D2.1 Conceptual & action framework

on

Low carbon | High air quality NbS potentials

JUSTNature | Work Package 2, Task 2.1

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ABBREVIATION LIST

Term	Description
AR	Assessment Report
BGI	Blue Green Infrastructure
CiPeL	City Practice Lab
D	Deliverable
EbA	Ecosystem-based approach
EO	Earth Observation
ES	Ecosystem Services
EU	European Union
FFH	Flora, Fauna & Habitat
GI	Green Infrastructure
GHG	Greenhouse gases
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
LST	Land surface temperature
LULC	Land use land cover
MRT	Mean Radiant Temperature
NbS	Nature Based Solutions
NDBI	Normalized Difference Built-up Index
NDVI	Normalized Difference Vegetation Index
PET	Physiological Equivalent Temperature
SDG	Sustainable Development Goals
SET	Standard Effective Temperature
SOC	Soil Organic Carbon
T	Task
UGI	Urban Green Infrastructure
UHI	Urban heat island
UHRI	Urban Heat Risk Index
UTCI	Universal thermal climate index
WHO	World Health Organization
WRI	World Resource Institute
WP	Work Package

EXECUTIVE SUMMARY

The overall objective of the Horizon 2020 project JUSTNature is the activation of nature-based solutions (NbS) by ensuring a just transition to low-carbon cities, based on the principle of the right to ecological space. As such, it introduces an ethical baseline or compass, which frames the various actions of the project: to ensure the right to ecological space, and to uphold the duty of not constraining that of others, to be achieved by the activation of nature-based solutions for low carbon cities of high air quality.

As the acronym already indicates, JUSTNature introduces the normative notion of justice. An initial analysis of the scope of nature-based solutions and the role of justice suggests that issues of social and environmental justice are only considered peripherally, and that so far no dedicated research community has addressed the topic. It has been revealed that, although some attention has been directed at questions of social justice (e.g. inclusiveness) and procedural aspects (e.g. co-creation and participative processes), a more comprehensive debate on the role of environmental or climate justice aspects in relation to the activation and implementation of NbS has rarely taken place.

This report has the overall objective of determining the scientific knowledge base and developing a framework for assessing Low carbon | High air quality NbS potentials. It aims to:

1) Provide a conceptual framework, which guides on ethical notions such as equality, inequality, and equity, and on key concepts such as the various dimensions of justice, why justice, why ecological (space) justice, and how to activate NbS accordingly.
2) Introduce an action framework, which outlines the knowledge base for 6 identified (in-) justices challenges, which frame action on Low carbon | High air quality NbS potentials.

A structured process (knowledge brokering) - that facilitates the creation, diffusion and use of ideas and understandings across a diversity of actors with different (disciplinary) backgrounds - has been used for generating the knowledge base. This included phases allowing research breath and phases focusing on research depth. It involved methods such as an integrative literature review, and was accompanied by various feedbacks loops and discussions with a community of practice, including the city representatives of the City Practice Labs (CiPeLs) and urban planning community. This occurred in the framework of

workshops, or was supported by the development of outputs such as a concept note and a survey.

Chapter 2 provides insights into how link key justice concepts, and in particular ecological (space justice), to the activation of NbS. It explains how the use of justice notions can help addressing the root of a problem, and driving community rather than individual actions. It argues that ecological (space) justice weaves ecological considerations into ethical considerations of (environmental) justice. It also puts at the forefront ecological functionings (e.g. air purification, temperature regulation, carbon storage, etc.), which can form ecological constraints, driven by conditions or factors across various dimensions, from the environmental dimension and the built environment to socio-economic dimension and individual vulnerabilities. By introducing the right to and duty of not constraining the ecological (space) of others, Chapter 2 introduces a hierarchy based on an ethical compass, which can also further inform the implementation of the Sustainable Development Goals (SDGs). This led to the development of a 4-tier system for activating Low carbon | High air quality NbS, which requires to consider (in-)justice challenges, an action hierarchy, and defined principles before looking into NbS categories and measures. In this regard, it further expands on the principles of justice, which can be considered, and informs the selection of indicators to identify pre-NbS (potentials) and evaluate progress post-NbS (monitoring and evaluation).

Chapter 3 expands the knowledge base on 6 key challenges or visions to be claimed by the identification (and expected activation) of Low carbon | High air quality NbS potentials:

- Air quality (in-)justices
- Thermal (in-)justices
- Carbon (in-)justices
- Flora fauna habitat (non-)inclusiveness,
- Spatial (in-)justices
- Temporal (in-)justices.

Each according chapter introduces various definitions and describes key aspects to consider regarding the extent to which various environmental, built environment, socio-economic and individual vulnerability conditions drive (in-)justices. It highlights the potential of NbS to address the challenge, or whether there are risks of deflecting attention from the need to focus on other measures (e.g. to rapidly phase out fossil fuels to reduce carbon emissions). It also highlights interlinkages between the various challenges, to emphasise synergies (e.g. addressing increased temperatures and impact on air pollution) as well as trade-offs (e.g. addressing low density urban areas to reduce greenhouse gas emissions though risk of losing a diversity of habitats). Finally, it discusses the need for a basket of indicators that integrates various considerations to appraise the NbS potential of addressing each (in-) justice challenge.

The work is far from finished, the report presenting intermediary results, inherently influenced by the researchers and what knowledge they called upon. In line with interpretive research, it needs to be put up to further scrutiny, especially in practice, to generate actionable knowledge, which means not only relevant for the practice but also 'usable' by people to transform their city.

1 INTRODUCTION

1.1 Aims and objectives

The overall objective of the Horizon 2020 project JUSTNature is the activation of nature-based solutions (NbS) by ensuring a just transition to low-carbon cities, based on the principle of the right to ecological space. As such it introduces an ethical baseline or compass, which frames the various actions of the project: to ensure the right to ecological space and to uphold the duty of not constraining that of others, to be achieved by the activation of nature-based solutions for low carbon cities of high air quality. This especially concerns the four key identified innovation dimensions for the activation of NbS, 1) effective governance, 2) long-term NbS system maintenance and operation, 3) social & innovative business models and market design, and 4) efficient technologies and applications. Hereby, City Practice Labs (CiPeLs) constitute the backbone of the project's activities by delivering community-engaged, co-explored, and co-decided innovation.

As the acronym already indicates, JUSTNature introduces the normative notion of justice. With the increasing adoption of the NbS concept to address grand societal challenges such as climate change, biodiversity loss and human well-being simultaneously, it was only a matter of time until questions of justice also became pertinent. Cities in particular represent a complex setting where climate impacts are not distributed evenly, where low-income households are more often highly exposed to environmental ills, and environmental amenities are increasingly exclusive to high-income households.

However, an initial analysis mapping the scope of nature-based solutions and the role of justice suggest that issues of social and environmental justice are only considered peripherally and that so far no dedicated research community has addressed the topic (Cousins, 2021). A scrutiny of the report outlining the state of the art of EU funded NbS projects (European Commission, 2021), reveals that some attention has been directed at questions of social justice (e.g. inclusiveness) and procedural aspects (e.g. co-creation and participative processes). However, insights from different justice scholarships were often used interchangeably (e.g. social and environmental justice), not necessarily discussed more profoundly or applied piecemeal-like to the extent they help frame how nature-based solutions address a defined societal challenge. A more comprehensive debate on the role of environmental or climate justice aspects in relation to the activation and implementation of NbS has rarely taken place, and as such, it remains unclear how the concept effectively contributes to addressing justice considerations. This regards at least three key elements framing a justice claim-making process: distributional (who gets what), procedural (who gets asked) and recognition (who gets asked how) justice.

JUSTNature kicked off in September 2021 with a timeframe of four and half years. Besides the gender guidelines (D1.4) this report as such represents one of the first publicly available outputs, delivered as part of Task 2.1. Being part of Work Package 2 on Recognizing Low carbon | High air quality NbS potentials, Task 2.1 has the overall objective of determining the scientific knowledge base and developing a framework for assessing Low carbon | High air quality NbS potentials. It aims at providing further insights into how or in what way activating different NbS can help addressing defined challenges simultaneously, such as directly and indirectly combatting air pollution, contributing to climate change mitigation and also contributing to climate change adaptation, bearing in mind synergies and trade-offs as well as justice considerations.

In this regard, the report's specific objectives are:

- Creating a conceptual framework, which provides guidance on key concepts such as the various dimensions of justice, why justice, why ecological (space) justice, and how to activate NbS accordingly to inform and consider other project activities.
- Developing an action framework, focused on outlining the body of knowledge for the activation of Low carbon | High air quality NbS potentials, taking into consideration how NbS categories and measures sustain defined functions and benefits while accounting for how these are spatially distributed and are reflecting needs or demands, in relation to identified key challenges or justice visions to be claimed.

In a subsequent step the knowledge base that has been created informs the development of an ecological (space) justice strategic planning game toolkit, in order to further transform the findings into actionable knowledge, which means not only relevant for the practice but used by people to transform their city.

1.1.1 Outline and scope of this report

Chapter 1 provides an introduction into the aims and objectives of this report on the creation of a conceptual and action framework on Low carbon | High air quality NbS potentials. It also outlines the various chapters and their scope (1.1.1), as well as interlinkages with other project activities (1.1.2). In addition, it introduces the methodological approach to broker the knowledge in order to inform the development of the framework and how this was validated by the urban planning community and the city representatives of the CiPeLs as part of the Community of Practice (1.2).

Chapter 2 presents the conceptual framework informing the activation of NbS to ensure the right to ecological (space) justice. It introduces different ethical notions such as equality and inequality, equity as well as various dimensions of justice (2.1) to explain why justice and what kind of justice to be considered (2.1.1). It introduces key dimensions of justice which have been or can be linked to the activation of NbS more specifically: environmental, climate & energy justice and a just transition (2.1.2). This is followed by explaining in more detail the concept of ecological (space) justice or injustices (2.1.3) and concludes with the role of values in defining justice in relation to NbS. What follows is an outline of how questions of justice link to grand social challenges (2.2), how these have been linked to NbS (2.2.1) and to the Sustainable Development Goals (SDGs) (2.2.2) and introduces suggestions on how to integrate ecological justice considerations into the SDGs (2.2.3.). Chapter 2 concludes on outlining a conceptual way forward to activate NbS for ecological (space) justice (2.3). This begins with introducing the principles or legs of ecological (space) justice to be considered (2.3.1), re-evaluates the various definitions and classifications of NbS (2.3.2) to propose a hierarchical tier system for the activation of NbS, which introduces 4 levels to be considered (2.3.3). It concludes how these considerations shape a systemic monitoring and evaluation of ecological (space) justice sustained by NbS (2.3.4).

Chapter 3 provides the knowledge base of the action framework. It consists of 6 sub-chapters, addressing the various identified challenges which frame action on Low carbon | High air quality NbS potential. This refers to air quality (in-)justices (3.1), thermal (in-)justices (3.2), carbon (in-)justices (3.3), flora fauna habitat (non-)inclusiveness (3.4), spatial (in-)justices (3.5), and temporal in-justices (3.6). They all follow a similar structure, introducing a definition (3.x.1) based on applied concepts and the drivers of (in-)justices across environmental conditions to the built environment, followed by the NbS contribution (3.x.2) whether in relation to NbS categories and measures or the action hierarchy that the activation has been following, at the same time outlining interlinkages with the other key challenges, both synergies and trade-offs (3.x.3), and introducing considerations on indicators to appraise the NbS (in-)justice potential (3.x.4),

Chapter 4 includes insights from the community of practice, who in different networks or constituted by the city partners of the CiPeLs have been engaged to validate the generated knowledge base. This involved the organisation of various workshop and webinars with the CiPeLs, informed by a concept note (4.1), and included the development of a survey to be shared with the community of urban planning practitioners (4.2), though also run with representatives of the CiPeLs (4.2.1).

Chapter 5 concludes on the way forward. It informs how the results will be used to lead to actionable knowledge through the creation of an ecological (space) justice strategic planning toolkit. It introduces how follow-up Tasks such as 2.2 are expected to inform the according development and resulting testing, how this links to the activities of other work packages and is expected to feed into the development of the expected Handbook on Identifying Low carbon | High air quality NbS potentials in Cities as a concluding deliverable of work package 2.

1.1.2 Interlinkages with other project activities

The report has been informing the development of ecological / socio-economic status and spatial disparities profiles (Task 2.2), especially in relation to the challenges framing Low carbon | High air quality potentials and the various baskets of indicators. It has also supported activities in relation to defining & visualising Low carbon | High air quality NbS potentials and scenarios for meaningful future development trajectories in the city practice labs (Task 2.3) as part of the temporal (in-)justice challenges in particular. These various activities are expected to feed into the final Deliverable 2.4, the previously mentioned handbook.

In addition, the following interlinkages with other Work Package need to be especially highlighted:

⇆ Work package 3 (Life-cycle monitoring and evaluation of Low carbon | High air quality NbS impact): The activities of WP3 provided input into discussions on indicators as part of this report, whereas the generated knowledge base has informed the indicator development for the life-cycle monitoring and evaluation (Deliverable 3.1).

⇆ Work package 4 (Design, facilitation and evaluation of City Practice Labs): The generated knowledge base has been validated in the framework of two meetings with the CiPeLs to discuss existing challenges. This has informed the co-identification and mapping of stakeholders and initiatives (Deliverable 4.1), whereas the results of the latter are going to be used for framing the transformation of the report results into actionable knowledge as part of the local and collaborative CiPeL workshops. The output of this report is also expected to impact the development of the training toolkit for the city facilitation teams (Deliverable 4.4).

⇆ Work package 5 (Low carbon | High air quality NbS design and implementation in CiPeLs): The generated knowledge base has already informed decisions on the NbS concepts designs in the CiPeLs and the selection of the pilot areas (Deliverable 5.1), and it is expected further continuing to do so with the further transformation into actionable knowledge (e.g. ecological justice strategic planning toolkit).

⇆ Work package 7 (Low carbon | High air quality NbS systems governance): The report has laid out the basis for procedural and recognition justice considerations in relation to defining NbS co-governance, whereas insights from the Work Package will inform key principles to be applied as part of the 4-tier system for NbS activation (Deliverable 7.1).

1.2 Methodological approach

1.2.1 Rationale of knowledge brokering

Knowledge brokering is interpreted as a structured process that facilitates the creation, diffusion and use of ideas, understandings and ultimately knowledge across a diversity of actors with different (disciplinary) backgrounds. The complexity of the topic and the normative nature of questions of justice requires an approach that allows time for reflection as well as going back and forth between a complex and systemic research question and the seeking of more explicit explanations. As such the focus is put on an abductive inquiry, '*seeking to explicate what would make a puzzle less perplexing*', following not necessarily a linear but '*circular-spiral pattern*' (Schwartz-Shea & Yanow, 2012: 27-28).

As such, the rationale of the knowledge brokering process, its phases, various steps, outputs and inputs considered two foci (see Figure 1):

- Allowing breath, to inform the structuring of the conceptual and action framework.
  Phases: Phase A - Scanning and selecting of literature & Phase C - Validation by Community of Practice
  Outputs/Inputs: Intuitive and project list of literature, concept note and survey
- Focusing on depth, to allow an in-depth interpretation and judgment of results.
  Phases: Phase B – Deepening & partly Phase C - Validation by Community of Practice
  Outputs/Inputs: Writing list of literature, concept note and survey informing discussions with the City Practice Labs (CiPeLs).

This to begin with builds on the decision to select an integrative rather than systematic literature review as a key process, for deemed most suitable for re-assessing, defining and conceptualising and for combining different disciplinary perspectives (Snyder, 2019), which results into the development of a conceptual and action framework. Whereas a systematic literature review consists mostly of a quantitative sampling of in particular peer-reviewed journal publications, the integrative review is not necessarily systematic but ranges from intuitive (e.g. snow-balling) to a structured qualitative process, considering peer-reviewed articles to books and other documents. The integrative literature review consists of two main processes or outputs:

1. An intuitive and project list of literature, building on the existing knowledge of literature of those carrying out the literature review and paying special attention to publications provided by EU Horizon 2020 funded NbS projects (see Chapter 1.2.2).
2. A writing list of literature, following the restructuring of the various sections of conceptual framework and of the identified thematic clusters, and gathered by using an according template and following a defined framework (see Chapter 1.2.3).

The two lists informed the shaping of the conceptual framework and of the thematic clusters laying at the basis of the action framework, which structures the assessment of Low carbon | High air quality NbS potentials.

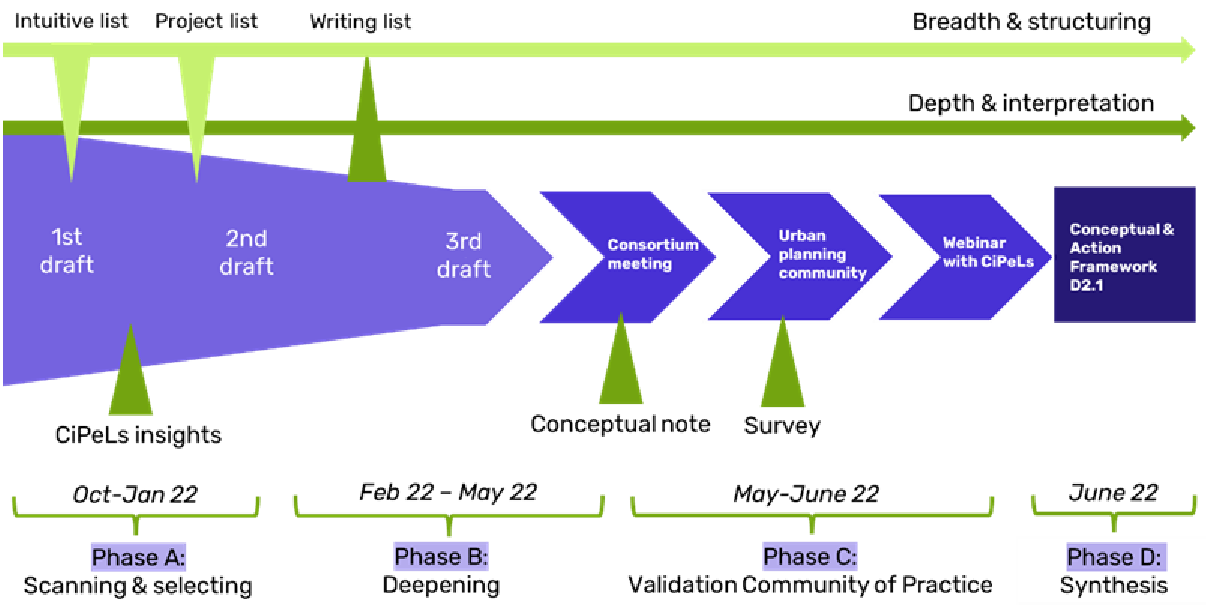

Figure 1: Rationale of knowledge brokering

The integrative literature review and shaping of the conceptual and action framework was accompanied by continuous loops of feedbacks and interactive discussions with the partners involved in WP2 and city partners. These consisted of:

- Dedicated workshop with the partners directly involved in the various activities of the WP, as well as discussions during regular WP2 meetings
- Dedicated workshop with the CiPeLs representatives as well as attendant project partners at the beginning of the process as well as part of a webinar introducing the conceptual and action framework
- Presentation of a concept note at the first project consortium meeting, to inform the discussions in the various WPs
- Setting up of a survey to be distributed to the global urban planning community, as well as being tested with the CiPeLs

The various activities and results are further outlined in the according chapters, e.g. on the validation by the community of practice (Chapter 4). Not necessarily, the process has occurred as linearly as presented in Figure 1, following an oscillating pattern between breadth and depth, between intuitive and interpretive literature review, and various loops of feedbacks and validations. They have all subsequently informed the final synthesis phase leading to the conceptual and action framework finally taking shape. In line with an abductive research logic and interpretive research (Schwartz-Shea & Yanow, 2012), the report does not provide overall, definite conclusions, but presents intermediary results, which will be put further up to scrutiny, especially in practice, to transform it into actionable knowledge (Mach et al., 2020) (see Conclusions).

1.2.2 Intuitive and project literature list: Storming project partners' brains

Zotero is a free, open-source online tool and application, which aims at providing support for collecting, organising, sharing and citing research. It allows the creation of dedicated groups for the sharing of a library of items, including files, tags or notes.

It was decided to create a Zotero group (*JUSTNature - WP2 conceptual framework_Input partners*) for the sharing of publications amongst partners, which they consider key in informing the assessment and development of the conceptual and action framework (intuitive and project lists). Following a discussion of the proposed thematic clusters, an initial list of tags was developed to structure the collection of literature (see Annex 1 for the detailed list). This list of tags consists of different layers considered central for the structured review:

- Layer 0: Refers to important features of a publication. Initial focus was put on key concepts (e.g. environmental justice), publications developed in the framework of Horizon 2020 NbS projects (e.g. impact indicators handbook), meta-research studies (e.g. NbS & air quality), defined case examples as well as collection of data and monitoring
- Layer 1: Refers to the thematic clusters initially identified as key for defining Low carbon | High air quality NbS potentials. These refer to i) ecological space and disparities, ii) socio-economic space and needs, iii) rethinking the built environment and iv) temporal scale considerations
- Layer 2: Includes tags that refer to more specific key words considered relevant for the thematic clusters. For example, in relation to ecological space and disparities, tags such as NbS typologies, urban green and land use categories or NbS/urban green and air pollution are used. Tags such as neighbourhood segregation & NbS or NbS & gentrification are applied for socio-economic space and needs, city & air quality for the built environment and historic impact of urban planning for temporal scale considerations.
- Layer 3: This layer refers to a tag suggested by a partner, in addition to the already identified tags. A few key ones were suggested, such as 'ecosystem disservices', 'gender inequalities', 'pathways for NbS integrated approach' and 'NbS impact'.

The contributing partners were asked to add 10 to 15 items to the group library, tagging them using the different layers. Besides tags, also notes could be added to an item, to very briefly explain why an item was considered important.

The first brainstorming process on Zotero resulted in the collection of overall 77 items.

As regards the thematic cluster layer, within the 'ecological space and disparities' tag, 48 publications have been collected, in relation to the important key features layer mainly figuring 'key concepts' and 'meta-research studies', and regarding specific content in relation with NbS and urban green & air, and NbS and gentrification.

13 items have been collected within the 'socio-economic space and disparities' tag, mainly focusing on topics such as NbS and gentrification, built-environment inequalities, spatial

disparities and gender inequalities, and mostly classified within the 'key concepts' and 'case example studies'.

Overall, 20 items, most of them classified as meta-research and key concepts studies, were collected for 'built-environment' layer; most of the studies focused on 'urban green and land use', 'climate change adaptation and mitigation', and 'air quality and inequalities'. Only one tag was present for the temporal scale layer, with reference to an EU Horizon 2020 NbS project publication relating to 'urban planning cultures'.

On February 3rd, 2022, a workshop was held with all WP2 project partners. The core part of the workshop was to present the work done up to that point in reviewing the current, relevant literature and presenting the proposed new structure of the conceptual and action framework. Some of the ideas represented in their findings were concentrated around NbS, SDGs, current distribution patterns and their associated socio-economic links, and different lenses of 'justice' to be considered. In the collaborative portion of the workshop, attendees reflected and shared their perspectives on what had been presented and how to proceed. They were quick to share that we needed to build clearer definitions for commonly used terms and concepts as well as the interconnected nature of the work done so far for WP2 with other WPs, more specifically WP7. The group emphasised an importance of investigating the various drivers of injustices, namely the built environment and social and economic conditions. Carbon (in)justice and spatial/housing/land use (in)justices were suggested to be considered as part of the action framework moving forward. Recommendations were made in how to define dimensions of actions as well as a large list of potential indicators. The collaborative work carried out during this workshop went on to inform the re-drafting of the report, the development of writing list as well as the development of a first concept note (see Annex 4).

1.2.3 Writing list of literature: A structured and interpretive review

Following the activities of the creation of an intuitive and project list and discussions of re-drafting the various chapters of the conceptual and action framework, the approach of creating the writing list was defined. This especially concerned the development of the action framework, and the newly identified six key components of ecological (space) justice, as considered of relevance for determining Low carbon | High air quality NbS potentials. It includes air quality, thermal and carbon (in-)justices, as well as flora-fauna-habitat (non-)inclusiveness, spatial and temporal (in-) justices.

This involved a shift from focusing on breadth regarding the knowledge to be generated to a focus on depth, to generate meaning to various concepts and the action framework in particular. Rather than being interpreted as based on the collection of data or evidence, the sense- or meaning-making is considered inherently influenced by the researchers and who they call upon (Schwartz-Shea & Yanow, 2012). In an interpretive review this relates to the indirectly called upon knowledge in written materials, documents and publications. To ensure that this generated meaning narrates a defined understanding of the key concepts and thematic clusters, the review was structured according to a demarked process.

For each of the 6 thematic clusters or components of ecological (space) justice to define Low carbon | High air quality NbS potentials the researchers were asked to:

a) Use available literature insights to define the component, by looking into how various studies address (or not) relevant i) environmental conditions, ii) socio-economic conditions, iii) individual conditions & individual vulnerabilities, and iv) the built environment.
b) Outline the contribution of NbS by scrutinising the available literature (using related terms such as green infrastructure, urban green areas, and ecosystem services) and list the NbS blocks and measures (e.g. urban forests, green walls) most frequently discussed.
c) Outline interlinkages to any of the other 5 key components described in the literature, highlighting how strong they are, depending on the extent to which they have been discussed in the literature.
d) Include a list of indicators, which have been introduced in the literature, especially from Horizon 2020 publications, and can be useful to form a basket of indicators to measure progress in relation to a component, taking into consideration to which driver(s) of (in-) justices they link, how they relate to NbS contributions, which leg of justice they predominantly address, and giving indication on the level of integration.

To ensure a structured approach, it was suggested to proceed as follows:

1. Use the 'component template tables' to collect relevant, synthesised information from the literature. The process is kicked off by building on the intuitive list, followed by additionally scrutinising selected references & carrying out a word search on Google Scholar, Web of Science, Scopus, etc. (see template in Annex 2).

2. Further synthesize the information into the according tables provided in the related sub-chapters, and provide an indicative assessment where suggested (e.g. integration level, interlinkages).
3. Deepen and discuss the information of the tables in the various sections.

It needs to be noted that such an interpretive review poses some challenges, especially if researchers are involved who are firmly rooted in defined disciplinary backgrounds or used to a positivistic approach of data collection rather than knowledge generation. A strong disciplinary focus bears the risk of not sufficiently taking into consideration knowledge generated outside the own discipline even if involving similar concepts (e.g. inequalities). A strong positivistic approach of (also qualitative) data collection often leads to a mere collection of references, and a strong hesitation to propose own interpretations or conclusions, building on one's own knowledge and research experience (though making this transparent). Such challenges can be addressed to a certain extent by a structured process (e.g. extensive feedback loops), but foremost also require the involvement of researchers who are experienced in seeking interdisciplinary breath. The same is suggested for processes focused on transferring this knowledge into practice and for practitioners involved in the activation of NbS.

2 DEFINING ECOLOGICAL (SPACE) JUSTICE AND NBS

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2.1 From various justice dimensions to defining ecological (space) justice

2.1.1 Why justice and what kind of justice

While notions of equity, equality, inequality, justice and injustice might often be used interchangeably, seemingly just another version or the other side of a coin, how different disciplines have approached the topic hints at a particular reason for doing so or at the aim of a particular framing (Gantioler, 2019). This matters because framing in turn influences the scope for claim-making and action in practice. Below we explore key related terms and their definitions in the literature as well as outlining particular reasons for their use (Figure 2).

