org/10.2166/bgs.2019.922.
[182] J. Kirchherr, D. Reike, M. Hekkert, Conceptualizing the circular economy: an analysis of 114 definitions, Resour., Conserv. Recycl. 127 (2017) 221–232, https://doi.org/10.1016/j.resconrec.2017.09.005.
[183] Y. Uchiyama, E. Blanco, R. Kohsaka, Application of biomimetics to architectural and urban design: A review across scales, Sustainability 12 (2020) 9813, https://doi.org/10.3390/su12239813.
[184] H.S. Benites, P. Osmond, Bioconnections as enablers of regenerative circularity for the built environment, Urban. Plan. 6 (2021) 25–39, https://doi.org/10.17645/up.v6i4.4373.
[185] T. McPhearson, E. Andersson, T. Elmqvist, N. Frantzeskaki, Resilience of and through urban ecosystem services, Ecosyst. Serv. 12 (2015) 152–156, https://doi.org/10.1016/j.ecoser.2014.07.012.
[186] D. Haase, Urban wetlands and riparian forests as a nature-based solution for climate change adaptation in cities and their surroundings, in: N. Kabisch, H. Korn, J. Stadler, A. Bonn (Eds.), Nature-Based Solutions to Climate Change Adaptation in Urban Areas: Linkages between Science, Policy and Practice, Springer International Publishing, Cham, 2017, pp. 111–121, https://doi.org/10.1007/978-3-319-56091-5_7.
[187] B.C. O'Leary, C. Fonseca, C.C. Cornet, M.B. de Vries, A.K. Degia, P. Failler, E. Furlan, J. Garrabou, A. Gil, J.P. Hawkins, D. Krause-Jensen, X. Le Roux, M. A. Peck, G. Pérez, A.M. Queirós, G. Różyński, A. Sanchez-Arcilla, R. Simide, I. Sousa Pinto, E. Trégarot, C.M. Roberts, Embracing nature-based solutions to promote resilient marine and coastal ecosystems, Nat.-Based Solutions 3 (2023) 100044, https://doi.org/10.1016/j.nbsj.2022.100044.
[188] V. Perricone, M. Mutalipassi, A. Mele, M. Buono, D. Vicinanza, P. Contestabile, Nature-based and bioinspired solutions for coastal protection: an overview among key ecosystems and a promising pathway for new functional and sustainable designs, ICES J. Marine Sci. 80 (2023) 1218–1239, https://doi.org/10.1093/icesjms/fsad080.
[189] N. Frantzeskaki, S. Borgström, L. Gorissen, M. Egermann, F. Ehnert, Nature-based solutions accelerating urban sustainability transitions in cities: lessons from Dresden, Genk and Stockholm cities, in: N. Kabisch, H. Korn, J. Stadler, A. Bonn (Eds.), Nature-Based Solutions to Climate Change Adaptation in Urban Areas, Springer International Publishing, Cham, 2017, pp. 65–88, https://doi.org/10.1007/978-3-319-56091-5_5.
[190] H. Xu, L. Liu, P. Ding, Building climate resilient City through multiple scale Cooperative planning: experiences from Copenhagen, IOP Conf. Ser.: Mater. Sci. Eng. 1203 (2021) 032063, https://doi.org/10.1088/1757-899X/1203/3/032063.
[191] A.N. Angelakis, J.B. Rose, Evolution of Sanitation and Wastewater Technologies through the Centuries, IWA Publishing, 2014, https://doi.org/10.2166/9781780404851.
[192] C. McGinn, Our dual nature, in: C. McGinn (Ed.), The Meaning of Disgust, Oxford University Press, 2011, p. 0, https://doi.org/10.1093/acprof:oso/9780199829538.003.0007.
[193] J. Böhme, Z. Walsh, C. Wamsler, Sustainable lifestyles: towards a relational approach, Sustain. Sci. 17 (2022) 2063–2076, https://doi.org/10.1007/s11625-022-01117-y.
[194] W.W.A.P. UNESCO, UN World Water Development Report Leaving no one behind, UNESCO, Paris, 2019. Item available at: https://unesdoc.unesco.org/ark:/48223/pf0000367306.locale=en.
[195] WWAP (United Nations World Water Assessment Programme) (Ed.), The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource, UNESCO, Paris, 2017. https://unesdoc.unesco.org/ark:/48223/pf0000247153.
[196] IEA, Special Report: Water-Energy Nexus – Analysis, Paris, 2016. https://www.iea.org/reports/water-energy-nexus (accessed January 23, 2024).
[197] M. Choudhary, C.N. Peter, S.K. Shukla, P.P. Govender, G.M. Joshi, R. Wang, Environmental issues: A challenge for wastewater treatment, in: Mu. Naushad, E. Lichtfouse (Eds.), Green Materials for Wastewater Treatment, Springer International Publishing, Cham, 2020, pp. 1–12, https://doi.org/10.1007/978-3-030-17724-9_1.