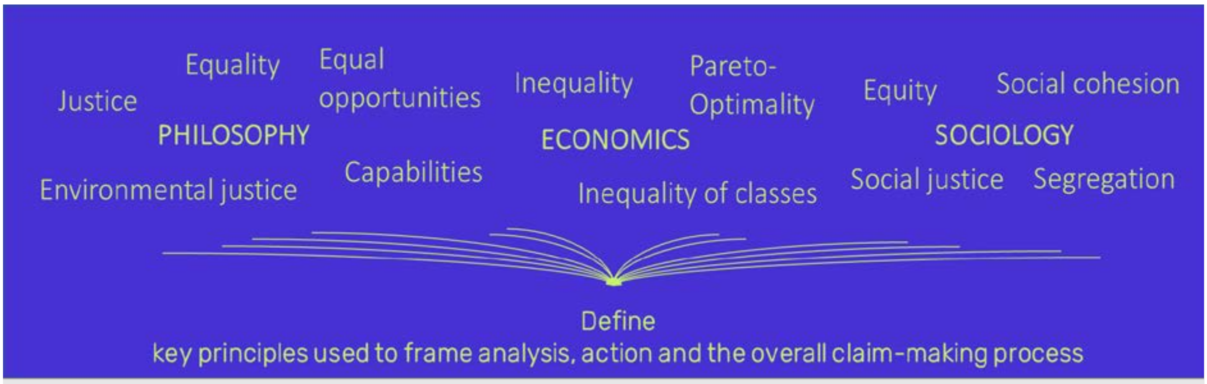

Figure 2: Disciplines and applied ethical notions, based on Gantioler, 2019

Ideas of equality often remain in the domain of philosophical discussions, where rather than being associated with all people (or species) becoming equal, it is more often a consideration of being of equal worth (Pojman & Westmoreland, 1997). Besides this more common underlying agreement informing discussions, other aspects are more disputed (Pojman & Westmoreland, 1997), between:

- Egalitarians (what should be equalized), and non-egalitarians (what is the moral significance of equality),
- Representatives of formal theories (key to focus on processes that lead to equality) and content (key to focus on characteristics of what equality is to be achieved),

- Ways of achieving equality, whether everyone is brought up to the level of the best off, everyone is brought down to the level of the worst off, or the worst and best off are brought to a level where they meet in between.

The classical philosopher Aristotle, a proponent of formal theories, set the stage for many theories on justice to come, whether in opposition or to complement his notions. Differing between distribution and corrective justice, he presumed justice to be achieved when equals are treated equally and non-equals unequally, and thus some receive what is 'deserved' and thus aiming at a 'proportional' equality (Gosepath 2011 in Gantioler 2019). More current philosophical discussions on the notion of justice have been driven by John Rawls' 'Theory of Justice' (Rawls, 1971). Different to Aristotle, he questions the role of merit in defining justice, but lays out an institutionalized process, the theory of a hypothetical contract. Building on the tradition of social contracts, a theory based on the assumption of humans being selfish and thus needing moral norms to form a tacit contract, he argues that the latter can be achieved by bargaining parties discussing its fundamental terms behind 'a veil of ignorance', which ensures objectivity and impartiality. In opposition, other philosophers argue for a bottom-up process or popular participation, defining the 'veil of ignorance' as a misleading fiction, given a process where no one knows each other cannot be realistically convened (Bunge 1989 in Gantioler 2019). More recently, and in line with a utilitarian approach, it was argued that what is defined as 'just' depends on subjective preferences and individual circumstances, and thus pursuing any grand scheme of justice is futile. Especially spatial planners should thus focus on questions of injustices (Davy, 1997). Others argue that using an injustice perspective means using a master frame for effective community mobilizing (D. E. Taylor, 2000).

Due to the existing major disputes, notions of equality as such have often been abandoned in practice. Very strong opposing notions have resulted in the 'temptation' of deciding that '*when [competing theologies] attack their rivals, they seem completely successful, the result being a mutual self-destruction*' (Pojman & Westmoreland, 1997:2). The only exception remains the idea of equal opportunities, entering political philosophy in relation to the development of policies and their instruments. Nowadays, it is often reduced to its most basic interpretation, that of the opportunity to compete in a given market or society, rather than being interpreted as providing equal life chances according to specific criteria (Pojman & Westmoreland, 1997). Introduced especially by the discipline of psychology is the theory of equity, mostly in opposition to equality and its interpretation as equal opportunities. Equity theory is most often associated with the (perceived) fairness of amounts received and thus distributional aspects (Folger, 1986). More recently and especially in political sciences, discussions on equality have been informed by the theory of capabilities (Nussbaum, 2006; Sen, 1973). Rather than focusing on the distribution of resources and primary goods, the attention is shifted to basic entitlements, to make people capable to do and to be (e.g. to control one's environment), influenced by goods and services, social context and individual choices.

Of key interest to economics is the notion of inequality, in particular of the distribution of income and wealth, as providing ample opportunity to focus on objective measurement based on ever more complex mathematical endeavours. It is argued that inequality *per se* not necessarily can be deemed bad or good, but it depends whether the occurring differences are perceived as just (Gantioler, 2019). For example, some economists consider socio-economic inequalities in fact to be an important driver of innovation and economic development (Ostry et al., 2014), whereas others take a more critical view, referring to the corresponding negative consequences and costs for society and the economy (Stiglitz, 2012). This is often judged by economists based on considerations of efficiency in the distribution of resources, determined by relative positions or pareto optimality, where a person's (or consumer's) utility cannot be increased without reducing that of other persons (or consumers). In addition, for many years and still pushed by some theorists, the predominant view has been that inequality will solve itself along with economic growth and increased income (Topuz, 2022).

The discipline of sociology historically has pursued the study of a diversity of dimensions to define social inequality and social justice (Gantioler, 2019). In relation to social inequalities, deemed to have become a key focus of sociology due to the attempt of the discipline to move increasingly towards 'measurable' approaches, these are often separated into vertical and horizontal considerations and analyses (MacNaughton, 2017). Vertical social inequalities refer to inequalities resulting from a defined higher or lower socio-economic status, usually considering variables such as education, income or job characteristics and social outcome. It also includes the class-model perspective, which has again gained momentum in recent years, in political philosophy, but also political economy in particular. It divides the population into mutually exclusive categories, which are defined by key variables in relation to socio-economic aspects (Grusky & Kanbur, 2006). Horizontal social inequalities refer to different lifestyles and milieus, which derive from defined characteristics, linked to variables such as age, gender, religion or immigration background and also modify or condition the relationship between humans and the environment. They bear the risk of leading to more accentuated forms of vulnerabilities (Sultana, 2014) (see Box 1). The line between these two perspectives of social inequalities cannot necessarily be drawn neatly, as in practice they are strongly interlinked (Jayaraj & Subramanian, 2006). However, some argue that vertical social inequalities in a range of policy arenas, such as in relation to human rights, have not yet been as much of a focus and need to be adequately addressed (MacNaughton, 2017; Sandel, 2020a).

Social justice is applied to determine at what point these social inequalities can be defined as just or unjust, whereas especially in a policy context social cohesion often comes into play, as a desirable objective of decreasing social inequality, also related to the contribution of NbS. However, social cohesion can hold different meanings depending on the disciplines involved and research interests, considering either the tightness of social relationships or more largely referring to a cohesive society which is characterized by a sense of belonging, fighting exclusion or marginalization (Bruhn, 2009; J. Chan et al., 2006). One main point of criticism in relation to social cohesion is that the concept often neglects the existing multiple values in societies and multitude of cultures that are supposed to inform the resilience of urban societies in particular (Fonseca et al., 2019).

Box 1: Social inequalities, justice and gender

Gender is a key aspect of justice to consider in the JUSTNature project. In JUSTNature, the **term 'gender'** is used as the characteristics of women, men, girls and boys that are socially constructed, including norms, behaviours and roles associated with being a woman, man, girl or boy, as well as relationships with each other.

Gender produces and reproduces social inequalities (WHO, 2022). In most societies, women have less access to power, resources and decision-making (Lorber, 2010). Moreover, women tend to bear inequitable environmental burdens and have less control over environmental decisions as opposed to men, which both have an impact on their health (Bell, 2016). To combat these inequalities, JUSTNature developed **Gender Guidelines** (D1.6), which are practical recommendations for implementing gender empowerment in different tasks.

The application of notions such as social cohesion, but also social inequalities (no claims of what ought to be) and social justice (mostly focused on addressing defined identities and social groups and neglecting human-nature relationships) has been much disputed, in an urban and environmental context in particular. Social justice was for example discussed in opposition to other concepts of justice, such as libertarian justice (promoting the strong and maximizing liberty) or utilitarian justice (promoting the most and maximizing happiness), adding to a planner's dilemma for which one to opt for (Davy, 1997). Others argue for the need to shift from an approach of individual and cultural preferences to a more objective approach that considers consciously creating better (environmental) conditions for all citizens (Fainstein, 2010).

2.1.2 Environmental justice, climate justice, energy justice or just transition?

In relation to some of the grand societal challenges to be addressed by NbS (see Chapter 2.2 for more details), there are four fields of scholarship on justice that can be considered key in framing the justice claim-making process for this field of research and action: environmental justice, climate justice, and more specifically energy justice and a just transition (Table 1).

The environmental justice movement originated in the 1980s among Black and Latinx communities in the United States, later developing into a theory first advanced by sociologist Robert Bullard in the early 1990s. This largely occurred in relation to concerns about the uneven distribution of social and environmental burdens (e.g. air pollution, toxic waste) between communities along the lines of race/ethnicity, social class, gender, age, and/or location (Temper et al., 2015). Differently in Europe, in the 1980s and influenced by the discipline of economics, discussions mostly focused on questions of distributional impacts related to the costs of defined environmental policy instruments (Merk, 1988). The field of environmental justice later further expanded the thematic focus, widening the scope and introducing new structured frames of an environmental justice claim-making processes (Walker, 2011). It also turned to questions of environmental goods (e.g. urban green spaces) and their similarly inequitable distribution (Anguelovski, 2013), as well as moving beyond the original distributional focus to address other principles of justice (Brooks & Davoudi, 2018), such as on procedural and recognition aspects (see detailed outline in Chapter 2.3.1).

In addition, it needs to be considered that the notion is often interpreted differently depending on the geographical area and local context. As illustrated previously, in the US the focus was laid on environmental ills in particular along the lines of race/ethnicity or also gender. For example, in Germany, environmental justice is mainly concerned with how defined social conditions (e.g. vertical inequalities such as income or horizontal ones such as age or gender) affect individuals' exposure to environmental burdens and access to environmental resources as well as their individual vulnerabilities (e.g. psycho-social burdens, individual health and individual resources), and as such overall health as a main aspect of human well-being (Böhme et al., 2015).

Influenced by the concept of ecosystem services (e.g. provisioning services such as food and raw materials or regulating services such as air purification and carbon sequestration) entering the international biodiversity policy arena in the mid-2000s, aspects of fairness and ethics began to be increasingly discussed in relation to the distribution of benefits sustained by healthy ecosystems and the conservation of biological diversity. Initially, the discussions focused on potential trade-offs between different services (e.g. recreation and safeguard of water quality) or disservices (e.g. allergies) (Jax et al., 2013). It then also built on questions of fairness regarding the generation (e.g. favoured biophysical functions), distribution (e.g. who benefits on a spatial and temporal scale) and articulation (e.g. how values of defined benefits are emphasized or not) of ecosystem services (Ernstson, 2013). With the green infrastructure concept gradually being adopted by the spatial and urban planning community, questions of environmental justice also began to emerge with respect to its practical implementation, in particular regarding the distribution of urban green areas but also in relation to their accessibility, as well as consideration of different values among user groups (Gantioler, 2019; Kabisch et al., 2016).

More recently, the environmental justice scholarship has also turned towards the rights of nonhuman species and the need to address these (Pineda-Pinto et al., 2022; Schlosberg, 2013), as is outlined in more detail in the chapters introducing ecological space (2.1.3) and when discussing habitat-flora-fauna inclusiveness (3.4).

Table 1: Different branches of (environmental, climate and energy) justice scholarship and their key perspectives

Environmental justice	Climate justice	Energy justice	Just transition
• Initially all about the distribution of environmental ills or burdens • In Europe, key focus on the distributional effects of environmental policy instruments • Increasingly focused on the 3 tenets of distribution of environmental quality (both ills and goods) and integration of procedural and recognition aspects. • Working on the further integration of the rights of nonhuman species	• Initial discussions focused on the distribution of greenhouse gas emission rights • Global perspective related to the questions of accountability and unequal geographical distribution of climate change impacts (e.g. developing countries) • Key focus put on climate vulnerable groups and intergenerational equity considerations (e.g. future generations) • Entered IPCC scientific assessment report recently, in call for normative judgments	• Youngest notion and closely aligned with climate justice considerations • Global fair dissemination of the benefits and costs of energy services • Focus on inclusiveness, especially in relation to the social impact of a low-carbon transition • Considers affordability of energy services, in relation to notions such as energy poverty	• Originated in emerging shift from extractive to renewable energy shift and concern for workers' rights. • Joint conceptual space for integrating the various notions of environmental, climate and energy justice • Shall allow to address interconnected sustainability challenges simultaneously • Emphasises a transition to a defined goal or the claiming of a defined ought-to be

Besides introducing NbS as an 'enabler of the expansion of the solutions space', one of the latest contributions to the IPCC's sixth assessment report (AR6) (IPCC, 2022a), addressing climate change impacts, adaptation and vulnerabilities, for the first time introduces the notion of climate justice. Building on the recognition of unevenly distributed vulnerabilities to climate impacts and capacities to adapt in AR5 (IPCC, 2014), the introduction of the notion, besides supporting science-based evidence opens the opportunity for normative judgments to assess whether climate change adaptation measures in particular are not just effective, but also equitable. Climate justice is defined as comprising '*justice that links development and human rights to achieve a rights-based approach to addressing climate change*' (IPCC 2022a: p6). The authors introduce three key principles: 1) *distributive justice*, defined as allocation of benefits and burdens not only between individuals and nations but also generations, 2) *procedural justice*, referred to as who decides and participates in decision-making, and 3) *recognition*, outlined as basic respect and vigorous engagement of a diversity of cultures and perspectives. These three tenants have also been widely adopted by scholars when describing environmental justice, though depending on the scholarship and the application have been interpreted slightly differently (see Chapter 2.3.1).

The report acknowledges that climate justice means different things depending on the context where it is applied. However, it can generally be argued that climate justice scholarship has picked up a more global perspective, putting emphasis on the consequences of a rapidly changing climate especially (though not only) for vulnerable groups in the Global South, who typically bear less responsibility for causing carbon emissions (McCauley & Heffron, 2018). It also takes into consideration long-term temporal aspects of justice, i.e. the injustice of today's children and future generations bearing the burden of increased climate impacts created by their predecessors. Some scholars have also advocated for greater attention to local level climate (in-)justices, e.g. in relation to differentiated climate vulnerabilities and benefits from adaptation planning (Shi et al., 2016).

Often closely aligned to climate justice are considerations of energy justice. Related scholarship has defined energy justice as '*global energy system that* fairly disseminates both the benefits and costs of energy services, and one that has representative and impartial *energy decision-making*' (Sovacool et al., 2017: p.677). As such, it also builds on a global perspective, looking into justice implications regarding energy production and systems, energy consumption, energy activism, energy security, energy policy and climate change (Jenkins et al., 2016). Lenses that are commonly applied are those already adopted in relation to environmental and climate justice, referring to distributional aspects of benefits and ills (e.g. regarding the siting of energy infrastructure), recognition (e.g. of the specific energy needs of defined target groups such as the elderly) and procedural justice (e.g. gender inequalities in governance bodies related to energy systems). Special attention has been given to the social impact (e.g. job loss) of moving towards low-carbon sources as well as aspects of energy or fuel poverty. The latter addresses aspects of distributional unfairness in relation to energy accessibility for consumption and considers the affordability of energy services necessary for human well-being (e.g. heating).

Just transition is a concept that originated in relation to the necessary shift away from fossil fuels and towards renewable energy sources, with a focus on workers' rights in particular in the face of job losses associated with the closure of extraction and production facilities. Some scholars have suggested it has potential to serve as a joint conceptual space for reflection and to unite justice scholarship foci, across environment, climate and energy justice, especially by applying the re-occurring triumvirate of tenets (distributional, procedural and recognition) (McCauley & Heffron, 2018). This might address several interconnected sustainability challenges simultaneously, much like the concept of NbS, at the same time introducing a transformative component, which further emphasises a transformation or transition to a defined goal or the claiming of a defined ought-to be. However, the concept does not necessarily help to navigate conflicting targets and interests across the various foci (e.g. siting of energy infrastructure and environmental justice).

2.1.3 The concept of ecological (space) (in-)justice and its drivers

The concept of ecological space has been introduced in order to bring principles of ecology to bear on the concept of space, as such introducing a particular 'way of seeing', in spatial planning in particular (Gantioler, 2019). It aims to emphasise that '*all human interactions with the non-human natural world occur […] within a single biophysical reality*' (Hayward, 2007). The concept adopts the definition of ecological niche, to emphasise that humans, like other species, are not exempt from ecological constraints (e.g. temperature, food, air quality, water quantity and quality, or interactions biosphere) (Hayward, 2013). It also hints at the 'functional' nature (e.g. acquired resources and services) rather than the physical nature (e.g. needed habitat size) of ecological space. It is used to distinguish between a fundamental niche (the space fundamental for thriving) and the actually realised niche (the space realised e.g. to fulfil wants). For human beings it is assumed that their realised niche far exceeds the fundamental niche and that this is inherently linked to income and wealth, the latter allowing an extended physical and functional 'occupation' of ecological space. These considerations in particular emphasise that responsibilities or related ethical rights to ecological space and duties of not constraining that of others are not physically limited (e.g. also linked to land/property entitlements and political power).

The adoption of the concept actually was pioneered on the back of early climate justice considerations and their global implications in particular. It was applied to criticise the focus on applying distributive principles to emission rights, and to suggest a more comprehensive or systemic perspective (Hayward, 2007). Later on, it was used to emphasise the human right to a sufficient amount of ecological space and the moral precedence of not depriving others or assisting those that suffered of ecological space constraints due to biophysical necessities (e.g. droughts, floods) (Hayward, 2013), in line with discussions on ranking values linked to basic needs (Gantioler, 2019).

A similar precedence for nonhumans would also challenge us to rethink our eco-social responsibilities and duties to not infringe on Earth's biophysical constraints as well as to think in temporal and spatial scales that are more conducive for nonhumans (Houston et al., 2018; Peeters et al., 2015). Together, humankind and nature, in its totality, create a single, shared environment regardless of the hierarchical relationships within it. Therefore, the moral context used to justify the unrestrained exploitation of natural resources and ecological space for humankind's wellbeing should theoretically impose a responsibility and duty to sustain said natural resources (Ezra, 2017).

The notion of ecological (space) justice weaves ecological considerations into ethical considerations of (environmental) justice: of the finitude and vulnerability of ecological niches and the biosphere's diversity and the adequate distribution of ecological space for a diversity of species, more than just Homo sapiens, to thrive. Acknowledging a habitat as its own agent gives recognition to the work it provides for various components to function i.e., purifying water, contributing oxygen, providing nutrition, sustaining temperature. Within a justice framework, the interruption of the capabilities (of ecosystems) and functioning of large living systems is what would need to be addressed. The broadening of justice to habitats instead of an individual or a species need can be helpful in putting ecological (space) justice into action, as providing a common ground for action rather than focusing on individual nonhuman needs and human preferences.

Ecological space can be described as multi-dimensional space, first of environmental variables or conditions, which determine a species' space to thrive. Which particular conditions are relevant depends on the considered species. However, according to what was outlined above, using the concept also helps to consider common conditions, which contribute to human well-being and to a thriving biological diversity. The reference to ecological 'functionings' sustaining ecological space, different to the term 'function', hints at the importance of moving beyond a single purpose (e.g. for human well-being) or dimension (e.g. environment) to a complex system of interactions, also including the social space, socio-economic conditions, or conditions of the built environment, as schematised in Figure 3 (Gantioler, 2019).

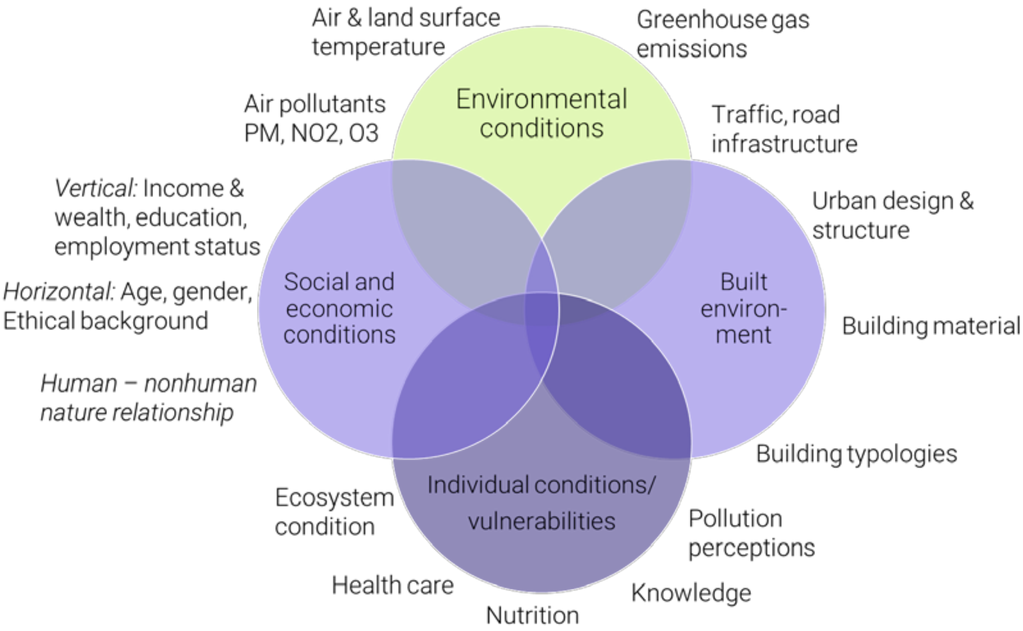

Figure 3: Drivers of (in-) justices across various dimensions and conditions

The built environment refers to conditions described by variables such as building structures and typologies, transport infrastructure, urban design or building materials. This highlights that ecological functionings can also be strongly influenced by the built environment (e.g. street canyons and air pollution or building materials and thermal comfort). Socio-economic conditions refer to the fabric of human-social interactions or relationships (including with nature), described by variables such as income and wealth, education, age or gender. Existing disparities or human-nonhuman nature relationships can have a significant impact on the occupation of ecological space (e.g. second homes in flagship landscapes). In addition, individual conditions or defined vulnerabilities refer to those variables that refer to individual burdens or resources or health, which impact the right to ecological space. This ranges from pollution or thermal comfort perceptions and individual knowledge to the available health care, nutrition health or also ecosystem condition.

In relation to how they impact the functionings, occupation and right to ecological space, the different variables can be described as drivers of ecological (space) (in-)justices. Across this complex system of interactions, a defined perspective or entry-point for interventions (e.g. policy, planning) can be selected, though paying attention to various interlinkages and considering that cumulative conditions of ecological space (in-)justices or what may be called 'winner-takes-it-all' or 'losers-suffers-it-all' hubs exist.

2.1.4 The role of values

In recent years, environmental justice debates have increasingly informed scholarship on sustainability transitions as well as socio-ecological transformation, as the notion requires discussions on important drivers such as values, norms and ethics (Köhler et al., 2019). This also has also to be seen in light of the most recent IPCC report stating that there is a need to move beyond 'technical governance' and to confront deeper values underpinning societies to achieve the necessary deeper changes (IPCC, 2022b). In addition, in 2018 the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) launched a review of values assessment methodologies, covering how the values of nature and its benefits have been conceptualized (conceptualization of values), what valuation methodologies and approaches have been used, and how they have been integrated into policy- and decision-making (IPBES, 2018). The report is expected to be published in July 2022.

Values can be assumed to influence the forming of visions, shaping of scenarios and world views, motives for societal changes and thus individual and community (non-) contributive actions. Whereas for some they are mainly a matter of individual (consumer) preferences, for others they are inherently linked to human needs and wants (Gantioler, 2019). The underlying ethical doctrine can be assumed to strongly determine the extent to which value judgment is viewed as something that is a matter of (consumer) taste and opinion (preferences based on the ethical doctrine of utilitarianism) or can follow reasoning and occurs based on experience and using empirical data (basic needs based on the ethical doctrine of agathonism) (Bunge, 1989). Especially, the latter also allows a ranking of values, by distinguishing between needs and wants, though requiring a defined guiding principle or ethical compass. For example, the ethical doctrine of agathonism has as its key focus 'a good life' (not maximizing happiness according to utilitarianism) and as a guiding principle 'Enjoy life and help live' (including both the right to and the duty to). These results in putting environmental questions at the forefront, as crucial for the survival of humankind, though it also allows integration of flora, fauna and habitat inclusiveness considerations to some extent (see Chapter 3.4).

The way this guiding principle is applied does not put into question the plurality of values (see Box 2), though it assumes a commonly shared basis arising from common needs, which still can be context-specific. As such, it may be helpful in applying a notion of justice that allows calling for community action rather than individual action, especially on ensuring the right to ecological space and the duty of not constraining that of others.

Box 2: Different value concepts towards nature

Central part of discussions of why to protect nature and conserve biodiversity evolve around whether something is valued for its own sake or for the sake of something else (Gantioler, 2019), and as such around 2 key notions:

Instrumental values: Nature having value as instrumental to the bearer.
Intrinsic values: Nature having value independent of the bearer.

In the market-theory domain, preference-based approaches have been used estimate nature's instrumental values (Kumar, 2010), to capture the socio-economic output of ecosystem services (total economic value), dividing them into:

Use values: direct use values (e.g. food), indirect use values (e.g. soil fertility), and optional values (future benefits)
Non-use values: bequest value (future generations might benefit), altruist value (someone else might benefit), and existence value (valued because it exists)

It has been discussed to what extent intrinsic values actually exist, as values are considered of not being able to exist independently of the human bearer (e.g. Bunge, 1989). However, the notion can also be interpreted as referring to something that is valued due to its end, and not necessarily as a means to an end (e.g. benefits for human well-being), a major concern issued in relation to instrumental values.

Due to the limitations of these 2 notions a third class of values has been introduced (K. M. A. Chan et al., 2016):

Relational values: Preferences, principles and virtues associated with relationships between people and nature.

They are considered to be widely spread, across a range of different philosophies, and are deemed to be able to '*capture the fundamental concerns for nature*' (K. M. A. Chan et al., 2016). They can involve:

Collective relational values: nature-relationship forming cultural identity, social cohesion or social responsibility
Individual relational values: nature-relationship forming individual identity, stewardship for a good life (eudaimonic values, stewardship virtue)

As ethical method it tends towards pluralism rather than monism, which poses some challenges regarding an ethical compass to rank values (Gantioler, 2019). Other argue that a distinction between descriptive and normative values needs to occur in order to properly inform sustainability transformations (Stålhammar, 2021).

2.2 Grand social challenges and nature-based solutions

2.2.1 Key societal challenges and NbS

Diverse definitions of nature-based solutions currently exist (see Chapter 2.3.2), and each definition, or its interpretation, puts emphasis on a defined problem that is expected to be addressed with the contribution of nature or solved by nature. However, some of the most widely recognized definitions have at least one vision or goal in common: that nature-based solutions represent actions working with nature to address grand societal challenges simultaneously.

There is already some policy integration quarrel as to whether this mostly refers to the twin challenges of climate change and biodiversity loss or to the so-called big three, which besides the two former challenges either includes human well-being or sustainable development more broadly. Human well-being puts a particular emphasis on aspects of health, and allows integrating environmental conditions more generally, including air pollution, whereas references to sustainable development are used to integrate not only environmental and health aspects but also other social and in particular economic aspects or questions of socio-economic inequality.

The growing awareness of the value of nature and the potential contribution of ecosystems in addressing environmental, social and economic challenges have been increasingly emphasized in the framework of global agendas. The Paris Agreement notes the importance of ensuring the integrity of ecosystems; the New Urban Agenda makes specific reference to nature-based innovation for urban and territorial planning; nature-based solutions have also been promoted in the UN Strategic Plan for Biodiversity and in the Sendai Framework for Disaster Risk Reduction (United Nations, 2015). More recently in 2022, the 5th session of the United Nations Environment Assembly (UNEA) adopted a resolution on nature-based solutions for supporting sustainable development, recognizing in particular the key opportunity of strengthening actions for nature to achieve the Sustainable Development Goals (UNEP, 2022).

The contribution of nature-based solutions in implementing the 2030 Agenda has been underlined by reason of their "potential to address key societal issues, such as climate change, disaster risk, biodiversity loss, air pollution, microclimate conditions and health and well-being of citizens" (EC, 2014).

The 2030 Agenda defines 17 Sustainable Development Goals (SDGs) and 169 targets, many of which are quantified and measurable through specific indicators. The Agenda stresses the importance of sustainable management of natural resources and the functioning of ecosystems to maintain economic activities and well-being of local communities. Indeed, in many of the SDGs and their associated targets biodiversity and ecosystems directly predominate (Gómez Martín et al., 2021).

Usually associated with conservation goals (SDG15 and 16), deemed in a broader context, nature-based solutions can relate to many other global goals, beyond those addressing biodiversity loss and conservation issues. According to the European Commission (2015), the presence of natural elements in urban areas can have a positive impact on the mental health of city dwellers, also fostering social cohesion (see Chapter 2.1.1) and addressing social issues such as socio-spatial disparities in and across cities. This makes the nature-based solutions one of the main instruments to accomplish the SDG 11, for making "cities and human settlements inclusive, safe, resilient and sustainable" and specific targets.

The Nature-based solutions Handbook, developed in the framework of the ThinkNature project (Somarakis et al., 2019), summarizes the connection between NbS and different SDGs, highlighting the relation between urban regeneration projects to objectives of improved health and well-being (SDG3), reduced inequalities and improved social cohesion (SDG 10), adapting and fighting climate change (SDG 13) and ensure sustainable energy (SDG 7); nature-based solutions can be also linked to the objectives related to sustainable management of water and sanitation (SDG 6), food security and nutrition (SDG 2), promoting equitable quality education (SDG 4), increasing awareness and equitable education, and support economic growth (SDG 8) and promoting green job opportunities.

The multi-functionality of the NbS, meaning their ability to simultaneously provide multiple functions to deliver a set of associated ecosystem services, gives them the potential to buffer the unfavourable impacts of climate change while proving multiple environmental, economic and social co-benefits. However, to assess the contribution of nature-based solutions towards tackling the key global challenges in terms of justice, equity and equality, requires retracing these concepts within the SDGs framework.

2.2.2 How do SDGs relate to ecological (space) justice?

Unlike their predecessors, the Millennial Development Goals (MDGs), eight clear and not measurable objectives that focused on some areas of sustainable development, the SDGs approach the sustainable development in a more holistic way, including measurable objectives and being readily adapted to national contexts (Gellers & Cheatham, 2019).

Being defined as "integrated and indivisible" and claiming to "balance the three dimensions (economic, social and environmental) of sustainable development" (United Nations, 2015), interaction between SDGs should result in co-benefits and synergies. However, in practice, this interaction might result in trade-offs and tensions.

Indeed, unlike the MDGs, that were centred on the idea of human dimensions of development (introduced at the beginning of 1990s by the UNDP), neglected in the past in favour of emphasis posed on economic growth, the SDGs came up from a wide negotiation process which saw the participation of a variety of stakeholders with different values and interests, inevitably leading to the broadening of development priorities and, in some cases, to the raising of tensions and contradictions.

Common directed critique to SDGs refers to the Goal 8 (Sustained economic growth) as hindrance to the achievement of other, ecologically and socially oriented goals (Grossmann et al., 2021). In terms of justice this express the failure of SDGs to counter the global economic and geopolitical systems that create injustices in the first place; "it will not be possible to achieve a "win-win" when the very systems which create poverty, hunger, inequalities and unsustainable development are upheld" (Menton et al., 2020).

Moreover, despite the high relevance SDGs have for environmental and social justice, these concepts are not directly addressed in their targets and indicators; even the Goal 16, which explicitly mentions justice, does not define the justice term, "bypassing the difficult question of how state definitions of justice inevitably privilege some actors' conceptions of justice over others". This absence of a direct reference to justice concept has roots in the development of the sustainable development concept itself and its evolution. As Agyeman & Evans (2004) assert, justice and equity are "at best implicit" in the Brundtlandt report and IUCN definitions of sustainable development.

Some authors (Gupta & Vegelin, 2016; Reid et al., 2009) argue that global goals focus more on social inclusiveness issues than ecological inclusiveness one, giving less importance to the safeguarding of those environmental conditions on which social and economic goals depend.
This consideration is coherent with the criticisms often moved to SDGs framework to uphold an anthropocentric approach, giving priority to human needs and failing to observe the importance of placing constraints on human activity that might exacerbate environmental degradation.

2.2.3 Suggestions for a socio-ecological approach to SDGs

The first attempt to move towards a new way of viewing the economic, social and ecological aspects of SDGs has been made by the Stockholm Resilience Centre, which provide the illustration that describes how economies and societies should be seen as embedded in the biosphere, moving away from the current sectorial approach where social, economic and ecological development are seen as separate parts, with each attributed a similar weight (Figure 4).

Figure 4: Integration of 17 SDGs across the biosphere, society and the economy.
Source: Stockholm Resilience Centre (2016)

This approach deserves credit for considering the interdependency between environmental, social and economic targets while recognizing the importance of ecosystem and biosphere as the basis on which all other SDGs sit. However, it still tends to maintain an anthropocentric approach in the consideration of essential benefits that ecosystems provide for current and future generations.

Some authors go further in recommending an extended consideration of sustainable development beyond human interests, towards an inclusive vision of both human and non-human needs in order to embrace ecological justice. Already in 2004, Agyeman & Evans suggested the need for 'just sustainability', to include in the sustainability approach an explicit focus on justice, equity and environment together. Kopnina (2016) stresses the need for a new set of ethical imperatives which include environmental and particularly non-human species into the moral sphere. Menton et al. (2020) argue for the incorporation of environmental justice for humans and non-humas as a prerequisite to sustainability, suggesting moving beyond a focus on principles of mainstream environmental justice (distribution, procedure, recognition and capabilities) towards a more intersectional approach.

Given the absence of an explicit justice reference in the SDGs overall framework, unpacking interactions within and among different SDGs, targets and indicators could allow to define their implications in terms of justice (Table 2). Gellers & Cheatham (2019) suggest disaggregating the different components of environmental justice to relate to different SDGs' targets according to the component to which they relate. As environmental justice is characterized by a plurality of definitions and interpretations that vary along academic lines, identifying and disaggregating justice dimensions and principles could be useful to address environmental justice issues within and across different SDG's targets.

Table 2: Unpacking interactions between SDGs and justice dimensions as well as principles

Sustainable Development Goals and Targets		Justice dimensions and principles
Goal 1. End poverty in all its forms everywhere		
1.4	By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance	– Shift focus from distribution of resources & entitlements in relation to horizontal social inequalities and vulnerable groups to address vertical social inequalities and to define procedural and recognition aspects – In relation to spatial disparities, consider access to different property entitlements (incl. community) and to nature's contribution to people more generally as a basis to end poverty
1.5	By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	– Move beyond social justice and poverty considerations on exposure to climate risks, to questions of accountability as part of climate justice – Include ecological space functionings of ecosystems as key consideration to build up resilience (ecosystem-based approach)
Goal 3. Ensure healthy lives and promote well-being for all at all ages		
3.9	By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	– Expand the notion of environmental justice: from the distribution of environmental ills to the access to environmental goods or ecological space functionings provided by ecosystems
Goal 5. Achieve gender equality and empower all women and girls		
5.1	End all forms of discrimination against all women and girls everywhere	– Integrate questions of procedural and recognition justice and considerations of needs in relation to ecological space justice
5.2	Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation	– Take into consideration question of urban (green areas) design and spatial disparities to achieve target
5.5	Ensure women's full and effective participation and equal opportunities for leadership at all levels	– Shift focus from ensuring equal opportunities to questions of procedural and recognition aspects

	of decision-making in political, economic and public life	also in relation to the occupation of ecological space
Goal 6. Ensure availability and sustainable management of water and sanitation for all		
6.6	By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	– Consider an adequate distribution of ecological space for a diversity of species and ecosystems to thrive, and according rights and duties
Goal 10. Reduce inequality within and among countries		
10.2	By 2030, empower and promote the social, economic and political inclusion of all, irrespective of age, sex, disability, race, ethnicity, origin, religion or economic or other status	– More strongly integrate considerations of vertical social inequalities, also in relation to the occupation of ecological space
10.3	Ensure equal opportunity and reduce inequalities of outcome, including by eliminating discriminatory laws, policies and practices and promoting appropriate legislation, policies and action in this regard	– Shift focus from ensuring equal opportunities to questions of procedural and recognition justice also in relation to the occupation of ecological space
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable		
11.5	Reduce the number of deaths and people affected by economic losses caused by disaster, including water-related disaster, with a focus on protecting the poor and vulnerable	– Expand notion of environmental justice, from the distribution of environmental ills to access to environmental goods or ecological space functionings provided by ecosystems – Consider adequate distribution of ecological space for a diversity of thriving species and ecosystems
11.6	Reduce the adverse per capita environmental impacts of cities, including by paying special attention to air quality and municipal and other waste management	– Expand the notion of environmental justice from the reduction of environmental ills to the securement of the right to ecological space in cities.
11.7	Provide universal access to safe, inclusive and accessible green and public spaces in particular for women and children, older persons and persons with disabilities	– Expand focus from physical access to functional access in relation to ecological space sustained by ecosystems and the built environment – Take into consideration aspects of connectivity and the creation of a fine-meshed network of urban supply or care system
Goal 12. Ensure sustainable consumption and production patterns		
12.8	By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature	– Instead of focusing on lifestyles, consider and integrate relational values between people and nature – Expand from providing information to increase consumer awareness to procedural aspects of citizen engagement
Goal 13. Take urgent action to combat climate change and its impact		
13.1	Strengthen resilience and adaptive capacity to climate related hazards and natural disaster	– Integrate ecological justice considerations in relation to nonhuman and human species (common resilience and adaptive capacities)
13.2	Integrate climate change measures into national policies, strategies and planning	– Consider how climate change measures impact ecological (space) justice as part of policy and planning processes

13.3	Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	– Expand from awareness-raising to procedural aspects of citizen engagement
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss		
15.5	Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	– Not only take into account the degradation of natural habitats but consider ecosystem quality and ecological space more widely as a common denominator for human and nonhuman species
15.6	Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed	– Include questions of how the diversity of genetic resources impacts considerations of ecological (space) justice, taking into due consideration human needs rather than wants
15.9	By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	– Capture the fundamental concerns for nature, consider the plurality of values though clearly indicating the ethical doctrine laying at the basis of any hierarchical decision on values
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels		
16.6	Develop effective, accountable and transparent institutions at all levels	– Expand to consider nature's agency and rights as part of ecological justice considerations
16.7	Ensure responsive, inclusive, participatory and representative decision-making at all levels	– Go beyond inclusion to consider aspects of corrective justice (e.g. environmental crime) – As part of procedural aspects considers effective implementation and enforcement, and formal anchorage of participation

The complexity of the socio-ecological systems in which NbS are implemented, which are dynamic and subject to continuous changes over time, require specific management regimes which could directly or indirectly affect elements of the system causing trade-offs and disservices (Gómez Martín et al., 2021) and affect the ability of NbS to address the societal challenges and the SDGs targets.

A better understanding of the NbS added value and impact through appropriate monitoring systems and indicators that assess the broad sustainability impact of nature-based solutions (Box 3), could also be used for monitoring progress towards the SDGs (see Chapter 2.3.4).

Box 3: SDGs Indicators

The instrument provided by the UN Inter Agency Expert Group on SDGs (UN-IAEG-SDGs), to support the implementation of the SDGs at national and subnational levels, is the **Global Indicator Framework**. The 231 indicators developed within the framework include consolidated and available indicators for most of the countries as well as indicators currently produced or not yet precisely defined at the international level. In this regard, SDG indicators are classified in three Tiers according to their level of methodological development and availability of data at global level.

Many international institutions and stakeholders have approached the indicator framework either by designing their own indicator sets or by adjusting the UN toolkit in order to make them accessible to as many subnational governments as possible. To mention a few:

- Guidance developed on SDG 11 by the UN-Habitat and the development in this context of the **City Prosperity Index** (CPI) with the aim to assist cities to align their policy-making processes to the 2030 agenda;
- **Eurostat** developed a set of 100 indicators that cover all the 17 SDGs;
- The European Commission's Joint Research Centre has presented its European Handbook for SDG Voluntary Local Reviews VLRs, which performs extensive research work on the status of indicators, data and sources for European local governments offering a framework to set up VLRs.

Data and evidence are at the centre of the SDGs and at the foundation of development policies and program implementation. Some authors (Reckien et al., 2017) underline how, despite the explicit reference in the SDGs to the need for sustainable and inclusive urban growth that minimizes inequalities, there are sparse data available for urban policy makers to understand whether they are on track to achieving global goals and targets. Disaggregation of data in thematic areas related to age, gender, economic status and income is one of the main focus areas on the Working Group activities and considered key to better understand the circumstances of multiple groups within society. Data should also be disaggregated spatially and the contribution of Earth observation (EO) and geospatial information is essential to support implementation at all levels. EO can provide valuable disaggregated data to assess the modifications caused by NbS implementation in terms of land cover, quantify multiple environmental NbS impacts, covering urban areas at different scales and enabling multitemporal NbS assessment.

The impact evaluation framework proposed by EKLIPSE identifies 10 societal challenges of urban areas that NbS have the potential to address, and proposes impact indicators for measuring the expected NbS benefits and co-benefits across these challenges (C. Raymond et al., 2017). The Task Force 2 Handbook for evaluating the impact of NbS elaborates on the societal challenges by dividing the challenge "Green space management (including enhancing/conserving urban biodiversity)" of EKLIPSE into two: "Green Space Management" and "Biodiversity Enhancement", and adding the challenge "Knowledge and Social Capacity Building for Sustainable Urban Transformation". The societal challenges identified in both frameworks can be linked to ecological space (in-) justices (Table 3).

Table 3: The societal challenges identified in EKLIPSE and in the EU Handbook, links to SDGs and ecological (space) justice

EKLIPSE societal challenges for urban areas (C. Raymond et al., 2017)	EU Handbook for NbS evaluation – societal challenges that can be addressed by NbS (EU, 2021)	Mapping of societal challenges that can be addressed by NbS to SDGs	Ecological space injustice examples
Climate mitigation and adaptation	Climate resilience	SDG13	Socio-economic spatial disparities create inequitable distribution of climate change risks, if these disparities are overlooked in climate adaptation and mitigation planning, injustices can be exacerbated (Anguelovski et al., 2016)
Water management	Water Management	SDG6, SDG14	Water management might be prioritised in privileged and central areas (Zuniga-Teran et al., 2021)
Green space management (including enhancing/conserving urban biodiversity)	Green Space Management	SDG2, SDG15, SDG9	Neighbourhoods where low-income population and minorities reside have less accessible, low-quality green spaces, (Zuniga-Teran et al., 2021)
	Biodiversity Enhancement	SDG14, SDG15	NbS planning mainly has an anthropocentric perspective, ecological justice equitably considers humans and nonhumans in the co-creation process (Pineda-Pinto et al., 2022)
Air/ambient quality	Air Quality	SDG3, SDG11	Poorer population neighbourhoods are exposed to lower air quality among other hazards in urban areas in many European countries (Ganzleben & Kazmierczak, 2020)
Urban regeneration	Place Regeneration	SDG11	Gentrification risk due to rising land value (Zuniga-Teran et al., 2021)
Participatory planning and governance	Participatory Planning and Governance	SDG16	Socio-economic position restricts access and power in decision-making (Ganzleben & Kazmierczak, 2020; Zuniga-Teran et al., 2021)
Social justice and social cohesion	Social Justice and Social Cohesion	SDG10, SDG5	Different social groups interact with nature in different ways, which should be considered when planning and evaluating NbS (Dumitru et al., 2020)
Public health and well-being	Health and Wellbeing	SDG3	Access to nature is linked to improved health and well-being, unjust access to nature creates unequitable distribution of associated health benefits (Ganzleben & Kazmierczak, 2020)
-	Knowledge and Social Capacity Building for Sustainable Urban Transformation	SDG4	Knowledge sharing for social capacity building needs to use accessible language and education in order to be inclusive and assist less advantaged population in understanding and engaging (Ganzleben & Kazmierczak, 2020 , Zuniga-Teran et al., 2021)
Coastal resilience	Natural and Climate Hazards	SDG13	Spatial disparities create inequitable distribution of climate change risks, in

			Europe poorer countries are at higher risk of climate change related hazards (Anguelovski et al., 2016; Ganzleben & Kazmierczak, 2020)
Potential for new economic opportunities and green jobs	New Economic Opportunities and Green Jobs	SDG8	Economic and employment opportunities need to be given to disadvantaged neighbourhoods through NbS interventions (Zuniga-Teran et al., 2021)

2.3 How to activate NbS for ecological (space) justice

With the increasing adoption of the nature-based solutions concept to address grand societal challenges simultaneously, it was only a matter of time until questions of justice also became pertinent. However, in relation to existing projects, for example financed by the EU Research and Innovation Programmes, considerations mostly regarded questions of social justice (e.g. with a focus on inclusiveness, vulnerable or marginalized groups) and procedural aspects (e.g. specific interests into co-design or co-creation and participative processes) (European Commission, 2021). Insights from different justice scholarships were often used interchangeably (e.g. social and environmental justice), not necessarily discussed more profoundly or applied piecemeal-like, to the extent they help frame how nature-based solutions address a defined societal challenge (e.g. natural climate solutions and climate justice). A more comprehensive debate on the role of environmental or climate justice aspects in relation to the activation and implementation of NbS has rarely taken place, and as such it remains unclear how the concept effectively contributes to addressing justice considerations.

In a study mapping the scope of nature-based solutions and the role of justice, results suggest that issues of social and environmental justice are only considered peripherally, whereas in particular research communities on urban applications and public health and well-being figure prominently (Cousins, 2021). The former addresses NbS especially from an ecosystem management perspective, whereas the second focuses on practical applications to improve human health (e.g. mental health). To form a dedicated research community on justice aspects, the author recommends to operationalise *just nature-based solution*, by looking into three focus areas: 1) race and class, 2) transformative co-production and 3) value articulations. This indicates a clear shift to considerations of procedural and recognition rather than distributional aspects.

However, as highlighted previously in relation to considerations of justice and the need not to neglect content due to the focus on formal aspects or processes when co-creating and co-governing better (environmental) conditions for all citizens, it is important to duly take into account the various tenants or principles of environmental justice. Thus, the first sub-chapter highlights what principles or legs of justice are considered for NbS and how they have been interpreted.

2.3.1 What principles or legs of justice for NbS

As previously touched on, the most accepted environmental justice and just transition framework acknowledges and emphasizes the existence of three principles:

1) Distribution of environmental goods and harms
2) Legitimacy of the environmental decision-making procedure, and
3) Recognition of differing needs, burdens and opportunities between and within communities, depending on a range of socio-economic factors.

This section outlines in more detail the 3 key principles flagged above, along with corresponding features of each, and in particular as they have been applied to NbS so far. Then, some lesser known yet equally relevant justice principles that scholars have also identified are introduced, that offer potential for an expanded understanding of to provide innovative ways to view the role of justice within the realm of urban NbS implementation (Figure 5).

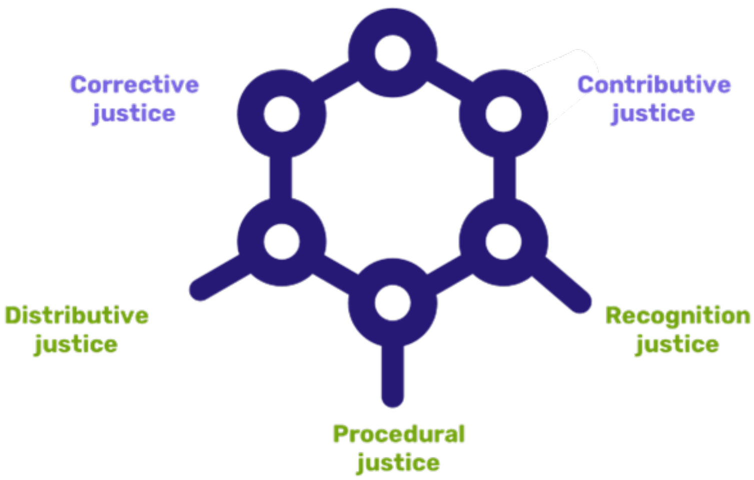

Figure 5: Key legs of justice for NbS

Distributional justice is possibly the most widely addressed principle of EJ, and addresses foremost the question of 'who gets what' (Gantioler, 2019). It has been found that the current greening orthodoxy tends to incorrectly assume that greening interventions produce positive results for all citizens (Gould & Lewis, 2017). These issues illustrate the need to adequately address disparities in the access, allocation, quality and quantity of environmental goods. The main features for distributional justice include the precondition for use (access, proximity, and the amount of green or blue space shared among citizens). When applied well, urban and green space planners must consider the objective and subjective issues that undermine use, access or enjoyment of green space, and what values attributed to nature are key drivers. A common issue of distributive justice, for example, is the restricted access to green and safe public spaces of quality for lower income areas and minority communities in comparison to more affluent and predominantly white communities that have historically enjoyed environmental privileges through the greater presence of nearby parks, coasts, and other green (Kotsila et al., 2020). Additional aspects focus on the quality of the NbS which considers that individual or communal experiences with quality can differ depending on the levels of naturalness, safety, fragmentation, management, or more abstract considerations such as quietness and tranquillity as well as functionality which are the physical characteristics that contribute differently to spatially distributed ecosystem services or benefits. The functionality aspect takes into account the characteristics of NbS such as location, typology, form, and size that influence the supply and performance of certain regulating ecosystem services such as heat mitigation or air pollution control (Kato & Geneletti, 2022).

The next central dimension of environmental justice is procedural justice which is exclusively related to the decision-making process in which environmental demands and long-term engagement with individuals and communities are to be achieved. It in particular relates to the question of 'who gets asked' (Gantioler, 2019). Whether it is a centrally designed intervention with limited input from citizens or community-led initiatives concerned with the use of a society's resources, additional considerations should be made if disadvantaged groups lack the time, energy, or financial resources that might be required for participation or to address pre-existing power imbalances that may shape procedural processes (Kotsila et al., 2020). Within the framework of NbS, it typically is addressed in the format of co-creating and co-designing with urban populations. Based on a literature review (Kato & Geneletti, 2022), the following key aspects have been identified:

- Information exchange, as main principal of procedural environmental justice, focused on making relevant information of the co-creation process comprehensive and available for all contributors, including potential benefited or affected communities,
- Inclusion and enfranchisement, giving voice to all involved parties in a meaningful way acknowledging the historical and cultural context,
- Representation, allowing a leading role for vulnerable communities, and
- Conflict solving, setting conflicts in less costly ways.

One introduced tool for mediation is by enhancing deliberative spaces where disagreements can be resolved and where the co-production process can be re-evaluated if the expected justice outcomes have not been fully met. It should be noted however that imbalances in power often present a major obstacle towards democratic participation in decision-making related to urban development, and unless these are actively addressed in planning and policymaking, outcomes are unlikely to be equitable (Hammelman, 2019). Some initial recent studies on NbS in relation aspects of environmental justice have looked into procedural aspects, politics and power dynamics in particular, regarding the governance of the solutions. For example, it is argued that nature-based solutions are more likely subject to be co-opted by powerful interests, focusing on defined activities and functions (e.g. tree planting and carbon sequestration) rather than the broad contribution to sustainability goals (van der Jagt et al., 2021).

Recognition justice is the third dimension of environmental justice and highlights the depreciation of some communities and their qualities through different hierarchical and dominant values. It relates to the question 'who gets asked and considered how'. While the notion is more recent, it is well established that there are many ways in which certain individuals and social groups can be included or marginalized due to their identities (i.e. ethnicity, race, gender, sexuality). To counteract such systemic exclusion, a recognition of differences, and that certain groups and individuals are more advantaged than others, must occur (Kotsila et al., 2020). Otherwise, there is a high risk that urban planning measures will be planned and implemented in a way that ignores existing environmental disadvantages, reinforces them, or even creates new ones. NbS planners need to acknowledge each person's varied capacities to meet physical or emotional demands based on their differentiated traits, conditions, and abilities while avoiding the pre-existing narratives that have historically ignored disadvantaged communities' realities. According to (Kato & Geneletti, 2022), some key aspects of recognitional justice are:

- Local knowledge, or how communities could use their knowledge and experiences to make sense of a solution,
- Social needs, or requirements to improve their living conditions),
- Diversity of preferences and values, or what people perceive is desirable or acceptable for them, and
- Broader perspectives on governance, or framings of good or legitimate governance and NbS management.

Acknowledging these features of diverse citizenship rights and livelihoods could enhance place-based attachment and connection with natural features to any NbS that are implemented. They will be further explored as part of the co-governance activities of JUSTNature's work package 7.

With the three principles above in mind, it is also important to introduce other principles of justice that could conceptually be integrated into the adopted framework approach for the JUSTNature project. While these other principles have distinct characteristics that shape their unique approach to fair NbS planning and implementation, each also have aspects of the three core principles woven into their application.

Contributive justice reconsiders what type of work is considered as a truly valuable contribution to the common good in comparison with what and how the free-market values other actions and the role of meritocracy in particular. A clear example of the gap between what the market rewards and what actually contributes to the common good in our modern economy is deemed the extreme growth of the finance sector (Sandel, 2020b). Another aspect of contributive justice relates to questions of decent work, closely connected to the SDG 8 on sustained, inclusive and sustainable economic growth.

The difficulty of contributive justice is because the common good is contestable. The moral debate it requires goes beyond what constitutes fairness to the re-evaluation of society's moral judgments. Because common purposes cannot be deliberated about without the participants seeing themselves as members of a community to which they owe something, pursuing contributive justice has many potential benefits as well as challenges. Often the mechanism for contributive justice is procedural, but the rationale and message is based in what we owe one another as a more unified community (Sandel, 2020a). Regarding the activation of NbS, this not only regards questions of the extent to which they help create new job opportunities, but also whether they support the creation of decent work. Also reviewing relational values towards nature plays an important role regarding the creation of a common purpose (see Chapter 2.1.4), as do questions of property rights (Gantioler, 2019). This regards what entitlements they confer according to what governance system, and how as such they in particular define 'who is able to contribute' to the activation of NbS.

Corrective justice is typically a rectifying function that relates one person to another according to the concept of equality or fairness (Weinrib, 2012). When one has acted in a manner that caused loss to some individual relative to a baseline then there is a duty on the actor to re-establish the original equality. This has huge implications for those who are liable for climate change. Ideally, contributors to global warming would be held liable for the environmental damage they cause. Realistically, however, the casual link between a particular set of GHG emissions and environmental damage to natural systems is much weaker in comparison with the deaths, injuries, and property losses via environmental damage such as extreme weather events (Adler, 2007). Furthermore, this relates to other types of justice when considering the specific issue of displacement and those affected are conceptually owed protection and assistance (Thornton, 2021). If we consider those who may be displaced in the coming years, we must also evaluate the implications of what one generation may owe future generations in virtue of causing climate change that puts future societies at risk of harm. As regards NbS and the challenges it aims to address, in relates to the application of the 'polluter-pays principle' and who is responsible of paying the costs, as well as not only the effectiveness but also the fairness of biodiversity offsetting measures, a conservation tool for balancing biodiversity losses (Maron et al., 2016). In addition, being the leg of justice more closely connected to how justice was historically interpreted e.g. by Aristotle, who distinguished between distributive and corrective justice (Gantioler, 2019), it also becomes a question of pursuing environmental crimes. This not only refers to the commonly considered pollution crimes (e.g. hazardous waste), but considers other key examples such as fishery crime, forestry crimes, illegal mining, and wildlife crime. Corrective justice may be pursued in the framework of corresponding legislation, such as the EU Environmental Crime Directive (EU, 2008b), which, due to the identified necessity of reforms, is subject to revision as part of the EU Green Deal, with plans for a set of priority targets, proposals and key acts to address climate change and environmental degradation.

2.3.2 Suitable definitions and classifications of NbS

For researchers and practitioners aiming to implement and monitor NbS, it is a necessary practice to identify and classify them. This in the first place requires defining NbS. The EU defined NbS as "actions which are inspired by, supported by or copied from nature" (European Commission, 2021), while IUCN defines NbS as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Cohen-Shacham et al., 2016). The more recent UNEA resolution on NbS for supporting sustainable development builds on this definition, but highlights sustainable use of ecosystems and considers the provision of ecosystem services as well as resilience (UNEP, 2022).

In general, NbS is understood as an umbrella term, which brings together different concepts. This includes green infrastructure (GI) - including urban green infrastructure (UGI) and blue green infrastructure (BGI) -, ecosystem-based approach (EbA), ecosystem services (ES) and others (Cohen-Shacham et al., 2016; Dumitru et al., 2020). As an umbrella term, NbS is clearly interrelated with these different concepts; sharing the same aim to balance environmental and social concerns to improve well-being for people and nature and have common principles such as participation and multifunctionality (Pauleit et al., 2017). If considering the long development of the GI concept, NbS is a rather more recently introduced concept. In comparison with the GI concept, NbS appears to lack network and connectivity considerations as well as the requirements of a strategic planning, which is inherently part of the GI definition (Gantioler, 2019). In this sense, GI seems to better support operationalization on various scale levels, yet also has a narrower thematic scope as NbS (Pauleit et al., 2017). The same accounts for EbA, which mainly focused on climate change adaptation. ES on the other hand have a broad thematic scope, but are in particular supportive to NbS in their ability to provide values of nature (Pauleit et al., 2017). The interrelatedness and often interchangeable use of these concepts means that NbS classifications build on or have significant overlap with classifications of related concepts, in particular GI. Important insights of GI classifications would, therefore, be worthwhile to consider in NbS classifications.

Many of the developed classifications come from guides or catalogues developed by and for practitioners (UNaLab, 2019; *URBAN GreenUP D1.1: NbS Catalogue*, 2018; World Bank, 2021). Some of the classifications try to be as comprehensive as possible, including NbS with highly differentiated functions and scales for example, between green roofs and renatured river banks (Castellar et al., 2021; Cvejić et al., 2015), or even social and participatory NbS (URBiNAT, 2021). Others focus more on a specific challenge or urban area (Calfapietra, 2020; Kimic & Ostrysz, 2021; Xing et al., 2017). The level of complexity of the classifications ranges from complex hierarchical structures (e.g. Castellar et al. 2021) to simple summaries of green and blue elements in urban spaces (Cvejić et al., 2015; Kimic & Ostrysz, 2021; UNaLab, 2019). Some classifications only propose approaches to classify NbS without indicating specific NbS (Eggermont et al., 2015).

As one of the first NbS classifications, Eggermont et al. (2015) proposed a classification of three levels of management: none or minimal management (type 1); development and implementation of multifunctional ecosystems (type 2); and creation of new ecosystems (type 3). In this way, they tried to align the NbS definitions of the IUCN, which focuses more on preservation of ecosystems, and of the European Commission, which focuses more on "green growth and sustainable development" (Eggermont et al., 2015). Somarkis et al. (2020) expanded this classification by defining in more detail the NbS actions for each category.

For type 1, the action would focus on protection and preservation strategies; for type 2, management and monitoring actions are defined, while for type 3 actions focus on restoration and creation as well as on urban ecosystems for example, ecological restoration of degraded terrestrial ecosystems and urban planning strategies (Somarakis et al., 2019). The World Bank, 2021) also considered this classification approach in their NbS catalogue and regarded it as particularly relevant for NbS planning, implementation and investment on a strategic level. Classification on level of management can support prioritizing existing NbS over new ones, which consequently can support a more efficient allocation of resources.

Another approach to classify NbS is through benefits received from them or, more commonly used, addressed challenges (Calfapietra, 2020; Dumitru et al., 2020; URBiNAT, 2021). These categories are in general described in terms of ecosystem services provided (see approach 4 in Somarkis et al. 2020) or, inversely, in terms of avoided issues and challenges (see approach 3 in Somarkis et al. 2020). Although a classification in addressed challenges or received benefits may be valuable to monitor the functionality of NbS, it is not recommended as the sole approach to classification. These classifications underline the utilitarian and anthropogenic-centric understanding of the NbS concept (Eggermont et al., 2015), which suggest that natural elements and processes need to be beneficial to us and investments in them can solve human-centred problems. Such understanding of NbS might prohibit consideration of different worldviews and values and hamper examination of social justice (see Chapter 2.1.4 and Box 2).

Instead of a classification approach, addressed challenges and perceived benefits might be better fit as goals for achieving NbS (Xing et al., 2017) or as one of several parameters to describe NbS (*URBAN GreenUP D1.1: NBS Catalogue*, 2018; World Bank, 2021). Bartesaghi Koc et al. (2017) Bartesaghi Koc et al (2017) found that GI measures were generally defined in terms of structural-configurational principles or more commonly functional-configurational principles. These principles offer multiple parameters to identify and describe NbS, but also to classify NbS. Often multiple parameters are used alongside each other or in combination to describe NbS. Frequently used parameters for classifying and describing NbS are scale and location i.e. neighbourhood, city, peri-urban, regional, etc. (Castellar et al., 2021; Kimic & Ostrysz, 2021; *URBAN GreenUP D1.1: NBS Catalogue*, 2018; World Bank, 2021; R. Young et al., 2014). Other parameters could support convenient assessment and comparison of NbS for practitioners, such as funding and labour (R. Young et al., 2014), difficulty of implementation, implementation cost bracket, replication potential, maintenance cost bracket, and amortization period (URBiNAT, 2021).

Such parameters can be used to describe NbS and in this sense can support the definition of what is considered a NbS and what not. Cvejić et al. (2015) and Kimic and Ostrysz (2021) describe GI on the parameters *Land-use types* and *Purpose* (e.g. wetland pond, cemetery). Within NbS classifications, more often an additional parameter is added, for example *Spatial configuration* (e.g. green corridors (World Bank, 2021)) or *Management & maintenance* (e.g. intensive green roofs (Xing et al., 2017)) or *Ownership* (e.g. private garden) (Castellar et al., 2021).

These parameters also allow to include technical solutions such as underground water reservoirs (Kimic & Ostrysz, 2021) or indoor potted plants (Xing et al., 2017). More recently, also NbS not fitting the structural- or functional-configurational principles are included in classifications, such as photovoice (URBiNAT, 2021) and city coaching (Urban Green UP, 2022). Such NbS are defined by their function to support planning and governance processes of NbS. Dependent on the interpretation of the definition of NbS, one can argue whether these technical and social NbS can be considered as NbS. Although some flexibility for interpretation can stimulate a joint understanding and cooperation (R. Hansen et al., 2021), for assessment and monitoring a certain degree of clarity of concept is needed (Brand & Jax, 2007; Markusen, 1999). Moreover, a too broad interpretation might render the concept hollow (Porter & Davoudi, 2012).

To support a clearer understanding of the concept, Connop proposed 5 criteria to define NbS: use of nature/natural processes; provision/improvement of social benefits; provision / improvement of economic benefits; provision/improvement of environmental benefits; net-benefit for biodiversity (Connecting Nature, 2020). Albert et al. (2021) introduced 3 criteria to define NbS: contribution to the alleviation of a social challenge, utilization of ecosystem processes, and practical viability. In addition, they suggest five planning principles to support the implementation process of NbS, namely; place-specificity, evidence-base, integration, equity, and transdisciplinarity (Albert et al., 2021). In a similar fashion, principles have been developed for GI in the past. Based on literature, Hansen et al. (2021) determined 4 main criteria for GI planning: integration of green and grey; connectivity; multifunctionality; and social inclusion. Monteiro et al. (2020) further identified multiscale, diversity, applicability, governance, and continuity as criteria, which include criteria for the GI solutions as well as processes. Similar to Albert et al. (2021), Natural England further developed this in criteria for the substantive and the procedural dimension. The substantive criteria outline "what good GI looks like": multifunctional, varied, connected, accessible, and responding to local character, while the procedural criteria outline "how to do good GI": partnership and vision; evidence; plan strategically; well-designed; and managed, valued and evaluated (Fanaroff, 2021). Defining such criteria cannot only support a clearer understanding of the NbS concept, but could also ensure certain qualities of NbS. Within NbS classifications such criteria seem, however, hardly to be considered.

2.3.3 A hierarchical tier system for activating Low carbon | High air quality NbS

Based on the above findings on NbS definitions and classifications, we suggest that a simple summary of NbS might not suffice to address the different qualities of NbS. Rather than focusing on a narrow definition, we expand our scope to use NbS as an umbrella concept to include related concepts. Complementing the NbS approach with related concepts might be the way forward to include NbS on different levels of planning, operationalization and monitoring. GI could support the integration of NbS on a strategic level in urban planning, while ES could support assessment, valuation and communication of the benefits of NbS in decision-making (Pauleit et al., 2017). Therefore, complementing the NbS approach with related concepts might be the way forward to include NbS on different levels of planning, operationalization and monitoring. We propose a hierarchical approach to NbS definition and classification, which would allow the most important parameters as well as principles for the JUSTNature project together. However, this multi-tier system should not become a complex system to catalogue NbS ever more sophisticatedly, but instead should support practitioners and researchers alike in strategically defining and implementing suitable NbS.

We propose a four-tier system of interrelated levels (Figure 6):

- Level 1 – Challenges
- Level 2 – Action hierarchy
- Level 3 – Principles
- Level 4 – NbS categories and measures

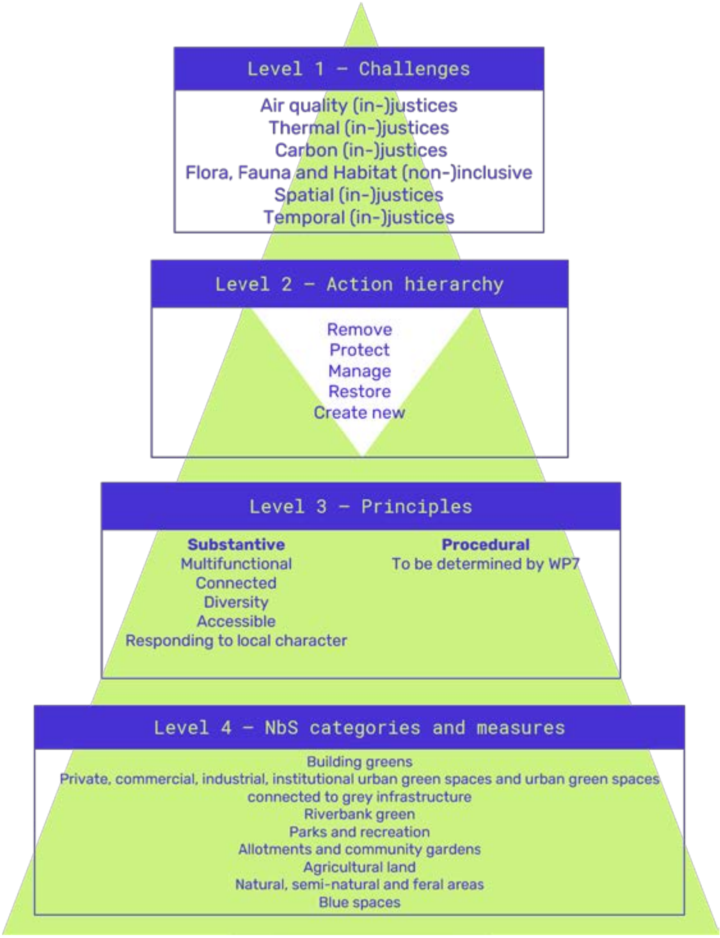

Figure 6: Proposed hierarchical classification system for NbS

The first level of the hierarchical classification system addresses the challenges and the just transition visions to be claimed and which the NbS are intended to address. Challenges are here interpretated as the main aims. For the JUSTNature project, this would refer to the six (in-)justice components for activating Low carbon | High air quality solutions: air quality, carbon and thermal, spatial and temporal (in-)justices as well as flora, fauna habitat (non-inclusiveness). This level supports selecting and prioritizing NbS, which fit the overall aims of the project, i.e. NbS that address the challenges the project aims to tackle.

The second level of the hierarchical classification system is based on classification approach of management levels as first defined by Eggermont et al. (2015). We elaborated this classification into an action hierarchy with five levels (Figure 7):

1. Remove threats to the right to ecological space and to existing NbS
2. Protect and conserve existing NbS
3. Manage existing NbS
4. Restore dilapidated NbS
5. Create new NbS

This action hierarchy supports prioritization of NbS planning, implementation and investment by providing indication which management level should be prioritized before the other. The first choice of action would be to remove any disturbances (e.g. air pollution, greenhouse gas emission), address the challenges at their very root, and as such eliminate threats to existing NbS. Then, secondly, comes to protect existing NbS. Thirdly to manage existing NbS to ensure their lifespan and quality. The fourth choice of action would be to restore dilapidated NbS. Only as the final step new NbS would be created. Such an approach was important to us to avoid that NbS are mainly applied as "end-of-pipe" solutions.

Figure 7: Proposed action hierarchy

Level 3 of the four-tier system is based on the principles for GI from the GREEN SURGE project Hansen et al. (2016) and Natural England (Fanaroff, 2021). Both projects defined principles for the substantive dimension (the "what") and the procedural dimension (the "how"). Within the JUSTNature project also both principles are addressed linking Work Package 2 with Work Package 7 on NbS governance. Within this deliverable the principles for the substantive dimension (the "what") are defined, while in Deliverable 7.1 the principles for the procedural dimension (the "how") are defined.

The principles for the substantive dimension emphasize the importance of multifunctionality, connectedness, diversity, accessibility, and responsive design that incorporates local needs and aesthetics. These principles are included to ensure the quality of single NbS as well as a multitude of NbS. For example, developing NbS that is connected with other NbS brings more benefit than a single, standalone NbS. The principle of multifunctionality does not only apply to a single NbS, but should also ensure to apply a diversity of NbS. At the same aspects of synergies and trade-offs or, generally, awareness of interlinkages are to be considered.

Finally, level 4 of the classification system looks at urban morphological types i.e. it classifies NbS based on the land-use type and purpose following mainly Cvejic et al (2015) and with additions from Kimic and Ostrysz (2021), URBiNAT (2021) and Urban GreenUP (n.d.). This classification provides a comprehensive system with broad categories to group different kinds of NbS regardless of their scale or functionality (see Table 4). In line with Castellar et al. (2021), NbS, which are inspired by nature, but not use nature or natural processes, are excluded. Any planning and governance supporting strategies and instruments are also excluded, as these will be included in Deliverable 7.1.

Table 4: Proposed set of NbS categories and measures

NbS category	NbS measures
Building Greens	• balcony • ground based green wall • façade-bound green wall • extensive green roof • intensive green roof • *green fences* • *ceramic green wall*
Private, Commercial, Industrial, Institutional UGS and UGS connected to grey infrastructure	• atrium • bioswale • tree alley and street trees, hedges • house garden • railroad bank • green playground, school ground • *green pavements* • *green parking pavements* • *cooling pavements (brightly painted, thinner pavements / permeable)* • *green noise barriers*
Sustainable drainage systems	• *runoff troughs* • *grassed swales* • *infiltration trenches* • *vegetated swales* • *(street side) bioretention basins* • *rain gardens*
Riverbank green	• *channel re-naturing (green walls for water channels)*
Parks and Recreation	• large urban park • historical park/garden • pocket park • botanical garden/arboreta • zoological garden • neighbourhood green space • institutional green space • cemetery and churchyard • green sport facility • camping area

Allotment and Community Gardens	• allotment • community garden • *community composting* • *small scale animal husbandry*
Urban Agriculture	• arable land • grassland • tree meadow / orchard • biofuel production / agroforestry • horticulture • *food production and leisure pavilion (integrated hydroponic / vertical growing systems)* • *urban mushroom farm* • *smart soils production and use*
Natural, semi-natural and feral areas	• forest (remnant woodland, managed forests, mixed forms) • shrubland • abandoned, ruderal and derelict areas • rocks • sand dunes • sand pit, quarry, open cast mines
Blue spaces	• wetland, bog, fen, marsh • lake, pond • river, stream – *engineering, maintenance, re-meandering, reopening corridors* • dry riverbed, rambla • canal • estuary • delta • sea coast • *surface water reservoirs* • *retention and infiltration water reservoirs* • *water squares* • *infiltration wells* • *infiltration boxes* • *underground water reservoirs* • *blue roofs* • *electro wetland (microbial fuel cells)* • *extending floodplains*
Technical	• *natural / Modular boxes to encourage pollinators* • *floating gardens* • *grow tile* • *mobile vegetable garden* • *Groasis Waterboxx – device designed to help trees grow in dry areas* • *beehive provision – constructed spaces for beehives* • *re-naturing/adapting existing infrastructure (unsealing surfaces, reprogramming areas under bridges, etc.)*

Note: Based on Cvejic et al (2015) and additions from Kimic and Ostrysz (2021), URBiNAT (2021) and URBAN GreenUP (n.d.) (in *Italic*).

2.3.4 Systemic monitoring and evaluation of ecological (in-)justice and NbS

To address the ecological space (in-) justices that occur in cities today, it is first needed to capture those injustices; to identify patterns (spatial and temporal) as well as interdependencies considering all the components that are part of the urban ecosystems and are subject to ecological space (in-) justices, or the source of them. Such patterns can be captured through suitably designed monitoring campaigns that will provide the data for performing informed impact evaluation to consecutively devise appropriate action plans. It is expected that the need for aggregated human-environmental indicators will increase as the demand grows for more integrative and inclusive sustainability. Along with this comes the risk of losing information or relationship causality during the aggregation (Jørgensen et al., 2013).

In recent years the recognition of the NbS potential in tackling the societal challenges has led to concentrated efforts towards developing the NbS implementation framework for eventually harnessing the most of their multi-functionality. The NbS multi-functionality potential, combining environmental, social, cultural, economic and health benefits (Somarakis et al., 2019), can bring NbS to be viewed as the main component of the ecological space in cities, thus making the NbS monitoring and evaluation particularly relevant to capturing and addressing the ecological space (in-)justices.

Recent systematic reviews of the NbS literature, with reference to NbS monitoring and multiple impact evaluation, reveal lack of systemic monitoring and evaluation across challenges and impact areas, being primarily focused on environmental impacts. The need for a systemic monitoring and evaluation approach to systematically capture the NbS socio-ecological impacts, synergies, trade-offs and disservices is highlighted (Charoenkit & Piyathamrongchai, 2019; Dumitru et al., 2020; Veerkamp et al., 2021). Lack of extended monitoring data that capture the potential of NbS through time, especially in relation to impacts that can be observed in the long term (i.e., climate change, social and health impacts), is also noted (Dumitru et al., 2020).

Besides, Mahmoud et al. (2021) find that unified monitoring and evaluation methodologies for NbS social, health and wellbeing impacts are lacking. With reference to social cohesion, Dumitru et al. (2020) observe that a clearer definition of the concept is needed for measuring the relevant evaluation indicators, for example to measure not only the fostering of social interactions, but also the quality of those interactions. In addition, NbS impact evaluation ought to account for diverse social groups (Dumitru et al., 2020) and expand on equity impacts (Hunter et al., 2019).

The evidence gap, resulting from insufficient monitoring and evaluation and lack of data, is a barrier towards the uptake of NbS interventions (Somarakis et al., 2019) and hinders the ability to adequately evaluate, plan and govern the interventions (Dumitru et al., 2020). Proof of the NbS multi-functionality, the multiple benefits and co-benefits, shall result from systemic long-term monitoring, across different scales and different stages of NbS implementation, targeting multiple impacted stakeholders and engaging them in a co-evaluation process (Mahmoud et al., 2021; Raymond et al., 2017). Effectively, it is necessary to know what tools and methods are available, what information each can convey and what their range of applicability is, for employing those most relevant to the evaluation subject (Kumar et al., 2021).

Much of the NbS related work in Europe is linked to EU funded projects (EU, 2020). Specifically in relation to the NbS expected impacts, NbS projects funded under the EU Horizon2020 R&I agenda have set the basis for developing the NbS monitoring and evaluation framework (EU, 2021). The state of the art on monitoring and evaluation of NbS is currently reflected in the EKLIPSE impact evaluation framework (Raymond et al., 2017) and the handbook produced by the NbS Task Force 2 (EU, 2021).

The EKLIPSE framework entails 7 stages, starting with the problem definition. This first stage offers the socio-ecological background that NbS is called to be placed into and will indicate what the expected benefits are in relation to the specific socio-ecological background and its needs. The monitoring and evaluation, including the impact indicators, will then be selected and planned accordingly. That is why, NbS monitoring and evaluation is viewed as *"transversal"* process, spanning across stages, and involving multiple-actors (impact evaluation experts & impacted stakeholders) within a long-term co-evaluation approach (Raymond et al., 2017). The Task Force 2 expands on EKLIPSE integrating the combined effort and best practice results of NbS projects, resulting in a detailed list of indicators per challenge area and the associated methods for determining and measuring the indicators. From that point of view, the handbook offers the most relevant, applicable, measurable indicators and methods currently available(EU, 2021).

Adjustments however need to be made to the proposed state of the art indicators and assessment methods, or new indicators to be developed, so that (in-) justices can be captured. The indicators need to capture the complexity of socio-ecological systems within urban ecosystems and reveal socio-ecological injustices, otherwise, a false picture is obtained. Especially in the case of NbS, a false idea of the potentials/impact might be obtained which can result in interventions not properly addressing the needs and possibly perpetuate injustices (Biernacka et al., 2020; Dumitru et al., 2020). Differences are shaped by uneven access to resources (e.g., due to poverty, structural racism, power relations), governance (e.g., risk management practices, engagement/exclusion of local communities), cultural factors (e.g., perceptions of nature, climate risks), and access to knowledge (e.g., social memory, diffusion of information) (Thomas et al., 2019).

Two main considerations for evolving the existing NbS indicators towards capturing injustices are:

1. that the same hazard/benefit can be more or less impactful to different people (Thomas et al., 2019).
2. that the socio-ecological (in-) justices have spatial characteristics (Zuniga-Teran et al., 2021).,

In framing the NbS monitoring and evaluation, the diverse social groups and the different ways that these interact with and are impacted by the ecological space, shall be acknowledged so as to so as to provide context specific evaluations and context specific interventions based on the principles of distributional justice (Biernacka et al., 2020; Dumitru et al., 2020). NbS Just planning and governance needs to base decisions on evidence on the distribution of environmental resources, meaning monitoring should focus on disaggregating its scope to reveal them NbS (Biernacka et al., 2020). Disaggregated data on social variables need to be collected, not least by gender and age, as prescribed in D1.4 Gender Guidelines, Chapter 5.

Considering that the socio-ecological (in-) justices have spatial characteristics (Zuniga-Teran et al., 2021), spatial analysis becomes integral to the NbS monitoring and evaluation framework and related indicators. Spatial analysis can be supported by technological advances in NbS monitoring including Earth Observation (EO) data and GIS tools that enable capturing the distribution of impacts and needs (Derkzen et al., 2015; Fletcher et al., 2021). Monitoring through EO is already a valuable tool for the NbS assessment, offering spatial information regarding the distribution of pressures and how these are modified with the introduction of NbS (Chrysoulakis et al., 2021).

Earth observatories provide a plethora of data mostly related to environmental parameters, land cover data and atmospheric data, but they do not describe how they affect people. To make the leap from understanding distributed impacts to distributional injustice, it is also crucial to identify differential vulnerabilities – i.e., the concept that the same hazard/benefit can be more or less impactful to different people (Thomas et al., 2019). Specific vulnerability depends on exposure, sensitivity, and the ability to adapt (Engle, 2011). It is not simply a stable environmental condition, but a volatile trait that is constantly shaped by dynamic socio-political, cultural, and economic processes (Bohle et al., 1994). To move towards mapping the socio-economic injustices and their distribution, EO data need to be supplemented by socio-economic data, coming for example from census data (Fletcher et al., 2021) or social science surveys (Biernacka et al., 2020). A challenge that remains to be overcome, are the varying levels in resolution of data coming from multiple data sources (Chrysoulakis et al., 2021; Fletcher et al., 2021), particularly in relation to population and socio-economic data (Fletcher et al., 2021).

Monitoring and evaluation efforts however need not only to be directed towards capturing distributional (-in) justices, but recognition and procedural (-in) justices as well, that are the underlying causes of distributional (-in) justice (Zuniga-Teran et al., 2021). Then a mapping can be identified among the types of indicators – i.e., structural, process, outcome indicators (EU, 2021) – and the principles of justice (Figure 8).

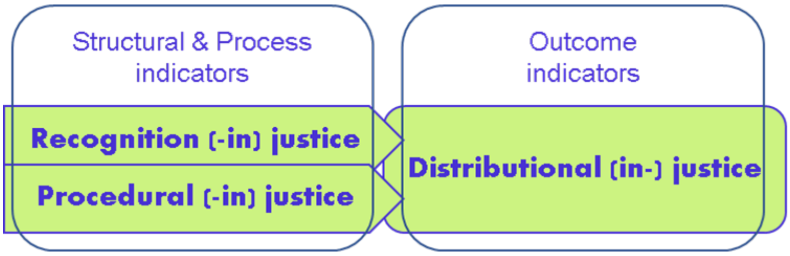

Figure 8: Mapping of justice principles to structural, process, outcome indicators

The NbS impact evaluation Handbook (EU, 2021) classifies the indicators as follows:

- *Structural indicators refer to supporting infrastructure and resources in place to achieve the desired goals (people, material, policies and procedures)*
- *Process indicators refer to the efficiency, quality, or consistency of specific procedures employed to achieve the desired goals*
- *Outcome indicators* refer to accomplishments or impacts

The structural and process indicators are those related to evaluation of resources and procedures for planning and decision making, and can reveal recognition and procedural (-in) justices for example in relation to participatory planning, co-creation, governance. The outcome indicators are related to impacts and results of NbS and can be linked with distributional (-in) justices.

Therefore, different indicators at different stages of the NbS planning and implementation are expected to be employed. The NbS monitoring and evaluation framework will be directly linked to the challenges that the NbS interventions are expected to address, in the case of JUSTNature these are the 6 identified: air quality, thermal, carbon, spatial, CO2, flora-fauna-habitat and temporal injustices. The challenges indicate the goals of NbS interventions and consequently the indicators to measure progress towards these goals.

With reference to the 4-tier system presented in the previous section, these will entail indicators suitable to measure/identify current state of challenges pre-NbS (potentials) (link to tier-1) and possibly help decide action hierarchy (link to tier 2), as well as evaluate progress made post-NbS. In addition, indicators suitable to evaluate expected progress at the design stage, to assist design decisions (link to tier 2), indicators for evaluating the process itself (link to tier 3) and finally indicators suitable to measure NbS performance during their lifetime (link to tier 4).

3 FRAMING ACTION ON LOW CARBON | HIGH AIR QUALITY NBS POTENTIALS

Besides providing guidance on key concepts such as ecological (space) justice and the according activation of NbS more generally, key objective of the report is to provide a body of knowledge that helps framing action on Low carbon | High air quality NbS potentials more specifically. The aim is to set out key knowledge that guides the strategic process of assessing Low carbon | High air quality NbS potentials in a city.

Potentials refer to the ability of something to develop, to be achieved and to become actual in the future, which is subsequently followed by decisions and measures that shape the actual implementation or activation. Low carbon | High air quality potentials are hereby not only determined by looking into ecosystems conditions, structures and configurations or NbS categories and measures and how they contribute to climate change mitigation and adaptation or air quality improvement, considering possible synergies as well as trade-offs. They are inherently linked to human and nonhuman needs and values, and in particular visions of justice that are accordingly claimed, or result from the injustices that are addressed.

Following the previously introduced 4-tier system for the activation of NbS, this includes the following 6 key challenges or visions to be claimed:

- Air quality (in-)justices
- Thermal (in-)justices
- Carbon (in-)justices
- Flora, fauna and habitat (non-) inclusiveness
- Spatial (in-)justices
- Temporal (in-)justices

They have taken shape during the different steps of the knowledge brokering process and following various feedback loops and discussions, also with the city partners. Whereas the first three are more closely aligned to defined environmental conditions, the last two are cutting across a range of different dimensions, and the Flora, Fauna & Habitat (non-) inclusiveness is perceived as a central focus informing the other challenges.

The line between these challenges cannot be drawn neatly, due to the various strong interlinkages, including synergies and trade-offs. However, everyone represents a defined entry-point for strategically assessing Low carbon | High air quality NbS potentials.

The various chapters are structured as follows:

Definition: For demarcating the challenge, this section introduces various concepts that have been coined and used to define notions of inequality, equity, injustices or justices in relation to the topic. It describes key aspects to consider, especially in what regard specific environmental, built environment, socio-economic and individual conditions drive the according (in-) justices.

NbS contribution: The section shades light on the contributions of NbS in addressing the challenge. This refers to the defined layers previously introduced and impacting the activation of NbS, such as NbS categories and measures or the NbS action hierarchy. It outlines what key legs of justice existing examples have addressed, though key focus is put on distributional aspects for the identification of NbS potentials.

Interlinkages with other key challenges: Describes interlinkages with the other 5 challenges, emphasizing potential synergies as well as trade-offs. It assesses how strong these interlinkages are and describes whether the effect is negative (injustice), neutral or positive (justice).

Basket of indicators: It discusses what needs to be considered for the selection of indicators to appraise the potential of addressing the challenge, and introduces a group of indicators. It suggests defined indicators, what drivers these consider, whether NbS contributions are integrated, which justice dimension is predominantly targeted, the level of integration it allows in relation to consider other challenges and the spatial mapping potential, to assess the feasibility of visualising the potential spatially.

The various chapters have been developed by a range of authors with different backgrounds, which, as highlighted in the methodological part, suggests a defined 'fingerprint', although countervailed by an according review. Names of authors and reviewers have been accordingly included.

3.1 Air quality (in-)justices

Authors: Pietro Zambelli, Silvia Croce, Samuele Zilio, Isabella Siclari, Sonja Gantioler (EURAC)
Review: Angeliki Mavrigiannaki (TUC), Sonja Gantioler (EURAC)

Air quality (in-)justices responds to the higher exposure to average values of air pollutants (e.g. NO_2, O_3, SO_2, CO and PM_{10} and $PM_{2.5}$) among different groups of the population and takes into consideration procedural impacts on the distribution of an Air Quality Monitoring Network and potentially resulting blind spots.

3.1.1 Definition

The World Health Organization highlights that "air pollution is now recognized as the single biggest environmental threat to human health" (*WHO Global Air Quality Guidelines*, n.d.). Thus, not surprisingly, after a review of the additionally gathered evidence and 15 years after the last update, in 2021 the WHO as part of its guidelines released new and more stringent air quality levels, needed to be able to protect the health of populations (World Health Organization, 2021). The air pollutants that are considered are Particulate Matter ($PM_{2.5}$ and PM_{10}), Ozone (O_3), Nitrogen Dioxide (NO_2), Sulphur Dioxide (SO_2) and Carbon Monoxide (CO). The update builds on evidence that globally the death toll and lost years of healthy life have only marginally declined since the 1990s.

In Europe, an analysis of the annual trends in ambient air pollutant emissions between 2000 and 2017 and trends in air pollutant concentrations indicates significant reductions for most of the air pollutants in the EU 28 member states (including UK) and subject to EU air quality legislation, such as the EU national emissions ceiling Directive (EU, 2016) or the Directive on ambient air quality (EU, 2008a) (Sicard et al., 2021). The emissions fell by 46% for NO_x, 31% for $PM_{2.5}$ and 29% for PM_{10} (see Box 4 for key sources). A briefing by the European Environment Agency (EEA) on Europe's 2020 air quality status compared to the new WHO guidelines, however concludes that although reductions in emissions were achieved and EU air quality standards were less largely exceeded, the share of EU urban population exposed to e.g. $PM_{2.5}$ concentrations above the new WHO guidelines amounted to still 96 per cent (EEA, 2022). In 2021, a study analysing premature mortality due to air pollution in 969 cities and 47 greater cities in Europe concluded that a significant amount of premature deaths could have already been avoided by lowering air pollution levels below the 2006 WHO guidelines, especially in cities with the highest burden of $PM_{2.5}$ and NO_2, especially located in Northern Italy (e.g. Brescia, Bergamo or Milan and Turin), Central-Eastern Europe (e.g.

Karviná in the Czech Republic or Górnośląsko-Zagłębiowska Metropolia in Poland) or capital cities such as Brussels (Belgium) (Khomenko et al., 2021).

Box 4: Key sources of air pollution in the EU and its cities

As regards **key sources of air pollution,** they can be various, both **natural and anthropogenic**, especially in relation to PM, which can result from direct emissions as well as being secondarily formed chemical compounds (e.g. organic carbon). The most well-known sectors of human activities contributing to air pollution are those were **combustion of fossil fuels or biomass** for the generation of energy occurs (e.g. heating, exhaust vehicle emissions), whereas others relate to **dust** from construction activities or also to the occasional **burning** of biomass (e.g. wildfires) (World Health Organization, 2021). In the EU 28 member states, between 2000 and 2017, the **transport sector** is deemed the largest contributor to total NO_x emissions (Sicard et al., 2021). With regard to PM emissions, an initial scrutiny by Emissions Analytics, an international vehicle emissions testing company, seem to indicate that in new cars the role of non-exhaust emissions such as from the use of tyres quite exceeds exhaust emissions per kilometre of driving, in particular as the weight of vehicles increases (Emission Analytics, n.d.), and might be an underestimated environmental concern.

A modelling study associating PM2.5 emissions e.g. to various sectors in **150 European urban areas** indicates that on average the **agricultural** (23 %, and in particular in German cities) and **industrial sectors** (20 %, in particular in Eastern European cities) are main contributors, followed closely by **natural events** such as dust events (19 %, especially in the Mediterranean area), and concluding with the **transport** (14 %, in particular in large and capital cities) and **residential sectors** (13 %, in particular Eastern European cities) (Thunis et al., 2018). However, it also concludes that sources of air pollution can be **very city-specific and vary widely**. An econometric analysis of 250 large urban zones in Europe, indicates that highly fragmented and highly constructed cities demonstrate higher N02 and PM10 concentrations, whereas more densely populated cities experience higher S02 concentrations (Cárdenas Rodríguez et al., 2016).

The notion of air quality (in-)justice has been most closely associated with the broader concept of environmental justice, in particular in relation to the distribution of environmental ills. A large body of literature analyses the inequality of exposure to air pollutants (referring to both concentrations as well as time of exposure). This refers to inequalities between countries (e.g. outsourcing of industrial production) and within countries for different socio-economic and cultural/race/ethnicity groups (Table 5).

Best studied in the United States, the analysis of daily time-series dataset of more the 23 million of Medicare beneficiaries in 968 U.S. counties shows a positive association of $PM_{2.5}$ and circulatory and respiratory hospitalizations, an increase of the risks over the last period of the study, and a significant effect on the risk based on: urbanicity levels, socio-economic status and on race, age and sex (C. Chen et al., 2022). In relation to disparities in the exposure to $PM_{2.5}$ air pollution emissions by people of colour in the US, in 2021 a study concluded that these are not caused by defined emission sources but are characterised by higher-than-average concentrations across all 14 analysed sectors (e.g. industrial, construction, heavy and light duty vehicles) independent of income level (Tessum et al., 2021).

Overall, in European studies the results are more varied, some reported a relation between high exposure and low socio-economic status or non-white ethnicity, other studies found a higher exposure for mid-level deprivation areas, and some other studies provide inconsistent results depending on the city (Verbeek, 2019). Verbeek identified a global association of income and foreign origin with a higher exposure to air pollution, The income parameter remains substantial and robust even if the analysis considers the spatial autocorrelation. *"Environmental justice issues in Italy are not likely to manifest themselves along racial and ethnic terms but instead in terms of social categories and gender composition"* (Germani et al., 2014). Furthermore, studies showed that immigrants from countries with a lower GDP per capita than the EU average, tend to suffer greater deprivation and more adverse social conditions (Moreno-Jiménez et al., 2016). In addition, currently under scrutiny is also the impact of smaller PM components on epigenetic mechanisms (genome expressions) and effects in relation to diseases such as asthma, cognitive abilities and mental disorders, and the risks of several generations being affected (Ferrari et al., 2019).

The analysis of the distribution of the Air Quality Monitoring Network (AQMN) for $PM_{2.5}$ and O_3 showed that *"substantial areas of the United States lack monitoring data, and among areas where monitoring data are available, low income and minority communities tend to experience higher ambient pollution levels"* (Miranda et al., 2011). Further studies also highlight that, not only there is a high correlation between pollution exposure and income, but that *"low-income (or non-white) neighbourhoods are also less likely to be monitored"* (Grainger & Schreiber, 2019). The authors find evidence that new monitoring sites *"are placed in areas that are, on average, relatively clean compared to the surrounding area."* The authors identify part of the issue the local regulatory agencies overseeing monitoring ambient pollution and at the same time ensuring that the law limits are respected. Therefore, *"If exceeding the ambient pollution standard results in a penalty for the local jurisdiction [...], the regulator would have an incentive to avoid monitoring pollution in areas that may be close to exceeding the standard. In addition, there could be political pressure to monitor in (or avoid) certain neighbourhoods"*. Another study provides evidence that the use of citizen science (I.e. PurpleAir) to equalize environmental knowledge *"can be exclusionary and may reproduce patterns of environmental injustice that such emerging technologies could potentially be leveraged to redress"* (Mullen et al., 2022). As such, procedural and recognitional aspects can be considered to have an important role in making inequalities of exposure to air pollutants visible (or not). It is argued that this also refers to the publicly and user-friendly access to emission data, refined monitoring at smaller scales (e.g., neighbourhoods and city blocks) or evaluation of urban planning professionals on ethical practices (Jennings et al., 2021).

Table 5: Specific conditions driving air quality (in-) justices

	Key insights	Key literature
Environmental conditions	The distribution of air pollutants (NO2, PM2.5, O3, etc.) is potentially linked to unequal exposure, generally of sensitive groups like elderly people, women and children, which tend to be more stationary and stay close to their home, and therefore are more sensitive to the local conditions that are surrounding their house. The procedural aspects linked to the distribution of Air Quality Monitoring Network tend to ignore the worst place (blind spot) because the AQMNs are developed to be representative of the average air pollutants' concentration value. The land use and the distances from specific land use categories like distance from green areas, water bodies, high roads, industries, etc.	(Miranda et al., 2011; Mullen et al., 2022; *WHO Global Air Quality Guidelines*, n.d.)
Social and economic conditions	The exposure to air pollutants is strongly driven by the income parameter, also depending on the country and region, and linked to other variables such as age, ethnicity, gender, etc.	(C. Chen et al., 2022; Germani et al., 2014; Moreno-Jiménez et al., 2016; Verbeek, 2019)
Individual conditions & vulnerabilities	Children, women and elderly people tend to be more exposed to the local concentration of air pollutants surrounding their home. The exposure of pregnant people to air pollutants' concentration might be the cause of pre- and post-natal issues, cognitive issues and can increase the possibility of Alzheimer disease.	(Citerne et al., 2021; Kilian & Kitazawa, 2018; Margolis et al., 2022; Nyadanu et al., 2022)
Built-environment	Urban structures can have a major impact on air pollution concentrations, especially for transported related pollutants, such as NO2, PM10 and SO2. This relates to the fragmentation, but also larger artificial areas and population density. The analysis of the spatial drivers of air pollutants in the urban context are the distance from the pollutants source and the micro-climatic conditions that might be driven by the vegetation structure surrounding the area of interest or the building morphology that might create urban canyons.	(Cárdenas Rodríguez et al., 2016; Gromke & Blocken, 2015; Tomson et al., 2021)

3.1.2 NbS contribution

Nature-based solutions can directly capture a portion of local air pollution emissions, however more studies need to be conducted to properly address the effectiveness of plants in real-life environments (Han et al., 2022; Tomson et al., 2021) and the main implications for human health (Diener & Mudu, 2021; Qiu et al., 2021). The removal of air pollutants by vegetation is affected by multiple interacting factors (e.g., plant species, vegetation configurations, vegetation position), vegetation parameters (e.g., leaf area density, drag coefficient and deposition velocity) and complex wind regimes (Tomson et al., 2021; Zhang et al., 2021). Under certain local conditions (e.g. canyons) the effect of trees can increase the air pollutants concentration (Gromke & Blocken, 2015; Tomson et al., 2021), whereas green walls, green screens and green roofs do not interfere with the prevailing ventilation and can mitigate urban PM pollution.

Particle deposition depends on vegetation species, pollution level and the residence time of PM in a street (Ysebaert et al., 2021). The vegetation capacity to reduce the pollutants concentration "*largely depends on its macro-morphology in relation to the physical environment*" (Tomson et al., 2021). A positive correlation is found between deposition and micro-morphological leaf traits (e.g. grooves, ridges, trichomes, stomatal density and epicuticular wax amount) (Corada et al., 2021; Tomson et al., 2021). Very efficient vegetation groups in the process of phylloremediation include "some species of vines (Parthenocissus quinquefolia), shrubs (*Forsythia x intermediata*) and in particular coniferous trees (e.g. *Larix decidua*). Broadleaf tree species such as *Betula pendula 'Youngii'*, *Quercus rubra*, *Cratageus monogyna*, *Acer pseduoplatanus*, *Tilia cordata Mill*. or *Platanus orientalis* turned out to be the most efficient in the process of phylloremediation" (Kończak et al., 2021). Another study takes into account the combined effects of combatting air pollution by removing PM, NO_2 and O_3, and potential disservices such as pollen and biogenic volatile organic compounds (BVOCs), as well as trees' resilience to diseases, pollution or drought in cities (Sicard et al., 2018). The authors conclude that the most effective tree species are considered to be: *Acer sp.*, *Ailanthus altissima*, *Carpinus sp.*, *Cedrus sp.*, *Crataegus sp.*,*Fagus sylvatica*, *Larix decidua*, *Liriodendron tulipifera* and *Prunus sp*..(Sicard et al., 2018). Less effective plant species are considered shrubs, linked to their robustness, and tree species such as *Quercus sp.*, *Populus sp.* and *Eucalyptus sp.*, as less efficient in removing O_3 and higher production of BVOCs. The least effective tree species seems to be the rather widely distributed *Robinia pseudoacacia* (Sicard et al., 2018).

Trees are recommended only in shallow street canyons, while hedges are recommended for shallow and moderately deep street canyons. The most effective hedges to reduce the pedestrian exposure are the continuous hedges (without gaps) with a minimum thickness of 1.5 m and a minimum height of 2 m. Green walls capture pollutants from nearby emissions sources; from the literature review green walls are more effective in capturing PM rather than gas pollutants. The literature concerning the green screens is still lacking, however, "studies to date have shown up to a 60% concentration reduction for PM_{10} and a 53% reduction for NO_2" (Tomson et al., 2021). Active Green Walls (AGW) can involve an active transfer of PM_{10}, not only for gravitational and diffuse deposition, but using a form of mechanical air transfer, with PM reduction of 42%, VOCs by 28%, 45% for $PM_{0.3-0.5}$ and 92% for PM_{5-10}. PM_{10} densities on leaves were higher on random configured design (heterogenous) than in a clustered design (homogenous) of plants.

As indicated in Table 6, NbS contributions to air quality (in-) justices are mainly determined by distances to defined land use categories such as urban green spaces. Arising injustices are mainly associated with the unequal access to green infrastructure and the ecosystem services it provides, especially in relation to individual health vulnerabilities (Jennings et al., 2021). However, it also relates to accessibility regarding the form and defined characteristics of green infrastructure (e.g. street tree density positively correlated with household deprivation), likely strongly interlinked with the urban design (Ferguson et al., 2018).

Table 6: Overview of the contribution of NbS and key types

	Key insights	**Key literature**
NbS contributions	• Multiple interacting factors are contributing to the removal of air pollutants (plant species, vegetation position and configuration, leaf characteristics, etc); • Under certain conditions (e.g. urban canyons) the trees can be not beneficial, while green roofs, green walls hedges, do not interfere with the prevalent ventilation and can reduce the concentration of air pollutants in air; • Green screens show Particulate Matter PM_{10} concentration reduction up to 60% and up to 53% for NO_2. • Studies on Active green walls show a PM reduction up to 45% for $PM_{0.3-0.5}$; up to 92% for PM_{5-10} and by 20% for VOCs	(Tomson et al., 2021; Zhang et al., 2021) (Gromke & Blocken, 2015; Tomson et al., 2021) (Tomson et al., 2021)
NbS categories and measures	• Trees • Green roofs • Green walls • Green screens • Active green walls • Hedges	(Tomson et al., 2021)

Table 7: Types of action and justice principles

	Key insights	**Key literature**
(Remove) Protect, Manage, Restore, New	Removal of air pollutant sources, by e.g. removing transportation related emissions: less car traffic and introduction of green mobility	(Sicard et al., 2018)

	Protect and effectively manage existing urban green maximizing air quality improvement potential (e.g. historic trees) Create new vegetated areas through the city • Prioritizing areas highly affected by air pollution concentration (e.g. narrow street canyons) • Selecting species focusing on - their air pollution tolerance and pollutant removal ability - physiological characteristics and habitat - allergenic effects • Select appropriate NbS categories for the characteristics of the site (e.g. choosing the right height of vegetation)	
Distributive, Procedural, Recognition	Distributive: • Provide equal access to green infrastructure and air quality regulating ecosystem services especially in relation to individual health vulnerabilities. • Making inequalities of exposure to air pollutants visible through user-friendly access to emissions data and refined monitoring at neighbourhood scale Procedural/Recognition: • Involvement of diverse residents in decision-making processes, recognizing needs and preferences that might result in trade-offs and undesirable effects in order to mitigate them and to increase awareness of beneficial effects. • Expert (urban foresters, planners and dendrologists) trained in inclusive community engagement to secure beneficial outcomes for residents. • Quantification of air pollution exposure in different locations through monitoring infrastructures refined at smaller geographic scales that more accurately reflect community demographics (self-organizing monitoring system - citizen science - might result in the exclusion of low-income and minority neighbourhood from information about local air pollution, resulting in additional inequalities and injustice) • Access to inventories of emissions data and user-friendly and publicly available ambient air quality monitoring should be guaranteed	(Jennings et al., 2021; Mullen et al., 2022)

3.1.3 Interlinkages with other key challenges

Air quality justice is strongly related to all the other justice challenges.

Air quality and thermal justice are clearly interlinked, as air pollution and heat conditions mutually influence each other. The emissions of O_3, PM_{10}, and NO_2 are exacerbated during heatwaves (P. H. Fischer et al., 2004). Furthermore, studies have confirmed the presence of synergistic health effects between heat and air pollution. The analysis of associations between air pollution and daily mortality during heat waves suggest that a considerable number of deaths could be attributed to the interaction between temperature and air pollution (Anenberg et al., 2020; P. Fischer et al., 2008). In addition, there are indications that changing climate and increasing air temperatures in particular can be important plant stressors, which increase the allergenicity of pollen (Schiavoni et al., 2017).

There is a clear connection between poor air quality and carbon justice. Aside from CO_2, many air pollutants contribute to climate change by affecting the absorption and reflection of the incoming solar radiation by the atmosphere. These are defined as short-lived climate-forcing pollutants (SLCPs) and include black carbon (i.e. a component of $PM_{2.5}$), methane and O_3. These pollutants last in the atmosphere less than CO_2, but present a higher warming potential and hence should be included in mitigation policies (Shoemaker J. K. et al., 2013).

Air quality is interlinked with spatial justice, as within cities, locally higher concentrations of air pollutants are common. Air pollution mainly affects those living in dense urban areas, where the majority of urban sources are located, and road emissions contribute the most to the deterioration of air quality. In general, air quality improves as the neighbourhoods become more rural (Strosnider et al., 2017). Higher levels of air pollution are also recorded in proximity to industries. In this case, there is also a danger of industrial accidents, where the spread of toxic elements can strongly affect the health of the populations of the surrounding areas (Manisalidis et al., 2020). Several studies have also proved that poor air quality is often prevalent in socio-economically deprived areas, also as consequence of local policies (Kenis & Loopmans, 2022). As an example, a study conducted in Great Britain over the decade 2001-2011 has proved the unequal effects of the efforts to meet the EC air quality directive limits. Indeed, the greatest improvements have been reached in the least deprived areas, while the most deprived areas have seen a further deterioration of air quality (G. Mitchell et al., 2015).

There is a strong link between air quality justice and flora and fauna inclusivity, as air pollution has a harmful impact not only on human health and living conditions, but also on wildlife, both inside and outside urban areas. One of the main stressors for biodiversity are nitrogen (N) emissions from fossil fuel burning and agriculture, which lead to an increased deposition of reactive N. This is a threat to plant diversity as it enhances the growth of some species contributing to more homogeneous plant communities and biodiversity loss, with consequences on ecosystem functioning and on several animals that depend on plants for nutrients and shelter (Bobbink et al., 2010; Dirnböck et al., 2017). O_3 and PM_{10} are also recognized as threats for urban ecosystems (Bell et al., 2011). A study considering four air pollutants (i.e. nitrogen, sulphur, ozone, and mercury) has identified effects of air pollution on all eight ecosystem types considered (Lovett et al., 2009).

- Aquatic ecosystems: the effects of acidity, nitrogen, and mercury on organisms and biogeochemical processes are well studied; they include the eutrophication of estuaries and coastal waters and the acidification of lakes.
- Terrestrial ecosystems: air pollution has serious impacts on biogeochemical cycling and soil acidification; furthermore, O_3 has been proved to reduce photosynthesis in many plant species.

The magnitude of the relation between air quality and temporal justice is mainly influenced by the extent of the reduction of air pollutants. Indeed, studies on future changes in air pollutants show that concentrations might mainly depend on each pollutant and on the mitigation scenario. Scenarios that involve weak actions on climate change mitigation and on reducing air pollutant emissions foresee an annual mean increase in both surface O_3 and $PM_{2.5}$ (Turnock et al., 2020). A future increased exposure to air pollutants might produce several consequences for human health. Studies have shown a positive correlation between prenatal exposure to $PM_{2.5}$ and PM_{10} and adverse birth outcomes (Nyadanu et al., 2022), and between early postnatal NOx exposure and asthma (Citerne et al., 2021). Air pollution is also negatively associated with sleep health (Liu et al., 2020) and cognitive decline and Alzheimer's disease (Kilian & Kitazawa, 2018). Furthermore, the increase of particulates emissions has been proved to be among the causes of the increase of temperatures in urban areas and the exacerbation of heatwaves (Kuttler, 2008). Hence, a potential future increase of air pollution levels might lead to severe consequences for both the environment and for human health.

Table 8: Overview interlinkages with other key challenges

	Key insights	**Strength and effect**	**Key literature**
Thermal (in-)justice	Air pollution and heat conditions mutually influence each other, high air temperatures increase air pollution with synergistic health effects	↓↑	(Anenberg et al., 2020; P. Fischer et al., 2008)
Carbon (in-)justice	Short-lived climate-forcing pollutants consistently contribute, together with CO_2, to climate change → their reduction is relevant in mitigation policies	↑	(Shoemaker J. K. et al., 2013)
Spatial (in-)justice	Exposure to air pollution and its health risks varies greatly within the same city; these spatial differences are linked to the structure of the urban areas and the proximity to	↑	(Kenis & Loopmans, 2022)

	sources of pollutants, but also to socio-economic indicators		
FFH-inclusive	• Atmospheric nitrogen deposition is a recognized threat to plant diversity and ecosystems functioning • Air pollutants have serious effects on biogeochemical processes and cycling on both aquatic and terrestrial ecosystems, consequently threating urban and non-urban ecosystems	🡅	(Bobbink et al., 2010) (Lovett et al., 2009)
Temporal (in-)justices	Temporal consequences are highly dependent on the future level of air pollutants: an increase might produce severe environmental consequences and impacts on human health	🡅	(Turnock et al., 2020)

Note: Strength and effect 🡇: strong negative interlink; 🡖: partial negative interlink; –: no correlation; 🡕: partial positive interlink; 🡅: strong and positive interlink

3.1.4 Basket of indicators

Green spaces (positively) affect air quality by particle deposition, dispersion or modification (Diener & Mudu, 2021). However, several studies have revealed that design and choice of urban vegetation are crucial elements in NbS decision-making processes (Janhäll, 2015). In fact, the most common indicators for air quality monitoring in cities focus on pollutants removal by vegetation types (Chiarini et al., 2021) and suggest recommendations for appropriate plant species selection to policy-makers (Barwise & Kumar, 2020).

A central parameter for measuring air pollution reduction potential is the Leaf Area Index (LAI), i.e. the extent of leaf area exposed to light and thus capable of producing oxygen and absorbing carbon dioxide. It is calculated as the leaf area (m^2) per ground area (m^2) and is dimensionless, ranging from 0 (bare ground) to over 10 (dense conifer forests) (Breda, 2003). Knowing the LAI, and the deposition amount of pollutants on vegetation, allows to estimate the quantity of pollutants absorbed by a certain region (Bottalico et al., 2016; Manes et al., 2016). Depending on the spatial resolution of the LAI (that can be derived from land cover maps or by remote sensing techniques), it is possible to assess micro-scale air quality and to monitor the impacts of urban vegetation on the built environment.

Air pollutants concentration is strongly influenced by urban morphology. Certain geometries and layouts affect the wind field, and therefore the movement of particles, in cities (Edussuriya et al., 2011). Some of these parameters, like the proximity to air pollution sources and the location of street canyons, can be used to monitor the impact of harmful emissions on human health.

Air pollution exposure is unevenly distributed across the urban population also due to individual socio-economic conditions and related spatial (in-)justices. Social deprivation variables – such as low household income, non-professional job, low education or non-owner occupier – significantly affect air quality of disadvantaged neighbourhoods (V. O. Li et al., 2018). Inclusion of these variables in the evaluation of air quality indicators for NbS will support mapping air quality progress through the lens of distributional justice.

Beyond spatially-explicit models, other relevant indicators that can be used to analyse air quality (in-)justices focus on the health impact of air pollutants removal, i.e. the evaluation of the environmental risk associated with long-term exposure to harmful substances (Tiwary et al., 2009), or on the monetary value, i.e. the estimation of the potential economic benefits delivered by NbS (Soares et al., 2014).

Table 9: Basket of indicators to appraise NbS air quality (in-) justices potential

Indicator (metric)	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of integration	Spatial mapping potential
Air pollutants removal by vegetation (combination of Leaf Area Index and air pollutants concentrations)	Distribution of urban green spaces	Environmental benefits (air pollution abatement) Trees, hedges, green walls, green roofs	Distributional	++	●
Distance from air pollution sources (e.g. road, etc.)	Proximity to sources of air pollution	Environmental benefits (air pollution abatement) Trees, hedges, green walls, green roofs	Distributional	++	●
Street canyons location (combination of Sky View Factor and traffic volumes)	Air pollutants concentration	Environmental benefits (air pollution abatement) Trees, hedges, green walls, green roofs	Distributional	+	●
Air pollution-induced environmental injustice (combination of Social Deprivation Index and air pollutants concentrations)	Social deprivation (low household income, non-professional job, low education, non-owner occupier)	Societal benefits (reduced inequalities) Trees, hedges, green walls, green roofs	Distributional	++	●

Health impact of air pollutants removal (Number of premature deaths/Number of hospital admissions)	Exposure to high levels of air pollutants	Societal benefits (improved health) Trees, hedges, green walls, green roofs	Distributional	+	-
Monetary value of air pollutants removal (Damage costs of air pollution)	Pressure on municipal budgets	Economic benefits (savings) Trees, hedges, green walls, green roofs	Distributional	+	-

Note: Level of integration -: no significant integration; some (+) to very high (++++)
Spatial mapping potential -: no significant mapping potential; O: some; ●: high

3.2 Thermal (in-)justices

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Thermal justice refers to the reduction of the inequitable distribution of extreme heat conditions and related risks across different areas within the same city and the vulnerable population.

3.2.1 Definition

Within urban areas, the inequitable distribution of the adverse effects of climate change, resulting in rising global temperature baseline with more intense and frequent heatwaves (i.e. protracted periods of excessive heat), is particularly evident. Furthermore, the uneven distribution of buildings, heat-absorbing artificial surfaces, and vegetation is the main reason why some areas are more affected by overheating than others, resulting in the urban heat island effect (UHI). This phenomenon occurs simultaneously to the increase of the global temperature baseline, hence exacerbating the urban heat risks.

Thermal injustice results from the impact of human activities on the physical environment and on the social structure of cities (B. C. Mitchell & Chakraborty, 2018).

The built environment and its characteristics are the major technological causes of the unequal distribution of thermal conditions in cities. Indeed, the UHI is caused by the excessive built surface, with artificial materials characterized by a high capacity to store and emit heat, by greenhouse gases emissions from industrial processes and transport, and by heat production from air conditioning systems (Box 5). Furthermore, urbanization processes result not only in an increase of built and population densities, but also in the transformation of vegetated areas into built-up areas, with a loss of vegetation and a reduction of cooling both from evapotranspiration and from shading (Kuttler, 2008). All these phenomena occur with different magnitude in different areas of the city, as a result from disparities in the planning, development and maintenance of urban areas (Reckien, et al., 2018).

Box 5: UHI: causes and magnitude

The urban heat island effect is a **complex phenomenon**, which consists of an increase of air temperatures in cities compared to the surrounding rural and suburban areas **(Oke, 1982)**. UHI is characterized by an **uneven spatial distribution**, and its **magnitude can be quite large**, depending on weather conditions, urban physical and geomorphological characteristics, and anthropogenic heat sources (Taha, 1997). The most important factors influencing UHI are related to: (i) increased short-wave radiation absorption and decreased long-wave radiation loss due to canyon geometry, (ii) increased long-wave radiation from atmosphere due to air pollution, (iii) increased sensible heat storage and decreased evapotranspiration due to construction materials, (iv) anthropogenic heat release, and (v) reduced turbulent heat transfer within the canyons **(Oke, 1982)**.

A review of research conducted in Europe showed that the reported **UHI intensity reach values up to 8-10 °C**. The intensity is usually higher in **calm and clear weather conditions** and more prominent during **night-time**, due to the greater thermal inertia of the urban construction materials (Santamouris, 2007).

Urban heat island has a **significant energy, environmental, and socioeconomic impact** on the urban environment. UHI, in fact, occur both in summer and in winter periods, with a serious impact on the buildings´ energy consumption for heating and cooling. During the summer season, higher urban temperatures have a severe effect on energy consumption, mainly associated with the increased cooling demand (X. Li et al., 2019; Santamouris, 2014). Furthermore, UHI increases the concentration of harmful pollutants (e.g. tropospheric ozone and VOC), and the emissions of GHG, and deteriorates indoor and outdoor thermal comfort, affecting health conditions of urban population (Akbari & Kolokotsa, 2016).

The social structure also plays a key role, due to the disparities in the ability of communities, especially vulnerable ones, to adapt to the effects of climate change and UHI. Thermal injustice is a distributive justice concern, as the marginalized communities are the least prepared for adapting to and mitigating the effects of high temperatures, and for coping with their adverse impacts (B. C. Mitchell & Chakraborty, 2018). The areas of the city most exposed to high heat levels are often inhabited by socially vulnerable groups. Indeed, the population with lower socio-economic status tends to reside in areas with less access to urban green infrastructure, and has a reduced ability to fund, maintain and develop private green spaces (Reckien et al., 2017).

Thermal injustices produce direct impacts on health conditions. The increase temperatures due to climate change and UHI might be beneficial when reducing the mortality and morbidity risks of cold temperatures, but results in heightened mortality and morbidity during periods of excessive heat or heatwaves (Reckien et al., 2017). Indeed, it is estimated that, nowadays, around 30% of the global population is exposed to health-threatening heat conditions for at least 20 days a year (Mora et al., 2017). Studies in literature report that urban temperatures above 27 °C also contribute in triggering mental and behavioural disorders (Cianconi et al., 2020; A. Hansen et al., 2008). Socially vulnerable groups, including people living below the poverty level, older people living alone, and people with pre-existing medical conditions are the most affected (Petkova et al., 2014; Vandentorren et al., 2006). Heat-related mortality is mainly associated with heath strokes and the exacerbation of existing health problems; it predominantly affects the elderly population. Recent heatwaves have demonstrated the significance of this phenomenon. The European heatwave in summer 2003 caused more than 70.000 victims (Kosatsky, 2005), while the event in summer 2010 has been estimated to result in more than 54.000 fatalities in European Russia (Revich, 2011). Heat-related morbidity causes the impairment of physiological functions, and a reduced workplace productivity in people working outdoor or in factories (Y. Sun et al., 2020).

Heat vulnerable groups include racial/ethnic minorities, people with low socio-economic status, young people / children, socially isolated older people, and disabled people (Gronlund, 2014; Renteria et al., 2022). Indeed, heat-related risk does not impact all citizens equally, but is strictly dependent on person-specific characteristics and socio-economic factors (Reckien, et al., 2018).

Person-specific characteristics include physiological attributes such as age, sex, disabilities and medical status. Age is the most relevant heat-vulnerability factor, as elderly have shown higher mortality and hospital admission rates during heatwaves (Reid et al., 2009). With regard to sex, women are usually more intolerant to heat than men due to physiological and thermoregulatory differences (Druyan et al., 2012). Furthermore, they might be often more exposed to heat due to the time spent indoor in spaces without adequate air flow or air-conditioning (Reckien et al., 2017). Finally, in terms of medical status, people with limited mobility or confined to bed, or with pre-existing health conditions, are more vulnerable to heat (Vandentorren et al., 2006).

Socio-economic factors encompass several social and location-specific characteristics. Several studies have found a correlation between low socioeconomic status and poverty conditions and heat-related morbidity or mortality (Gronlund, 2014; Reid et al., 2009). Working and living conditions also influence heat-vulnerability. Occupation is a risk factor for people working in not climate-controlled environments, as for example construction workers, farmers, and miners (Gronlund, 2014; Vandentorren et al., 2006). Inadequate housing, with buildings difficult to cool during summer and reduced ability to access to air conditioning, is another risk factor. Several studies have proved that the presence of air conditioning is a relevant protective element against heat-related mortality and morbidity (Reid et al., 2009). Lower income households are the ones facing the greatest difficulties in maintaining safe indoor temperatures during periods of elevated heat conditions (Sanchez-Guevara et al., 2019, p.). However, it has to be noted that the diffusion of air condition in all buildings is both not technically feasible in the short term (i.e. purchase and running costs are not sustainable for all residents), and not environmentally sustainable in the long term (i.e. related electricity consumption and greenhouse gases emissions) (Maller & Strengers, 2011). Finally, studies have shown that disadvantaged neighbourhoods have lower tree canopy cover (Jesdale et al., 2013; Landry & Chakraborty, 2009) and less access to urban greening (Byrne et al., 2016; Schwarz et al., 2015), and hence are hindered to benefit from the cooling effects from vegetation.

Apart from health impacts, thermal injustices in urban areas also lead to severe economic consequences. A recent study on the major cities around the world has estimated that the economic impact of climate change is increased by 2.6 times by the concurrent presence of UHI (Estrada et al., 2017). Economic damages are also caused by the reduced labour productivity in extreme heat conditions, especially during heatwaves. Studies have shown that the outdoor sectors are the ones most directly impacted by heat; however, these losses are propagated to the entire economy (García-León et al., 2021; Orlov et al., 2020).

Urban warming also significantly influences the buildings' energy consumption, increasing the energy needs for cooling (average increase: 23%), while decreasing the needs for heating (average reduction: 19%). Furthermore, studies have shown that, during the warm period, the peak electricity demand increases between 0.45% to 4.6% per degree of temperature rise (Santamouris, 2014).

Table 10: Specific conditions driving thermal (in-) justices

	Key insights	**Key literature**
Environmental conditions	• Climate change causes the global increase of temperatures and more intense and frequent heatwaves. • The reduction of vegetation due to urbanization processes is resulting in less cooling from evapotranspiration and shade. • The density of particulates emissions exacerbates urban overheating.	(Andrić et al., 2019; Hürlimann et al., 2022; Kuttler, 2008; Reckien et al., 2017)
Social and economic conditions	Heat-related risks are linked with: • social vulnerability: low education level, race, ethnicity; • lower socio-economic status; • social isolation.	(Reckien et al., 2017; Reid et al., 2009)
Individual conditions & vulnerabilities	Heat-related risks are also dependent on person-specific characteristics: • clinical frailty (pre-existing medical conditions) • disabilities • age (elderly and children are more vulnerable to heat stress) • sex (women are usually more intolerant and more exposed to heat)	(Reckien et al., 2017; Reid et al., 2009; Renteria et al., 2022; Rosenthal et al., 2007)
Built-environment	• The excessive built-surface and artificial materials are resulting in high heat storage and emission, and consequently urban heat island (UHI). • Greenhouse gases emissions and anthropogenic heat emissions from industrial processes, transport, and air conditioning also consistently contribute to urban overheating.	(Gelormino et al., 2015; Kuttler, 2008; Maller & Strengers, 2011; Santamouris et al., 2001; Vandentorren et al., 2006)

	• Housing conditions and insulation are associated with heat-related health risks, together with the presence/absence of air conditioning and the use of cooling techniques. • The unequal distribution of green areas and vegetation in cities causes the inequitable distribution of cooler areas with better human comfort conditions.	

3.2.2 NbS contribution

Several studies have proved that green spaces and water surfaces are heat risk-reducing environments, thanks to their ability to cool their immediate surroundings through evaporation and shading (Lee & Maheswaran, 2011; Reckien, et al., 2018). Furthermore, the replacement of impervious surfaces, like asphalt and concrete, by vegetation contributes in reducing the stored heat during the day and the emitted sensible heat during the day and night (Santamouris & Osmond, 2020).

Vegetation at street level plays the major role in mitigating high temperatures. The cooling capacity varies largely among vegetation types such as grass, shrubs and trees, and the maximum effectiveness is reached with urban forests, especially during daytime (Marando et al., 2022; Saaroni et al., 2018; Yoshida et al., 2015). The benefits of urban trees are well known. Multiple studies have analysed the impact from additional tree plantings on the maximum air and surface temperatures, showing a reduction of both parameters (Hall et al., 2012), and a consequent decrease of UHI intensity (Akbari et al., 2001). Indeed, trees influence the urban climate by shading and evapotranspiration. Shading usually produces larger effects over asphalt than permeable surfaces or building walls (Rahman et al., 2020), and in shallow and broader urban canyons (Coutts et al., 2016). Overall, the effect of urban trees on temperatures depends on various factors, including tree canopy size and density, the characteristics of each different trees' species, and the local prevailing meteorological and environmental conditions (Coutts et al., 2016; Y. Wang et al., 2015). Several studies focused on the effectiveness of urban parks in decreasing air temperatures (i.e. the so-called "park cool island") also confirmed the importance of incorporating tree species with an elevated shading potential (i.e. high leaf area index) to improve the thermal comfort conditions during hot periods (R. D. Brown et al., 2015; Saaroni et al., 2018). A recent study conducted on land surface temperature (LST) in 293 European cities confirmed that trees exhibit lower temperatures than continuous urban fabric in most cities, especially in summer and during heatwaves. Compared to build surfaces, LSTs observed for urban trees are on average 0-4 °C and 8-12°C lower, in Southern and Central Europe respectively. The cooling effect of green spaces without trees has been observed to be approximately 2 to 4 times lower than in the presence of trees (Schwaab et al., 2021). With regard to air temperature, an analysis of 29 studies showed that, despite the mitigation potential of trees is highly affected by local landscape and climate conditions, it is possible to identify some thresholds of potential temperature drop in cities (Santamouris & Osmond, 2020).

- The maximum decrease of the average daily peak temperature may not exceed 1.8 °C, even if the tree cover increases up to 100%, and it is close to 0.3 °C for an increase by 20%.
- At night-time, the maximum air temperature drop may not exceed 2.3 °C and is close to 0.5 °C for an increase of tree over of 80% and 20% respectively.
- The increased tree cover might produce a warming effect during night-time up to 2 °C due to the reduction of the re-emitted long-wave radiation.

Building greens also contribute to temperature reduction through evapotranspiration, and to the mitigation of the UHI, although to a more limited extent than vegetation at street level. However, at a building scale, green roofs and walls are an effective passive technique for reducing the heating and cooling energy and improving indoor comfort conditions (Raji et al., 2015). With regard to green façades, a recent systematic literature review has shown that the mitigation effect mainly depends on climate zone and on local conditions. Green façades are more beneficial during daytime, when more people are outdoors (Susca et al., 2022). The benefits provided by green roofs also mainly depend on local climate conditions, typology and design of the green roof, and building characteristics. The cooling potential of green roofs at street level has been found to be much lower than that of urban trees, due to their location several meters above the street (Ng et al., 2012). However, as during daytime roofs are among the hottest surfaces, green roofs greatly contribute in mitigating urban surface temperatures, especially when covering large areas (Norton et al., 2015).

Water bodies can also mitigate high air temperatures by evapotranspiration (ponds and fountains), or by transporting heat away from urban areas (rivers and canals). Larger water bodies provide a cooling effect also by absorbing heat during daytime, thanks to their elevated heat capacity (Aleksandrowicz et al., 2017). However, the cooling benefit provided by water bodies, especially when small in size, is usually limited to their proximity (Jacobs et al., 2020).

Table 11: Overview of the contribution of NbS and key types

	Key insights	Key literature
NbS contributions	Direct contributions: • Reduction of air and surface temperature thanks to evapotranspiration and shading; • UHI mitigation; • Improvement of outdoor human thermal comfort conditions; • Improvement of indoor temperatures and comfort conditions when applied on the building envelope. Indirect contributions: • Contribution to indoor temperatures and building energy consumption as result of air temperature reduction and UHI mitigation; • Positive influence on psychological wellbeing during hot periods; • Reduction of heat-related health issues.	(Schwaab et al., 2021; Susca et al., 2022; Y. Wang et al., 2015) (Akbari et al., 2001; Yoshida et al., 2015)
NbS categories and measures	Most effective in providing cooling: • Urban trees and forests (combined cooling effect of shading and evapotranspiration) Contributing to cooling the urban environment: • Parks, private gardens, community gardens • Forests, wetlands, grasslands ecosystems • Water bodies • Building greens: green roofs and walls	(Coutts et al., 2016; Schwaab et al., 2021; Yoshida et al., 2015) (Aleksandrowicz et al., 2017; Jacobs et al., 2020; Saaroni et al., 2018)

Table 12: Types of action and justice principles

	Key insights	Key literature
(Remove) Protect, Manage, Restore, New	Protect the existing vegetation in urban areas and avoid its replacement with artificial materials and built-up surfaces, to prevent the emergence of new highly overheated urban areas Effectively manage the existing vegetation to maximise the cooling benefits. Importance of irrigation: water-stressed vegetation has higher surface temperature and reduced transpiration Restore the existing vegetated areas (e.g. urban forests or rivers) to contribute in ameliorating the urban microclimate Create new vegetated areas and plant new trees: • prioritising areas highly affected by overheating, and lacking existing greening • based on environmental equity principles: relevance of public investments and policy strategies to reduce the disproportionate health-related impacts on marginalized and vulnerable population • carefully selecting the plant species, based on the required characteristics (e.g. degree of shading, capacity of evapotranspiration, etc.), on the location, and on the local environmental conditions	(Kabisch et al., 2016) (Leuzinger et al., 2010; Norton et al., 2015) (Wallace & Clarkson, 2019) (Norton et al., 2015) (Landry & Chakraborty, 2009; Schwarz et al., 2015) (García-León et al., 2021; Matthews et al.,

	• planning effective management strategies	2015; Tan et al., 2021) (R. F. Young & McPherson, 2013)
Distributive, Procedural	Distributive • Equal access to green areas and heat risk-reducing infrastructure for all the population, especially vulnerable ones • The equal distribution of green spaces should consider not only size, but also proximity and quality • Focus on interventions in areas with high exposure and sensitivity to heat and climate impacts Procedural • Involvement of local stakeholders in spatial planning with consideration of the mitigation and adaptation behaviours of residents • Evaluation of urban planning decisions based on their impact on health	(Feder et al., 2018; Marando et al., 2022) (Kondo et al., 2021; Mashhoodi, 2021)

3.2.3 Interlinkages with other key challenges

There are strong interlinks between thermal justice and the other challenges. Overall, strategies aimed at mitigating urban heat conditions might produce a positive effect (direct or indirect) also on the other justice components.

Thermal and air quality justice are strongly related. On one side, the higher density of particulates emissions is among the major factors causing the increase of temperatures in urban areas and exacerbating heatwaves (Kuttler, 2008). On the other side, studies have proved that air quality is strongly sensitive to extreme meteorological events. Indeed, heat stress can increase concentrations of tropospheric ozone (O_3), and exacerbate the toxicity of most ground-level airborne pollutants such as O_3 and particulate matter (Gordon et al., 2014; Hou & Wu, 2016). Furthermore, the health impacts caused by the simultaneous exposition to heat conditions and air pollution are larger than the effects of weather or air pollution alone, causing a reduction of lung functioning and irritating the respiratory systems, and consequently aggravating cardiopulmonary diseases (Neidell & Kinney, 2010; Zanobetti & Peters, 2015).

Carbon justice and thermal justice are intertwined. Indeed, studies have associated urban warming with a reduction of carbon sequestration by the existing vegetation, especially mature trees, due to constrained photosynthesis and transpiration (Meineke et al., 2016; J. Wang et al., 2021). The contribution to carbon sequestration of NbS used to mitigate urban heat depends on the characteristics of the vegetation species and pervious surfaces

(Velasco et al., 2016), but is also influenced by the land use changes produced by urbanization (Xu et al., 2018).

With regard to spatial justice, the population most vulnerable and with less ability to adapt to the effects of extreme heat generally lives in low-income areas, lacking access to social and economic resources, green spaces, and technological solutions to cope with heat (e.g. air conditioning) (Maller & Strengers, 2011; Reckien et al., 2017). Furthermore, the unequal spatial distribution of heath in cities is evident in the phenomenon of “cool islands”, areas with lower temperatures than the surroundings thanks to the presence of water features and densely vegetated areas (Byrne et al., 2016). Amenities like parks and waterfront locations increase neighbourhood desirability and property prices, and hence are not equally accessible to all urban residents (Reckien, et al., 2018).

Flora and fauna in urban areas are strongly impacted by the increase of temperatures and by UHI and would highly benefit by heat mitigation strategies that are also designed to be flora, fauna and habitat inclusive. Studies have shown that UHI produces impacts on the vegetation growing season unevenly distributed across areas of the same city, with potential harmful cascading effects on urban ecosystems (Kabano et al., 2021; Zipper et al., 2016). It also impacts the body size of urban fauna, and contributes to the fragmentation of urban habitats (Merckx et al., 2018).

Temporal justice is also strictly related to thermal justice, as the frequency, intensity, and duration of heatwaves is expected to increase due to climate change (Schär, 2016). Studies have shown that humans’ and mammals’ adaptation to warming has a robust upper limit, as under certain conditions the dissipation of metabolic heat is no more possible (Sherwood & Huber, 2010). Depending on the trend of global warming, this can strongly affect the future habitability of some regions and cities.

Table 13: Overview interlinkages with other key challenges

	Key insights	Strength and effect	Key literature
Air quality (in-)justice	Air quality and thermal justice are evidently correlated: • higher densities of particulate emissions contribute to increasing air temperatures; • high levels of heat stress decrease the air quality, increasing O_3 concentrations and exacerbating the toxicity of most airborne pollutants; • high temperatures increase the electricity demands, resulting in an increased operation of the power plants, which in turn raises the emission of pollutants	🡅	(Menon & Sharma, 2021; Santamouris, 2020; Ulpiani, 2021)

	The improvement of thermal conditions in cities might contribute to the amelioration of air quality.		
Carbon (in-)justice	• Urban warming is associated with a reduction of carbon sequestration by the existing vegetation. • Urban trees, among the most effective mitigation strategies for urban heat, contribute to carbon storage and sequestration.	🡅	(Meineke et al., 2016; Velasco et al., 2016; Xu et al., 2018)
Spatial (in-)justice	There is a strong association between the spatial distribution of heat exposure in cities, the corresponding levels of biophysical and socioeconomic vulnerability, and the spatial distribution of vegetation.	🡅	(Chakraborty et al., 2019; Santamouris, 2020)
FFH-inclusive	• Flora, fauna and habitats are highly impacted by urban heat stress and UHI. • The presence and creation of green spaces can contribute to flora and fauna richness and diversity.	🡖🡅	(Merckx et al., 2018; Salinitro et al., 2019, 2019; Zipper et al., 2016)
Temporal (in-)justices	• The frequency, intensity, and duration of heatwaves is expected to increase in the future due to climate change, exacerbating thermal inequalities in cities. • During future years, ambient temperature may considerably increase, raising serious concerns about future levels of heat-related mortality.	🡅	(Reckien, et al., 2018; Santamouris, 2020; Schär, 2016)

Note: Strength and effect 🡇: strong negative interlink; 🡖: partial negative interlink; –: no correlation; 🡕: partial positive interlink; 🡅: strong and positive interlink

3.2.4 Basket of indicators

The major indicator of thermal injustices in cities is air temperature, which is also the major indicator of the presence of UHI (Oke, 1982). Furthermore, air temperature is among the most relevant parameters influencing outdoor thermal comfort conditions, as it directly impacts the convective heat exchange between the human body and the outdoor environment, and it indirectly affects the radiative, evaporative, and respiratory heat exchange (Lai et al., 2020). Other relevant environmental parameters characterizing the microclimatic conditions in an urban area include relative humidity, surface temperature, wind speed and direction, shortwave and long-wave radiation.

The evaluation of the effects of the outdoor environment on the human body requires both human and physical parameters. Human parameters include the clothing level and the activity level. The physical parameters mainly refer to the basic variables describing the thermal environment in urban areas: air temperature, wind speed, relative humidity, and long-wave and short-wave solar irradiation. The latter are often summarized in the mean radiant temperature (MRT), an artificial measure introduced to parametrize the effects of the radiation fluxes reaching the human body (Kántor & Unger, 2011). To evaluate the thermal stress on the human body in the urban environment, these variables have been integrated in the calculation of the human thermal comfort indexes. The more common for outdoor conditions are the physiologically equivalent temperature (PET) (Höppe, 1999), the universal thermal climate index (UTCI) (Fiala et al., 2012), and the standard effective temperature (SET) (Gagge et al., 1986).

The spatial distribution of the UHI is also evident at urban level by the variations in the thermal exchange between land surface and lower atmosphere, resulting by the analysis of the distribution of land surface temperature (LST) (Voogt & Oke, 2003).

The urban land use and land cover are also relevant indicators for analysing thermal inequalities, as the effects on land surface temperature have been extensively documented. Indeed, different spatial arrangements of land cover features can significantly contribute in increasing (e.g. cover of buildings) or decreasing (e.g. cover of trees) LST (Zhou et al., 2011). Some indexes might be used to describe the spatial distribution of artificial surfaces and vegetation. These include the normalized difference building index (NDBI), describing the built structure density, and the normalized difference vegetation index (NDVI), related to vegetation abundance (Guha et al., 2018).

Finally, several heat risk/vulnerability indexes have been developed by combining some of the previously discussed indicators (Paranunzio et al., 2021). An example is the Urban Heat Risk Index (UHRI), which includes LST, NDBI and NDVI as variables of analysis (B. C. Mitchell & Chakraborty, 2018).

Table 14: Basket of indicators to appraise NbS thermal (in-) justices potential

Indicator (metric)	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of integration	Spatial mapping potential
Air temperature at pedestrian level (daytime and night-time)	Urban heat island intensity	Vegetation contributes in decreasing air temperature thanks to evapotranspiration and provision of shading.	Distributive	++++	●
Local environmental parameters: Relative humidity;	In combination with air and surface temperature, contribution to human thermal comfort/discomfort conditions	All types of NbS influence urban microclimate	Distributive	++++	●

Solar radiation (shortwave, longwave); Wind speed and direction					
Human thermal comfort indexes: PET; UTCI; SET (MRT)	Heat-related impacts on human body and activities	NbS might contribute in improving human thermal comfort, in particular when applied at street level (trees, urban forests and parks)	Distributive	++++	●
Land surface temperature (daytime and night-time)	Spatial extent and distribution of surface urban heat island Contribution to UHI and human thermal comfort/discomfort	NbS contribute in decreasing surface temperatures both at ground level (all types of NbS) and at the building envelope (green roofs)	Distributive	++++	●
Urban land use: Land Cover; Share of impervious surface; NDVI; NDBI	Higher shares of impervious surface contribute the most to urban heat; Built structure and vegetation also influence the spatial distribution of thermal conditions	Vegetated land cover usually shows lower surface temperatures	Distributive	++++	●
Heat risk/vulnerability indexes UHRI; etc.	Quantification of biophysical factors related to urban heat	Combination of the functionings described in previous lines	Distributive	++	●
Housing conditions: Household sizes; Occupancy rates; Insulation level; Presence of air conditioning	Effect of outdoor air temperatures on indoor conditions and heat-related health risks	Building greens contribute directly; other NbS contribute indirectly by mitigating outdoor conditions	Distributive	+	○

Note: *Level of integration* -: no significant integration; some (+) to very high (++++)
Spatial mapping potential -: no significant mapping potential; ○: some; ●: high

3.3 Carbon (in-)justices

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Carbon justice refers to the responsibility for GHG emissions, accountability for the distribution of the related environmental ills, and considerations on climate change mitigation potential of different ecosystems and their distribution across the city.

3.3.1 Definition

The notion of carbon (in-)justices strongly relates to the distributional frame of climate and energy justice in particular. This includes:

1) The responsibility or accountability for generating greenhouse gas emissions (as environmental ill and especially carbon dioxide emissions) of individuals, population groups, and various sectors in a city and between cities across different countries.

At the urban level this mainly concerns four key greenhouse gas emissions (GHG) (or carbon dioxide equivalent): 1. Carbon dioxide (CO_2), 2. Methane (CH_4), 3. Nitrous oxide (NO_2) and 4. Sulphur hexafluoride (SF_6). Energy (electricity and heating), industrial processes and product use, residential, transportation, waste and agriculture are the key sources of these GHG emissions. According to Marcotullio et al. (2013), in European cities the share of GHG emissions ranges between 45 and 55 per cent of total regional GHG emissions (including EU 27 as well as United Kingdom, Russia, Ukraine or Serbia and Montenegro). The energy industry (electricity and heating) is the largest contributor, ranging between 57-65%, followed by transportation (13-16%), industry (10-12%) and residential areas (9-11%). Agriculture and waste seem to play a minor role, though overall agricultural GHG emissions increase with distance from a city. High urban per capita emitters are described to occur in Eastern European cities in particular.

Questions of the distributional responsibility for GHG emissions are part of discussions and research on carbon inequality, not only in terms of who contributes the most (i.e. carbon footprint) but also who suffers the consequences of a resulting changing climate. At the global level and linked to questions of global income, this refers to the '*historical responsibility of a small number of developed countries for most of the cumulative greenhouse gas emissions*' (Hubacek et al., 2017), whereas impacts mostly occur in developing countries (e.g. small islands countries).

Based on work by the World Inequality Lab, an assessment of the global inequality of carbon emissions (CO_2equiv.) indicates that in 2019 the top 1% of emitters emitted on average 110 tonnes per capita (overall share: 17%), followed by the top 10% of emitters with on average 31 tonnes (overall share: 48%), whereas the bottom 50% emitted on average 1.6 tonnes (overall share: 12%)(Chancel, 2021). While in particular in many income rich countries carbon emissions per capita of the bottom 50% have even fallen between 1990 and 2019, they have increased faster for the top 1% than for any other group. Moreover, income and wealth inequality within countries becomes increasingly a driver of carbon inequality (Chancel, 2021; Gore, 2021).

Therefore, not surprisingly, one key area of research refers to the analysis of carbon inequalities within countries and carbon inequalities of households in particular, closely connected to research on income and wealth inequality, though also taking into consideration other socio-economic conditions. Although studies suggest strong correlations between urban CO_2 emissions and population size (positive), population density (negative) and economic growth rates (positive) (Marcotullio et al., 2013), the income effect, referring to the assumed correlation between income and emissions, seems to be less clear or more nuanced than might be assumed. A main reason are methodological limits related to CO_2 data repositories and urban allocations of emissions (e.g. due to energy production for heating and cooling occurring outside city boundaries). Some suggest to further look into variables such as the personal purchasing power, as an additional proxy indicator for GHG emissions embodied in the consumption of goods and services (Baur, Lauf, et al., 2015). These additional indirect emissions (e.g. from so-called 'embodied' energy used for the production of cement for buildings) can be significant. However, it is also argued that increased income not necessarily results into defined consumption expenditures, which can be translated into higher CO_2 emissions (Büchs & Schnepf, 2013). For example, higher income might have the effect of increased investment into higher quality, long-term products with high energy efficiency. At the same time, it cannot be assumed that this automatically occurs or that this does not result into a rebound effect, i.e. the increased energy efficiency of products is offset by increased or changing consumption patterns and lifestyles. However, it is suggested that smaller household size linked to low population density (and higher average dwelling area) more significantly correlates with higher CO_2 emissions, though also depending on electricity CO_2 intensity (CO_2eq emissions per electricity production) (Balezentis, 2020; Baur, Lauf, et al., 2015).

A comparison of the role of a range of household characteristics, including income, household size, age, worklessness, gender, education and rural/urban location, across home energy, transport, indirect and total household CO_2 emissions sheds some further light on the subject (Büchs & Schnepf, 2013). Study results indicate that in particular transport emissions are more positively correlated with increased income, though it also seems to lead to a general increase of home energy emissions. In relation to home energy emissions, economies of scale seem to play out in relation to household size, albeit especially older, workless or female-headed households have significantly larger home energy emissions, but lower transport emissions. This is also affected by the presence of children, in particular of younger age. What seems however to be clear is that a high education level is positively associated with higher emissions in all of the analysed areas (i.e. home, transport, indirect and total household)(Büchs & Schnepf, 2013).

A comparison of carbon inequalities or the distribution of carbon emissions between urban households and the urban economy (e.g. associated transport emissions) has not occurred in any detail, beyond comparisons of the residential and other sectors. Moreover, no direct comparison of carbon inequalities of households and suffered consequences was found, beyond linking aspects of socio-economic status to increased exposure to environmental ills caused by a changing climate (see for example Chapter 3.2 on thermal in-justices).

Table 15: Specific conditions driving carbon (in-) justices

	Key insights	Key literature
Environmental conditions	• Links to the responsibility for the generation of urban greenhouse gas emissions (carbon dioxide emissions equiv.) of individuals, population groups, various sectors, countries and regions. • This in particular refers to four key GHG emissions (CO_2, CH_4, NO_2 and SF_6), across key sectors such as energy, industrial processes, transportation and residential. • The placing of defined land use and land use cover (LULC) classes such as green urban areas in a defined distance from high density areas such as the city centre correlates with higher GHG emissions, as do larger shares of urban green areas linked to a reduced density and assumed higher transport emissions. This does not account for the climate mitigation potential of urban green areas.	(Baur, Förster, et al., 2015; Marcotullio et al., 2013)
Social and economic conditions	• Urban GHG emissions are significantly associated with higher population size, lower density, higher growth rates, and per capita income. • The household income effect is more nuanced than might be expected, being more strongly correlated with transport CO_2 emissions. However, this is also strongly impacted by methodological aspects. The correlation between high education and high GHG emissions in different areas, e.g. both home and transport is better established.	(Büchs & Schnepf, 2013; Marcotullio et al., 2013)

Individual conditions & vulnerabilities	The presence of children seems to increase GHG emissions of households, mostly in relation to home energy use, especially when children of younger age are present. Older, workless or female-headed households are suggested having significantly larger home related GHG emissions, though significantly lower transport emissions compared to their counterparts.	(Büchs & Schnepf, 2013)
Built-environment	Analyses of spatial drivers of greenhouse gas emissions in an urban context conclude that in particular parameters defining a discontinuous very low density urban fabric (with low degree of soil sealing, and mostly vegetated areas) have a strong impact, correlated with small household size and low population density.	(Baur, Förster, et al., 2015; Baur, Lauf, et al., 2015)

A modelling study suggests that spatial properties and land use and land use cover parameters (LULC) defining the density of the urban fabric linked degree of soil sealing, residential buildings typology, roads and vegetated areas, are strongly connected with urban greenhouse gas emissions. A low degree of soil sealing, small household sizes rather than large average residential buildings and a larger extent of vegetated areas parcels (i.e. discontinuous very low density urban fabric) is associated with higher urban GHG emissions in an analysis of 44 European cities (Baur, Lauf, et al., 2015). The study accounted for direct GHG emissions, related to energy, transport and buildings, rather than indirect emissions (e.g. service sector). However, also not included are indirect effects resulting from increased or reduced energy consumption related to cooling and heating due to changing (micro-) climatic conditions, and also related socio-economic (e.g. segregation) and environmental (e.g. precipitation and flooding control) impacts.

Analysis of the role of LULC classes (e.g. from built-up areas to parks and forests, etc.) and indicators (e.g. LULC hotspots, maximum extent from city centre, etc.) in 52 European cities, indicates that the increase of GHG emissions per capita is also correlated with the distance of urban green residential areas from the city centre, due to increased transport emissions (Baur, Förster, et al., 2015). It also suggests that larger sizes of urban green areas (e.g. forests, landscape parks or water bodies) link to higher GHG emissions per capita, as breaking up denser urban fabrics. However, the study does not make comparisons with other factors such as induced transport mission correlated with recreation in neighbouring landscapes. Moreover, it indicates that a further reason could be the failed accounting of their GHG emission reducing effect in urban inventories.

Thus, it is important to link the notion of carbon (in-)justices also to:

2) Considerations of the climate change mitigation potential (direct and indirect) of different ecosystems, at global level, within countries and as regards their distribution across a city, and
3) Capacity and duty to bear mitigation costs, linked to the question of accountability for contributing to GHG emissions drivers.

The latter refers to the application of the polluter pays principle linked to 'own choices', but also taking into due consideration *"potential 'needs' for emissions that do not arise from someone's own choice but from 'structural' circumstances"* (Büchs & Schnepf, 2013). This for example relates to (micro-)climatic and housing conditions, as well as socio-economic factors (e.g. household structures).

Mostly, these aspects have been explored at global level, especially in relation to so called natural climate solutions, referring to the measures that support the net removal of GHGs by capturing and storing them in living and dead organic material (IPCC, 2022b). However, in relation to some activities, such as on the expansion of forests (afforestation, reforestation or planting of trees) to mitigate climate change, this has raised some concerns, to the disadvantage of nature restoration more generally (IPCC, 2022b). At global level, it regards e.g. the offsetting of carbon emissions by developed countries in developing countries, rather than phasing out fossil fuels, to the detriment of native and biologically diverse ecosystems and use of resources by indigenous communities (Seddon et al., 2021). How this relates to NbS contributions to climate (in-) justices in an urban context is further explored in the following chapter.

3.3.2 NbS contribution

The mitigation potential of NbS involves the protection, sustainable management, and restoration of natural or modified ecosystems, and the reduction of GHG emissions through the conservation and expansions of carbon sinks, i.e. natural deposits that absorb carbon from the atmosphere (IPCC, 2022a). Protecting intact ecosystems such as forests, wetlands, grasslands, and restoring native vegetation cover enhances CO_2 removal from the atmosphere. Furthermore, improving the management of specific habitats can significantly reduce CO_2 release and increase carbon sequestration potential. Terrestrial ecosystems currently sequester 29% of annual anthropogenic CO_2 emissions; hence, conservation of existing intact habitats is essential to ensure the protection and permanence of important existing carbon stocks (Kopsieker, L., et al., 2021).

Girardin et al. (2021) estimate that the most significant contribution for cost-effective avoided CO_2 emissions comes from protecting natural intact forests, wetlands and grassland (4 Gt CO_2 year^{-1}), while restoring native forests and wetlands could contribute to avoid emissions for 2 Gt CO_2 year^{-1}, out of a total of 10 Gt CO_2 year^{-1} attributed to NbS. Protection is more efficient in terms of carbon storage potential as restored habitats may require over a decade to re-establish carbon cycling, and their carbon storage and sequestration potential may not be fully re-established (Kopsieker, L., et al., 2021).

If there is now general consensus on the role of green and blue infrastructures for climate change adaptation in cities, the potential of NbS to mitigate GHG emissions in urban context is more controversial. Urban green infrastructure in cities, including street trees, parks, green roofs or green walls and vertical forests, can contribute to carbon sequestration in above- and below-ground biomass and soil (see Box 6).

Given the role of cities in carbon dioxide emissions, many attempts have been made in order to quantify and understand the role of conserving or increasing carbon stored within different type of urban vegetation in offsetting CO_2 emissions (Zhao et al., 2016). Urban trees and forests are a key NbS in terms of mitigation potential, due to their capacity to store relatively high amount of carbon compared to other types of urban vegetation (IPCC, 2022a). According to the IPCC estimations (IPCC, 2022a), given 363 million hectares of urban land, urban tree cover averages globally 26.5%, storing approximately 7.4 billion tonnes of carbon. The estimated global annual carbon sequestration by urban trees is approximately 217 million tonnes (MtC) given an average carbon sequestration density per unit of urban tree cover of 0.226 KgC/m^2.

Nonetheless, some research has tried to investigate the role of other vegetation types in GHG mitigation in cities. Several studies have been conducted in order to evaluate the impact of green roofs, affirming that these NbS can form part of a strategy to reduce carbon content in urban air though largely depending on extent, climate and substrate and in particular linked to energy savings (Shafique et al., 2020). Ariluoma et al. (2021) estimated the carbon sequestration potential of residential yards showing how, despite the limited amount of carbon per single unit, scaled-up at the city level such measures may provide a significant contribution to climate change mitigation targets, highlighting also the role of urban planning to encourage tree planting and ensure growing conditions. Urban agricultural and allotments in cities can store and sequester a consistent amount of carbon over time due to plant activity and carbon content in soils. Moreover, allotments soils in cities have shown higher concentration of nutrients, including soil organic carbon, carbon to nitrogen ratios and total nitrogen than arable soils, indicating that small scale urban food production does not necessarily produces degradation (Thornbush, 2015).

Box 6: Mitigation potential of Soil Organic Carbon (SOC)

Globally, soils hold three times more **carbon** than the atmosphere. SOC has a role in climate mitigation through both conserving existing stocks and restoring stocks in carbon depleted soils.

Protection is particularly important because SOC is lost more quickly than it can be gained and, in some cases, it is not possible to restore SOC to the original levels on climate relevant timescales. The historical loss of carbon has been quantified by Sanderman et al. (2017). They estimate a **global carbon debt** due to agriculture of 133 Pg C for the top 2 m of soil, with the rate of loss increasing dramatically in the past 200 years; they also highlight the threat of future accelerated loss under **warming scenarios**.

The contribution of protection and restoration actions of SOC has been **quantified** by Bossio et al. (2020) as 25% of the potential of natural climate solutions (23.8 Gt of CO_2 equivalent per year), which include conservation, restoration and improved land-management actions, including reforestation, planting trees in croplands, grazing land management, peatland protection and others.

In forest ecosystems, the SOC mitigation potential is estimated to be 1.2 $GtCO_2$ e yr^{-1} (9% of the total); in wetlands, 2.0 Gt CO_2e yr^{-1} (72% of the total mitigation potential of wetland pathways). For agriculture and grasslands, 2.3 Gt CO_2e yr^{-1} (47%) is estimated to arise from SOC protection and sequestration, and 20% involves others GHGs involved with improved soil management practices.

Estimating the total contribution of different types of urban vegetation, some studies show that these can store an underestimated amount of carbon (Davies et al., 2011) and in some arid regions even more carbon than adjacent and rural areas (McHale et al., 2009). However, some regional or city-specific assessments of NbS mitigation potential also show a limited mitigation effects of direct net carbon sequestration (Nowak & Crane, 2002; (Barò & Gómez-Baggethun, 2017). Furthermore, the overall mitigation potential of NbS in cities is assessed as rather small compared to the overall emissions from cities (Reise et al., 2022; Strohbach & Haase, 2012). Therefore, the critical issue often raised in the context of mitigation potential of NbS remains the risk of deflecting attention from the need to rapidly phase out of fossil fuels and reduce carbon emissions (Seddon et al., 2020, Girardin et al., 2021).

Beside forests ecosystems, other ecosystems such as wetlands and grassland have a critical role in GHG mitigation. When in good conditions, wetlands provide many societal benefits and, due to their capacities to limit the availability of oxygen to soil microbes and decomposition of organic matter, they play a critical role in the carbon cycle (Malak et al., 2021). Despite the wide variety of ecosystem services provided by wetland in urban area (cooling effects, habitat for wildlife, recreational services, water quality improvement, mitigation to climate change), urban wetlands are usually not included more widely in urban planning decisions beyond the restoration of rivers and streams (Alikhani et al., 2021).

NbS in cities, through tree shading, green roofs and walls, offer a great potential to indirectly mitigate GHG emissions at building level, saving energy and consequently reducing the long-term fossil fuel consumptions (IPCC, 2022b). The energy saving potential of trees is a function of climate: in hot climates, deciduous trees shading a building can save cooling-energy use, in cold climates evergreen trees shielding the building from the cold winter wind can save heating-energy use (Akbari et al., 2001). Green roofs can mitigate air and surface temperature, while lowering the energy demand of buildings. Green roofs show to be more energy efficient than black roofs in all climates, reaching a maximum energy savings of 84 per cent in the cooling season though depending on the scale of implementation. The cooling effect can also lead to an increase of PV performance by a maximum average of 3,35 % (Manso et al., 2021). The potential of saving energy from air conditioning by green facades has been analysed in several climates: the use of a single green façade facing west in tropical climates resulted in 8-13% of the cooling load reduction and 20.5% for green walls covering the whole buildings; in oceanic and Mediterranean climates the energy demand of buildings with green walls on the east and west facades were found to be respectively 50.6% and 37.3% of the reference building energy demand (Charoenkit & Yiemwattana, 2016). Besides local climate conditions, the energy saving potential depends on several factors such as the system characteristics (e.g., substrate type, depth, moisture content) and building physical characteristics, e.g. height, insulation, building envelope, solar orientation, shading (Manso et al., 2021) and the orientation of the green walls have a particularly strong effect on energy performance (Charoenkit & Yiemwattana, 2016).

Another indirect effect of NbS on GHG emissions can be achieved by facilitating active mobility (IPCC, 2022b). Providing connected system of greenspace through the urban area may promote active transportation thereby reducing GHG emissions. Changes in urban landscapes, including the integration of green infrastructure in sustainable urban and transport planning, can support the transition from private motorized transportation to public and physically active transportation (IPCC, 2022b). Although there is no evidence of relation between improved connectivity for cycling and emissions reduction, there is evidence of increase in the cyclists' number in relation to the improvement of cycling infrastructure and bike-sharing systems (Félix et al., 2020), and in declining of the cost of cycling (Vedel et al., 2017). According to estimates given by the IPCC (2022b), the mitigation impacts of active travel can include a reduction of mobility-related lifecycle CO_2 emissions by about 0.5 tonnes per capita over a year when an average person cycles one trip per day more, and drives one trip per day less in a car, for 200 days a year.

Table 16: Overview of the contribution of NbS and key types

	Key insights	Key literature
NbS contribution	Contribution of NbS to carbon removal/reduction • Direct contribution - Intact ecosystems such as forests, wetlands and grassland remove carbon from the atmosphere. - Urban trees in particular but also other types of NbS in cities can store and sequester carbon while providing other ecosystem services (cultural and social interaction opportunities, social cohesion and sense of community, air quality improvement, energy consumptions reduction in building, food productions from urban agricultural NbS) • Indirect contribution: - Green roofs and green facades provide co-benefits improving air quality and reducing energy consumption on a building scale. - Providing a connected system of greenspace, integrating green infrastructure in sustainable urban and transport systems promotes active transportation supporting the transition to carbon neutral transportation systems, thereby reducing GHG emissions	(Girardin et al., 2021) (Thornbush, 2015) (Whittinghill et al. 2015); (Shafique et al., 2020) Ariluoma et al. (2021) (Charoenkit & Yiemwattana, 2016). (Manso et al., 2021) (IPCC, 2022a)
NbS categories and measures	• Forests, wetlands, grasslands ecosystems • Urban trees, parks, private gardens, community gardens • Green roofs and walls • Green networks, green corridors	

Table 17: Types of action and justice principles

	Key insights	Key literature
(Remove) Protect, Manage, Restore, New	• Protect intact forests, wetlands and grassland ecosystems is the most efficient measure in terms of carbon storage potential compared to ecosystem restoration (which may require long time or even not fully be re-established in their carbon sequestration potential), and new tree planting • Instead of planting new trees for carbon one should give priority to protection and restoration of existing ecosystems • Proper ecosystem management (grassland, urban forests, urban wetlands as well as urban soils) can reduce CO2 release and improves carbon sequestration potential as well as restoring native vegetation cover • Measures to remove carbon from the atmosphere or reduce release from the ecosystems must not be seen as substitute of measures for rapid fossil fuel emissions reduction • Planting new trees for carbon must take account of a series of aspects: - Biodiversity enrichment and planting of the most adapted trees in the right places where both climate and soil are suitable for the selected specie and in order to guarantee the balance of ecosystem functions - Guaranteeing the long lifespan of new trees - Possible trade-offs between diverse ecosystem services, e.g. carbon sequestration and biodiversity (protecting or	(Girardin et al., 2021) Kopsieker et al., 2021 Shafique et al., 2020 Reise et al., 2022 Liu and Slik, 2022

	restoring ecosystems may even require the removal of trees)	
Distributive, Procedural	Distributive: "The everyday governance of energy (or lack thereof) shapes matters of distributive justice." • Ensuring availability of low-carbon transitions to all people, providing energy to those living in poverty (energy access); • Supplying energy in a regular, fair and predictable manner (energy security); • Minimizing the environmental externalities and unequal burdens of energy extraction, provision and consumption (energy and climate justice) Procedural: Including a wide range of stakeholders in decision regarding low-carbon transitions	(Newell & Mulvaney, 2013)

3.3.3 Interlinkages with other key challenges

This section highlights the synergies and trade-offs between carbon justices and other challenges.

The relation between carbon justice and air quality justice is quite strong, since mitigation strategies aiming to reduce GHG emissions have, with few exceptions, a direct effect on other air pollutants emissions sources. However, trade-offs between carbon and air quality justice might exist considering different strategies. For example, planting trees for carbon sequestration might have positive as well as negative effects on air quality, depending on design of solutions and vegetation choice. Indeed, the effect of urban vegetation on air quality can be complex and depends on the level of pollution of a certain area. Indeed, roadside urban vegetation might lead to increased pollutants concentrations due to the reduced ventilation responsible for diluting the traffic emitted pollutants (Vos et al., 2013). Furthermore, air quality improvement would require low and/or close to surface vegetation (Janhäll, 2015), while the age of trees is an essential parameter for carbon sequestration, and mature trees with higher crowns will capture more carbon than other type of vegetation.

The relation with thermal justice is also particularly strong; some specific identified drivers of carbon injustices have been proven to be related to thermal justice issues as well. Synergies in mitigation measures can also be identified in tree planting, green roof and walls, their indirect impact on outdoor and indoor thermal comfort and their contribution to reduce urban heat island effect (Mutani & Todeschi, 2020).

Some spatial justice drivers such as the higher level of availability for some part of population to green spaces (especially private gardens), are often associated with urban sprawl, i.e., the expansion of peri-urban areas and urban development patterns characterized by low-density residential areas, which are associated with higher level of

GHG emissions. Distance from certain LULC types and a low level of LULC diversification are also related to higher GHG emissions due to the need to travel longer to meet certain needs, whereas more patchy urban LULC structure and the reduced travel distances could incentivize more low-carbon transport such as walking or cycling.

Relation between carbon justice and flora, fauna and habitat inclusion present some element of discussion. Low density urban areas, associated with higher level of GHG emissions, are also associated with higher diversity of habitats.
Furthermore, higher socioeconomic status, associated with household consumption pattern with higher carbon footprint, are also correlated with higher biodiversity (luxury effect), resulting from the creation and maintenance of private and public green spaces. The luxury effect is however symptom of unequally distribution of urban biodiversity benefits (Leong et al., 2018). Important considerations are also needed concerning mitigation measures and potential trade-offs occurring between tree planting for carbon storage and sequestration, and ecosystem restoration needs. In some cases, habitat restoration may involve a decision between managing land for carbon or enhancing biodiversity. Trade-offs and synergies between these two justice components provide some key insights regarding type of actions to be taken when implementing NbS for mitigation purposes. In these cases, a strategic integrated approach at the landscape level is critical.

Strong interlinkages can be found also in relation to temporal justice, as GHG emissions have long lifetime with intergenerational effects. Moreover, the emissions occurring in the past affect current generations just as the current emissions will affect future generations, with disproportionate effects on vulnerable populations. Long lifespan of mitigation strategies and long-term monitoring is thus essential to ensure the long-term carbon sinks potential of ecosystems and urban NbS implemented. Path dependency (outcomes based on past paths rather than present conditions) and carbon lock-ins (reinforcing inertia to a low carbon transition) (see Chapter 3.6 on temporal justice) present in cities constitute an obstacle to GHG emissions reductions; the historical development of urban areas and the interrelation between urban infrastructure, technology and behavioural systems create inertia and path dependency that are difficult to break (IPCC, 2022b).

Table 18: Overview interlinkages with other key challenges

	Key insights	**Strength and effect**	**Key literature**
Air quality (in-)justice	• Quite strong relation: mitigation strategies aiming to reduce GHG emissions have a direct effect on other air pollutants emissions sources • Trade-offs may exist:	↘↑	Vos et al., 2013 Janhäll, 2015

	Planting trees for carbon might have negative effects on air quality (e.g. reduced air flows), depending on design of solutions and choice of vegetation		
Thermal (in-)justice	• Some drivers of carbon injustices have been proven to be positively correlated to thermal justice (e.g., the most densely and heavily built urban structure types are associated with higher surface temperature and higher GHG emissions). • Synergies in mitigation measures can be also identified: tree planting, green roof and walls and their indirect impact on outdoor and indoor thermal comfort contribute to reduce the urban heat island effect	🡑	Weber et al 2014 in Baur et al 2015 Mutani and Todeschi, 2020
Spatial (in-)justice	• Urban density, intra-urban distances and LULC compositions influence GHG emissions per capita • Sprawling urban patterns are highly correlated to GHG emissions; • Distance from certain LULC also matters, due to the need to travel longer to meet certain needs. • A more patchy urban LULC structure and the reduced travel distances are correlated to lower GHG emissions and could incentivize more low-carbon transport such as walking or cycling.	🡓🡑	Baur and Forster, 2015
FFH inclusion	• Low density urban areas, associated with higher level of GHG emissions, are also associated with higher diversity of habitats • Higher socioeconomic status, associated with household consumption patterns with higher carbon footprint, is also correlated with higher biodiversity, resulting from the creation and maintenance of private and public green spaces (Luxury effect) • Potential trade-offs can occur between tree planting for carbon sequestration and ecosystem restoration needs	🡓🡕	Leong et al., 2018
Temporal (in-)justice	• GHG emissions have a long lifetime with intergenerational effects • Path dependency and carbon lock-ins present in cities constitute an obstacle to GHG emission reduction • Long lifespan of mitigation strategies and long-term monitoring is essential to ensure the long-term carbon sinks potential of ecosystems and urban NbS implemented	🡓🡕	IPCC, 2022

Note: Strength and effect 🡓: strong negative interlink; 🡖: partial negative interlink; –: no correlation; 🡕: partial positive interlink; 🡑: strong and positive interlink

3.3.4 Basket of indicators

The previously outlined analyses provide important insights into the complexity of the endeavour to clearly allocate the generation of GHG emissions to cities, neighbourhoods, households, or defined population groups. The difficulty increases when also accountability is considered, i.e. who is to be hold into account regarding decisions or behaviours that drive GHG emissions, due to own choices (applying the polluter pays principle) or emission needs linked to structural circumstances.

The following basket of indicators provides an overview of what might be useful to map or strategically assess NbS potentials in relation to carbon (in-justices) at different scales, regarding the distribution in the generation of GHG emissions as well as the climate mitigation potential of defined types of NbS. This refers to storage (i.e. carbon accumulated over a longer period), sequestration (i.e. changes in the carbon stored over one growth season) as well as avoided GHG emissions (e.g. due to cooling effect). It is suggested to create sub-baskets of indicators or clusters that refer to key aspects of the carbon (in-)justices definition, to define:

1. Low carbon/ high carbon generation zones or sites.
2. Low carbon / high carbon mitigation zones or sites.

These clusters can be composed by different sets of indicators defining low carbon / high carbon zones, in relation to those describing the status quo (and setting up GHG emission inventories) to those indicating key drivers, responsibilities and potential accountabilities in relation to NbS contributions.

Low carbon/ high carbon generation zones or sites

In order to localize low carbon/high carbon generation zones the focus goes on carbon footprint estimation within the city. Different approaches are used for carbon accounting at different scales. At national and regional level, carbon accounting methods usually focus on sources of emissions. These refer to the production-based carbon accounting approach and are consistent with the territorial-based approach proposed by the IPCC, which accounts for in-boundary carbon emissions.

Consumption-based carbon accounting methods are evolving to move beyond in-boundary carbon emissions and evaluate the trans-boundary lifecycle emissions of all goods and services linked to consumption patterns. Consumption-based methods allow accounting not only for direct emissions, but also for indirect emissions, i.e. those embodied in transportation, household energy, food, goods and services, providing information on carbon footprint related to households' consumption patterns. Several methods are used to quantify the households' emissions, based on statistical knowledge about the characteristics of the residents within a certain area. Aggregating such data at neighbourhood level would provide key spatially located information for decision about mitigation actions. Consumption-based perspectives are however, severely limited by the availability of data and uncertainties of the methods used (G. Chen et al., 2019).

Other methods have been used to provide spatial information on high or low carbon emissions generation areas, accounting for some key drivers of emissions occurring within a city. Neighbourhood characteristics, e.g. population size, population density, dwelling area, can provide a preliminary spatial location of emissions. Indeed, several households' characteristics have been found to play a role in carbon emissions, such as household size, income, location. The aggregation at neighbourhood level allows to decompose the household carbon footprint's drivers like neighbourhood walkability, home size, vehicle type. On this basis, the intersections between social and demographic factors, emissions drivers, and exposure and explore how these relate to social inequalities can be analysed.

Table 19: Basket of indicators to appraise NbS carbon (in-) justices potential

Indicator (metric)	**Drivers of (in-) justices**	**NbS contribution**	**Justice Dimension**	**Level of integration**	**Spatial mapping potential**
Cluster low carbon / high carbon generation zones or sites					
Carbon emissions due to building cooling/heating tCO_2eq/y	Provide information on location of buildings with higher level of C emissions	Indirect contribution	Distribution	+++	○
Carbon emissions from vehicle traffic t C/y	Provide information on areas within the city with higher level of C emissions	Indirect contribution	Distribution	+++	○
Household size	Proxy indicators of emissions related to consumption patterns	Indirect contribution	Distribution	++	●
Household income	Proxy indicators of emissions related to consumption patterns	Indirect contribution	Distribution	++	○
Dwelling ownership	Determines energy saving potentials & avoided emissions	Indirect contribution	Distribution Procedural	++	○
Walkability index	Indicator of connectivity and potential for avoided emissions	Key focus on green networks	Distribution	+++	●
Number of cars per 1000 inhabitants	Drivers of low/high carbon emissions related to transportation	Key focus on green networks	Distribution	-	-

Proportion of people living near public transport (%)	Determines energy saving potentials & avoided emissions through improved connectivity	Key focus on green networks	Distribution	+	●
Coverage of bicycle lanes (%)	Determines energy saving potentials & avoided emissions through improved connectivity	Key focus on green networks	Distribution	++	●
Building age/construction year	Determines energy saving potentials & avoided emissions	Key focus on urban trees, as well as green roofs and walls	Distribution	-	●
Population density	Determines energy saving potentials & avoided emissions	Key focus on urban trees	Distribution	-	●
Cluster low carbon / high carbon mitigation zones or sites					
Above -ground biomass carbon density (Mg carbon per hectare)	Determines capacity of carbon mitigation based on carbon storage and sequestration	Key focus on urban forests & trees, and to some extent herbaceous & woody vegetation on a city-wide scale	Distribution	+	○ (associated with land use/cover classes or defined parcels, e.g. green roofs)
Below-ground biomass carbon density (Kg per square meter)	Determines capacity of carbon mitigation, also linked to aspects of water retention or nutrient conservation	Key focus on herbaceous & woody vegetation on a city-wide scale	Distribution	+	○ (associated with land use/cover classes or defined parcels, e.g. green roofs)
Soil sealing (%)	Proxy indicator to determine soil climate mitigation potential	Key focus on defined land use/cover classes and degree of pervious surfaces	Distribution	+++	○ (associated with land use/cover classes)
Urban tree inventory (age, species, stem size)	Determines capacity of carbon mitigation	Urban forest and trees, also to determine low carbon densities	Distribution	++	○ (often limited to location and species)
Urban tree canopy (carbon density) (kg carbon per square meter canopy cover)	Determines capacity of carbon mitigation based on carbon storage and	Key focus on urban forests & trees not only to determine low carbon densities	Distribution	++	●

	sequestration + avoided emissions	but also avoided emissions			
Land cover ownership (public/ private/ mixed/other)	Determines capacity of carbon mitigation based on carbon storage and sequestration + avoided emissions	Key focus on the roles of privately owned & managed land versus publicly owned and managed land	Distributional, Procedural	+	●

Note: *Level of integration* -: no significant integration; some (+) to very high (++++)
Spatial mapping potential -: no significant mapping potential; O: some; ●: high

Low carbon / high carbon mitigation zones or sites

When it comes to defining low carbon / high carbon mitigation zones or sites, indicators applied to determine the so-called carbon densities come into play, and they often combine different methods to assess:

- Amount of carbon stored/sequestered within above-ground vegetation
- Amount of carbon stored/sequestered within below-ground biomass
- Avoided emissions from energy savings

To determine carbon stored and sequestered in above-ground vegetation, for many years the "stratify and multiply" approach has been commonly used (Spawn et al., 2020), though only more recently increased attention has been paid to cities (see Box 7) (Strohbach & Haase, 2012).

Box 7: NbS Carbon mitigation potential in cities – Some numbers

An analysis of above-ground carbon storage by urban trees in Leipzig (DE) estimated a carbon storage of 316,000 Mg Carbon based on an average of 11 Mg C per ha (Strohbach & Haase, 2012). The latter is based on per ha values of different land cover classes, ranging from single and semi-detached houses (14 Mg C per ha) to multi-story houses (4 Mg C per ha), small woodland (80 Mg C per ha) and riparian forest (highest with nearly 100 Mg C per ha). Interesting is the difficulty to assess some private land cover classes (e.g. gardens) due to failed access for field sampling.

In another study in the US, an average urban tree canopy storage density of 11.8 t C (or Mg) per ha has been estimated based on an analysis in the cities of Los Angeles and Sacramento (McPherson et al. 2013). Average sequestration values amounted to 0.68 t C per ha and year and avoided emissions to 0.44 t C per ha and year.

In an analysis of urban greenspace land-cover effects on soil organic carbon in Leicester (UK) (Edmondson et al., 2014), an average storage of 9.9 kg per square meters was calculated for 21 cm depth, being highest in domestic gardens (13.5 kg per square meters) and lowest in arable land (7.7 kg per square meters). It suggests that urban expansion into intensively managed agricultural land might actually improve soil organic carbon stock, though might be heavily negative if expanding e.g. into moorland.

It assigns specific biomass estimates or 'standards' to defined land use cover classes (e.g. semi-detached houses area in ha). This can be either based on literature reviews, build on an existing urban tree inventory or obtained by field sampling. A more comprehensively elaborated urban tree inventory (e.g. location, species, age and stem size) can be useful for integrating carbon (in-)justices dimension considerations with air quality (e.g. air cleansing and air flow) and thermal (in-)justices dimensions (e.g. cooling effect). The field sampling includes the identification of defined plots for defined land cover classes to determine e.g. urban tree age, stem size (diameter at breast height) and species. This allows a more robust assessment, which beyond socio-economic and spatial attributes takes some specific ecological conditions into account when adopting a transfer function, i.e. transferring values from a 'study site' to a 'policy site' (Kettunen et al., 2013; McPherson et al., 2013; Strohbach & Haase, 2012). Belowground carbon density is often just roughly estimated by assuming a defined root biomass as percentage of aboveground biomass (e.g. 25%), with soil organic carbon under trees assumed to be higher than under shrubs or grasslands. However, recently more precise 'root-to-shoot' estimates have been produced (Spawn et al., 2020), e.g. based on soil sampling (Edmondson et al., 2014), given the risk of otherwise immensely under- or overestimating soil organic carbon stocks of defined natural elements also in cities, due to the dynamics of soil organic carbon storage and sequestration e.g. linked to land use and management, restricted root space, water availability or soil compaction (Bossio et al., 2020). Especially in relation to the latter issues of land ownership, both for long-term above and below-ground carbon storage land ownership status (e.g. privately owned and managed land versus publicly owned and managed land) becomes crucial, to asses responsibilities as well as accountability aspects (Davies et al., 2011).

Another approach consist of using status and changes of urban tree canopy abundance to estimate the carbon stored in the vegetation, and determined by urban tree age, stand density, managements practices as well as neighbourhood age and land use (McPherson et al., 2013). Based on remote sensing data, it provides information on the layer covered by leaves, branches and stems and is used to assess the carbon stored within, but also to calculate avoided emissions. Combining it with information on location, building age classes and assuming defined tree effects on wind speed and evapotranspiration, this information can be used to calculate annual heating and cooling energy effects (t CO2eq. per year) in dependence of population and building density and counting for multiple tree impacts (McPherson et al., 2013). Results have shown that avoided emissions are highest in correlation with high population and building density. Impacts from improved energy efficiency of cooling devices and renewable energy technologies (e.g. PV) have however not been accounted for.

Especially in relation to current greenhouse gas emissions accounting, it needs to be noted that the existing frameworks such as suggested under the UN Framework Convention on Climate Change (UNFCC) focus on capturing flows between sources and sinks and resulting from human activities. Also the more extended UN System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA-EEA) used to over-emphasise the ecosystem service of carbon sequestration, as a 'positive net carbon balance' between stocks and flows (United Nations et al., 2012). According to an assessment (Keith et al., 2021), this bears the risk that sequestration is maximized (e.g. planting of tree and management of forests with high growth rates) and the benefits of long-term storage underestimated, taking into account also the stability and resilience of carbon stocks. The recent revision of the SEEA-EEA (to SEEA-EA) aims to increasingly take into consideration aspects such as ecosystem conditions, and the notion of ecosystem capacity (the ability to sustain ecosystem service flows) (Edens et al., 2022). In relation to NbS for climate change mitigation accounting, the need of taking into account ten key components is highlighted, for example referring the quality of carbon stocks being accounted for (to consider risks of damage and loss e.g. due to wildfires), or to account for ecosystem condition and carefully consider the reference level of the natural state (Keith et al., 2021).

3.4 Flora, Fauna and Habitat (non-)inclusiveness

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Integrates justice for nature i.e. an extension of justice considerations to nonhumans that prioritizes the environment at the species-, individual-, or the ecosystem level in contrast to the anthropocentrism embedded in most environmental justice discourse.

3.4.1 Definition

Understanding how cities contribute to and support global biodiversity becomes increasingly important since the urban footprint is predicted to grow, and the impacts of climate change will increase (Spotswood et al., 2021). However, generally there is a pervasive impression of a dichotomy between cities and nature, cities representing strongholds where humans outplay nature and which exist nearly independently from the biosphere. Representatives of the landscape urbanism school of architecture have rejected this binary opposition, in particular between urban and landscape, although with the risk of assuming that all natural or semi-natural elements of ecosystems are already lost, whether in the city or beyond (Thompson, 2012).

Cities are abiotically and biotically unique with a distinctive topography, edaphic (soil), and hydrologic characteristics. They are the quintessential 'anthrome', a type of ecosystem formed by global patterns in human populations and their use of land over the long-term, with different environmental gradients stretching from high density urban centres into surrounding rural areas, featuring different densities of human-built structures, proportions of impervious surfaces, levels of reduced vegetation cover, pollution levels, and a disproportionately different numbers of exotic species (Des Roches et al., 2021). As such, rural – urban gradients are defined by different interrelations of population density, land use, habitat types, and the proportions of native, exotic, and domestic species in biotic communities (Erle C. Ellis, 2019). Nevertheless, cities are also embedded within and ecologically linked to their surrounding landscapes, These surroundings can vary widely from relatively intact ecosystems to ones highly modified by agriculture or plantation forestry to novel ecosystems (McKinney et al., 2018; Spotswood et al., 2021). Thus, despite their uniqueness, cities should not be seen as standalone ecosystems, but ones that are connected to a larger system.

Nowadays, cities are the ecological space where most people encounter flora and fauna, most strongly impact their condition and evolvement, and profit from their ecosystem services (Weisser & Hauck, 2017). For example, human activities (e.g. construction), social patterns (e.g. recreation) and processes (e.g. planning) affect the urban ecology by modifying habitats or influencing connectivity between different ecosystem elements, but also evolution through the selection of preferred variants and or defined species traits. The effects of and subsequent adaptations of flora and fauna can vary over fine spatial and temporal scales. It includes for example drifts of human-affiliated species such as pests, disease vectors, and invasive alien species as a result of human (non-)construction patterns, or certain species adapting to urban heat islands, by migrating into 'cooler' neighbourhoods which simultaneously reflects human inequalities of those neighbourhoods as well (Des Roches et al., 2021).

In addition, the ensuing feedback loops between ecosystems, populations, and gene flow also occur towards society in the form of ecosystem services and disservices (Des Roches et al., 2021). The latter are strongly affected by high rates of changes in biological diversity across multiple trophic groups (e.g. herbivore) and as well in the manifold ecosystem functions required to supply individual services (Felipe-Lucia et al., 2020). While urban biological communities and their eco-evolutionary feedback processes highlight the complexities and deep interconnectedness of nature in cities, they are highly relevant for the success of NbS management, in order to conserve and restore ecosystem functions and contributions to people within and outside cities through ecosystem services and disservices (Des Roches et al., 2021).

City-specific characteristics, its surroundings landscapes, along with vast variations in how flora and fauna respond to urbanization, leads to large differences in how urban NbS initiatives can be utilized to contribute not only to human well-being but also to provide nonhuman or biodiversity benefits (Spotswood et al., 2021). Urbanization can be synonymous with the destruction, fragmentation, and profound alteration of habitats. Animals' range of movement and choice, for exploring, foraging, mating, nesting, migrating, resting, etc. are restricted by fences, wires, roads, and impasses, or are confined to protected places, while plants face new and increased disturbances within their limited and fragmented space such as changing temperatures, altered hydrological patterns, and increased toxins. Cities can be the source of increased risks and new sources of stress or death: collisions with high-rise buildings, windows and cars, poisoning and pollution, killing and relocation, and pollution from chemicals, noise, or artificial light (Delon, 2021). The declining current density of species in cities is best explained by anthropogenic attributes (e.g. land use, buildings, neighbourhood age) instead of by non-anthropogenic factors (e.g. geography, climate, topography) (Aronson et al., 2014).

In addition, a wide range of flora and fauna may move into cities as their ecological niches or ranges shift, while others may be unable to migrate out from cities and become urban-locked, not only due to land use changes (e.g. disappearance of vacant land) but as a direct result of a changing climate (e.g. altered rural landscape and abiotic factors). Given the associated population declines and even extinctions associated with habitat fragmentation and urban development, it can be inferred that climate change will exacerbate these phenomena as species are pushed to migrate into or through cities regardless of whether the urban is conducive for migration or not (Noll, 2018). In this case, there is an ethical argument to be made about these species being nonhuman climate refugees and what forms of justice they are entitled to.

However, it would be wrong to assume that cities are only a hostile environment and not including nonhuman benefits. The uniqueness of cities can also create a unique set of resources to buffer some species during stressful periods and provide release from threats faced in surroundings areas (Spotswood et al., 2021). Urban areas tend to be highly dynamic systems that provide manifold habitats with surprisingly high biological richness. This richness occurs across a wide variety of mostly novel ecosystems (Kowarik et al., 2011), ranging from highly managed ecosystems to fully unmanaged wild ecosystems (Threlfall & Kendal, 2018). Understanding how flora and fauna interact with cities will be key to improving their inclusivity. Certain species may be able to move easily across the urban-rural gradients, while others may be limited exclusively to urban or rural areas; some migratory species may only use cities as a stopover site. This depends on a species traits and their tolerance to urbanization, resource and habitat availability, and the presence of threats in the cities as compared to the surrounding area (Spotswood et al., 2021).

Cities still retain endemic native species as well as threatened species (Aronson et al., 2014). Some may persist only in remnant primary habitat patches from pre-urbanization and are considered “last chance” species. Other species have been found to achieve higher reproductive success in urban areas compared to surrounding landscapes even if they are not actively opting to in urban zones (Spotswood et al., 2021). The suitability of urban areas as a habitat is affected by their green characteristics, often in small-scale, heterogeneous spaces as seen in abundance and diversity over the seasons (Kowarik, 2018). These small, sometimes unconsidered green spaces can be abundant in urban areas ranging from fully managed ecosystems like small parks, backyards, gardens, neighbourhood common areas, or business parks, to fully unmanaged wild ecosystems like vacant lots and derelict land which have all some potential regarding species conservation (McKinney et al., 2018; Mühlbauer et al., 2021). This mosaic of green spaces can support the increase of regional habitat heterogeneity and genetic diversity (Spotswood et al., 2021). Although less often addressed in NbS, these 'wilder' urban ecosystems have been shown to facilitate natural processes, provide habitat and ecosystem services, and even have greater biological abundance as compared to residential lots without the same risks of green displacement prevalent in other urban green spaces (McKinney et al., 2018).

The existence of this particular biological abundance in neglected margins is not accidental. Like other social forms of marginalisation, these sites potentially challenge the status quo of current spatial relations of power and injustices between humans and nonhumans (Houston et al., 2018). Nonhuman and human nature relations have historically been and are continually being commodified through domination, exploitation, and eradication at multiple scales and in manifold settings as goods for the ultimate benefit of humans or in relation to their use or consequential value (see Chapter 2.1.4).

Justice considerations for nonhumans should be integrated into the framework of NbS planning and implementation for various reasons including to improve urban ecosystems' adaptation to climate change. An extension of justice to nature, for once, aims to take human desires out of consideration and prioritise the environment at the species- or individual - level as well as at the ecosystem level. A central objective of nonhuman justice is to foster conditions of coexistence that align with the goals of justice across different levels (Delon, 2021).

Justice can occur at the individual level as well as at a collective level (like species, ecosystems, habitats) since the relationship between the two is multidirectional. "The litho-, hydro-, anthropo-, cryo-, bio- and atmospheres rely on the functioning of the other spheres just as the beings in each sphere are interwoven. This emphasizes justice as a matter of interdependency across and within the spheres, from the large to the very small" (Celermajer et al., 2020). Broadening ecological justice parameters towards entire habitats can be helpful because the notion of ecological space can be murky (see Chapter 2.1.3).

To neglect the anthropogenic environmental ethics perspective (see Box 8) embedded into environmental justice as well as NbS projects or related policies risks hampering the ongoing efforts to respond effectively to the findings and recommendations of the IPCC, IPBES, FAO and others (Arcari et al., 2020; Eggermont et al., 2015). Given that anthromes cover threequarters of Earth's surface (Ellis, 2019), the necessity of nonhuman justice is even more vital, if the complex problems facing cities are to be addressed in a more inclusive, sustainable, and equitable manner.

Box 8: Central perspectives of environmental ethics and NbS

Anthropocentric thinking views nature as a resource to be exploited for human benefits. This perspective recognizes the reality of ecological harm and advocates for protection on the grounds of enlightened self-interest (Ex: Hardin's "Tragedy of the Commons").

Homocentric ethics advocates for the stewardship of nature but only because there is a recognition that human happiness and flourishment ultimately depends on the natural world and should therefore be protected. Whether grounded in rights-based theories of justice or a utilitarian view for general welfare, this is most often the framing used to celebrate and encourage the use of NbS.

Biocentric ethics extend moral significance to nonhuman life forms in the same way that moral considerations were extended to formerly excluded groups based upon sex, race, etc, and in the same way that people are considering future generations. While it is considered that 'every life form is equal' to biocentrists, important questions are raised about what our duty is to not encroach upon the interests of other life forms.

Ecocentric thinking extends moral considerations not just individuals or specific species but also to ecosystems. While a biocentrist will also support protecting environments, it is for the sake of protecting individuals within that ecosystem in comparison to an ecosystem who gives the land itself some moral standing.

('The Ethics of Sustainability', 2007).

To do so, we must ask ourselves what justice for flora, fauna and habitat looks like, as we transition cities around Europe to more low-carbon ways of functioning. Utilizing an ecological justice framework to rethink NbS in and for cities builds upon the '*equitable distribution of environmental goods and bad* [as well as procedural and recognition aspects such as] *social–ecological interconnectedness, nature's agency and capabilities, representative justice and participation in decision-making'* (see Table 22) (Pineda-Pinto et al., 2022).

The considerations outlined to investigate nonhuman justice are diverse, as are the motivations or perspectives of academics doing so, thus increasing the difficulty to accurately define flora, fauna, and habitat inclusivity.

Within the NbS context, there is an underlying theoretical recognition of the importance of nonhumans, ecosystem integrity and functionality, and an importance in considering their needs and capacities through multi-functional nature-based solutions design and planning, at least when considering their consequences for human well-being. The introduction of flora, fauna, and habitat inclusivity also provides an opportunity to step back from the default narratives of urban problems and solutions being human-based and to consider the needs and priorities of nonhuman living beings with whom we co-exist, and are intricately entangled with, in all environments (Fitzgibbons, 2021). Nonetheless there is a knowledge gap in how to design and plan nature-based solutions in a non-anthropocentric manner (Pineda-Pinto et al., 2022).

Table 20: Specific conditions driving flora, fauna and habitat (non-) inclusiveness

	Key insights	**Key literature**
Environmental conditions	Unequal distribution of common environmental goods like protected areas and elements designated for human-valued species and common environmental bad such as pollution sources, contaminated land, and an uneven distribution of urban development	(Pineda-Pinto, Nygaard, et al., 2021)
Social and economic conditions	Flora, fauna, and habitats are primarily valued by what (dis) services or benefits they provided to people. Studies show ecosystem services as being most at risk in poor communities where low vegetated cover is found. Additionally, the age of a neighbourhood and its socio-economics influence urban vegetation cover and biodiversity (luxury and legacy effects).	(Clarke et al., 2013)
Individual conditions & vulnerabilities	Human and nonhuman conditions and vulnerabilities add value to traditional environmental management and to their relations with surrounding communities by potentially identifying hotspots for unique ecosystem risks and coinciding environmental justice community risk. These are typically categorized as (1) unique cultural relationships to resources; (2) connectedness of on-site and of-site resources and habitats; (3) health of threatened, rare, and unique cultures and communities; and (4) linkages between ecological, eco-cultural, and public health for monitoring and assessment.	(Burger et al., 2022)
Built-environment	• Profound alteration of habitats • Limited range or ability to move • Increased and new disturbances within their limited and fragmented space such as changing temperatures, altered hydrological patterns, and increased toxins such as pollution from chemicals, noise, or artificial light. Urban design and neighbourhood age defining uniqueness of habitats and resources, and potential of small and unconsidered green and open spaces as important habitats (e.g. vacant lots, old buildings, railways sites)	(Spotswood et al., 2021);

3.4.2 NbS contribution

It is not obvious to all, but 'speciesism', the discrimination because of differences among species, and human exceptionalism are also replicated in the planning of cities and NbS projects. Varied valuations of nature are implicit, which leads to double standards in terms of care and resources. We relate for instance differently to more popular kinds of nature. This refers to birds, native mammals, insects, aesthetic plant communities as well as species valued for their ecosystem and social/health services than other species who are either less apparent in urban areas or even considered as nuisances (Arcari et al., 2020). Or it becomes visible in relation to 'flagship' ecosystems or urban green areas (e.g. large landscape parks compared to vacant land)(Gantioler, 2019). Therefore, if the intention is to create more equitable multispecies urban areas, the similar ethical and value-based questions should be asked about diverse nonhuman constituents of the areas where NbS is to be implemented as are asked about the diverse local, human populations. And questions of urban ecosystem quality can help to develop a common framework to develop ecological space for the thriving of both human well-being and biodiversity and ecosystems.

The theoretical approach of extending justice considerations to the nonhuman world and to social–ecological processes in NbS planning and design allows creating a new perspective or new to use with which to interpret and understand urban areas. Disaggregating the different justice principles and how they apply to flora, fauna, and habitats will be key to responding to the local context, capacity, or needs in various cities based upon their local circumstances, data availability, and by potentially expanding the 'types' of justice parameters and indicators used (Pineda-Pinto, Herreros-Cantis, et al., 2021). There have been cases where an individual animal or habitat has been legally granted aspects of personhood, but the examples are few. Nonetheless, to not prioritize dismantling the speciesism in urban NbS, just because it has rarely been done before, is an argument against progress and innovation. Judge Rowan Wilson recently stated in a dissent that *"… to whom to grant what rights is a normative determination, one that changes (and has changed) over time*." (New York Court of Appeals, 2022).

Distributive justice from an ecological justice perspective is about the equity between human and nonhuman interests in the allocation of environmental goods and bads, ecological functions, and benefits. On a global scale, the fact that the majority of net primary productivity has already been co-opted for humans and that more than half of ecosystems services are being degraded brings forth valid questions about what is equitable in terms of our' fair share' of ecological appropriation (Washington et al., 2018). In urban areas, the most poorly distributed elements are pollution sources (including factories, extractive industries, and landfills), contaminated land (brownfields), and an uneven distribution of urban development (Pineda-Pinto, Nygaard, et al., 2021). Improved inclusivity would highlight these unequal patterns of degrading activities to nonhuman and humans or works towards a fair distribution of natural capital so that nonhumans and humans can coexist and flourish (Pineda-Pinto, Herreros-Cantis, et al., 2021). The common traits of ecological space justice are most prevalent here. So are most traditional ecological environment indicators, which measure manifold biotic and abiotic factors, and can also be used not only to determine ecological risks but also human community risks. With these metrics, the monitoring and the outcomes of initiatives focused on justice for flora, fauna, and habitat integrity can be most often observed (Burger et al., 2022).

Simultaneously sustaining human well-being and ecological integrity will always be a litmus test for public decision-making. Yet, it is the integration of the following principles of justice where an NbS project can rise to the challenge and evolve from being only focused on the more traditional, anthropocentrically valued environmental issues to truly comprehensive, multidimensional view that enables multispecies representation and their subsequent inclusivity. Recognitional justice would identify social–ecological interconnectedness, including relationships across multiple scales, adaptive capacities, and values. With this understanding, potential synergies, trade-offs, and non-utilitarian multifunctionality can be assessed. Pineda-Pinto takes the definition of recognitional justice further, when advocating for the acknowledgement, appreciation, respect, and to act in nature's interest (nature's agency) (Pineda-Pinto et al., 2022).

While rarely addressed in reviewed literature, procedural justice requires not only the recognition of nature's agency, but also the inclusion of it into decision-making processes by facilitating the collaboration and reciprocation between humans and nonhumans. There are obviously limitations to overcome in 'multispecies' participatory processes and issues such as power imbalances, representativeness and misrecognition would need to be overcome. Furthermore, additional support would be needed for knowledge exchange between stakeholders along with education and community engagement with nature as an active agent (Pineda-Pinto et al., 2022).

The capabilities approach that often complements the main principles of ecological justice (see Chapter 2.1.1) addresses the integral aspects of nature's capacity to sustain the fundamental ecological processes, functions, and structures that allows flora, fauna, and habitats to regenerate, be resilient, and flourish (Fulfer, 2013). When extending the capabilities approach to nonhumans in practice, any NbS project should recognize nonhuman vulnerabilities and needs, adaptive capacity, and ecosystems' integrity. This is especially important in urban settings where the capability of nature to flourish is strongly driven by human activities and legacies (Pineda-Pinto et al., 2022). Spatially depicting the needs and vulnerabilities of these ecological structures, such as biodiversity, ecosystem functioning, habitat connectivity at various geographic and temporal scales, will better inform NbS implementation and make it more inclusive to nonhumans by improving how nonhuman capabilities and integrity are considered as well as their subsequent management.

Ecological justice theory very often seeks to include marginalized humans along with nonhuman communities and their ecologies, when pursuing recognitional justice, procedural justice, along with the capabilities approach. This is captured well by a study, which attempts to integrate environmental justice with ecological and eco-cultural indicators that provide parity with ecosystem indicators (Burger et al., 2022). These types of indicators can be categorized as

1) Unique cultural relationships to resources;
2) Connectedness of on-site and off-site resources and habitats;
3) Health of threatened, rare, and unique cultures and communities; and
4) Linkages between ecological, eco-cultural, and public health for monitoring and assessment.

These additional considerations add value to traditional environmental management and to their relations with surrounding communities by potentially identifying common hotspots for unique ecosystem risks and coinciding environmental justice community risk (Burger et al., 2022).

All NbS categories and measures can be targeted by flora, fauna, and habitat inclusiveness, by taking into due consideration species needs, the general provision of a diversity of habitats or by considering ecosystems uniqueness and diverse quality. As such there is not a predominant NbS type or contribution, although key focus has often been put on biotopes or areas protecting natural and semi-natural ecosystem elements. Following the reasoning that led to the development of Figure 8, it is the structural and process indicators that would directly inform the NbS categories and measures best suited for the specific context and associated distributional (in)justices, as helping to take duly into account or recognize flora, fauna and habitat needs and include nature's agency as part of procedural processes which determine distribution and level of inclusiveness.

Table 21: Overview of the contribution of NbS and key types

	Key insights	Key literature
NbS contributions	Key focus on biodiversity benefits linked to conservation and restoration of habitats and ecosystems	(Cohen-Shacham et al., 2016; Spotswood et al., 2021)

NbS categories and measures	*Applies to every type of NbS.* Special consideration to be attributed to aspects of • Habitat connectivity: Part of a network Isolated or edge effects, and to the • Habitat function more widely: Absolute size and shape Vegetation coverage & characteristics such as density, distribution or altitude, age, succession and maintenance Degree of naturalness and disturbance	(Böhm et al., 2016; Pineda-Pinto et al., 2022)

Table 22: Types of action and justice principles

	Key insights	Key literature
(Remove) Protect, Manage, Restore, New	Remove environmental threats, sources of pollution, and other stressors that impact species and habitats. Protect existing ecosystems (or fragmented parcels) and ecological space to contribute to connectivity Manage target species and habitats using detailed and multiscale data from robust monitoring to better track ecosystem functioning and integrity over time and that reflects nuances within a heterogeneous site. Restore ecosystem functioning and integrity, including habitat connectivity and ecological spaces that meet the many needs of species throughout their entire life cycle, when compromised based upon the target species and/or habitat. New NbS-based projects should include nonhumans into the earliest stages of project conception and design so that the target species and habitats can aid or act as inspiration during the initial design processes.	(Spotswood et al., 2021)
Distributive, Procedural, Recognition, Capabilities	Distributive Distribution of environmental goods and bads across ecological space in addition to tradition environmental indicators to observe and quantify ecological integrity and functioning. Procedural Inclusion of flora, fauna, and habitats in the decision-making processes by facilitating the negotiation and reciprocation between humans and nonhumans. Recognitional Identification of social–ecological interconnectedness, including relationships across multiple scales, adaptive capacities, and values. Additionally, includes advocating for the acknowledgement, appreciation, respect, and to act in nonhumans' interests (nature's agency) Capabilities Consideration of the integral aspects of the living process i.e. nature's capacity to sustain the fundamental ecological	(Fulfer, 2013; Pineda-Pinto et al., 2022)

	processes, functions, and structures that allows flora, fauna, and habitats to regenerate, be resilient, and flourish in NbS design and management. This includes a recognition of vulnerabilities and needs and adaptive capacities.	

3.4.3 Interlinkages with other key challenges

In many ways, improving FFH justice can positively influence all other (in)justices given the multidirectional relationships in human-nature systems at varying temporal, spatial, and social scales. The interdependent nature of these linkages has also negatively highlighted the magnitude that FFH has not been included or prioritized in urban settings. Potential conflicts exist for example when selecting, which habitats or species are to be targeted with NbS, as well as with humans when their preferences are not prioritised. The manifold ways that nonhumans are valued by local groups, according to the previously introduced relational value aspects, affect how their inclusion is manifested in NbS in urban areas and it strongly interlinks with spatial (in-)justice considerations.

Table 23: Overview interlinkages with other key challenges

	Key insights	**Strength and effect**	**Key literature**
Air quality (in-)justice	• Local increased atmospheric CO_2, nitrogen and other gasses change vegetative phenology with cascading effect to the fauna it supports with effects at the habitat and regional level. • Acidification, eutrophication leading to plant damage	↘↑	(European Commission, 2021)
Thermal (in-)justice	• Flora and fauna can suffer disproportionately from warming and urban heat island effects similarly to humans. • Flora and habitats have potential to contribute to passive cooling • Phenological changes and adaptive traits are already being observed. • Acclimatization to warming in urban areas may contribute to pre-adaption to climate change through higher heat tolerances. These communities could act as a source population to recolonize surrounding rural areas in the future.	↘↗	(European Commission, 2021; Spotswood et al., 2021; R. Sun et al., 2012)
Carbon (in-)justice	• FFH already bear an extremely disproportionate amount of environmental burdens from GHG emissions without contributing or limiting the possible carbon sequestration. • Urban NbS has an opportunity to improve climate resilience via GHG storage and sequestration	↑	(European Commission, 2021)

Spatial (in-)justice	• Urbanization has accelerated habitat fragmentation. Increasing ecological space connectivity and establishing corridors or stepping stones with NbS has potential to strongly improve FFH functioning and integrity • The distribution, quantity and quality of urban green space are inherently multifunctional by providing regulating and provisioning ecosystem services alongside a range of cultural and social benefits	↘↑	(European Commission, 2021)
Temporal (in-)justices	• Given the symbiotic relation with intergenerational justice, being responsible for enhancing the longevity of ecosystem functioning and resources is important. • Understanding the legacy effect and consequences of historical socio-environmental conditions. • The varied life spans of diverse flora and fauna, the different requirements throughout life cycles, and potential responses to future climate projections should be considered.	↘↑	(European Commission, 2021)

Note: Strength and effect ↓: strong negative interlink; ↘: partial negative interlink; –: no correlation; ↗: partial positive interlink; ↑: strong and positive interlink

3.4.4 Basket of indicators

In ecology and environmental planning, it can be a struggle to clarify the different understandings of commonly used, yet ambiguous terms such as biodiversity, introduction, naturalness, community, ecosystem, and even environment as well as whether they are used as an ecological component or as a measure (descriptive or normative) (Heink & Kowarik, 2010). Traditionally, ecological indicators that are examined spatially for understanding ecological risks from stressors are selected to provide information about a target species itself. At an ecosystem level, there are additional indicators including endangered/threatened species, species of special concern, species assemblages, and unique habitats, as well as ecosystem structure (e.g., species diversity) or function (energy transfer, predator–prey relationships) (Burger et al., 2022). Assuming biodiversity alone is desirable in urban areas for its ecosystem services and human-nature interfaces opens the risk of conflicts at a later stage. The type of urban nature of the site, the target species or habitat, as well as what planning phase the project is at are just a few of the central factors that dictate how to proceed in improving FFH-inclusiveness (Apfelbeck et al., 2020).

The breakdown of these discrete environmental and/or population integrity and functioning metrics to track and foster the multiple benefits or burdens of urban NbS has its weaknesses in the attempt to fully outline or spatially depict the multi-scale and multi-temporal interconnectedness of nonhumans and their urban areas. The complexity and heterogeneity of cities and surroundings areas with multiple levels of governance along with lacking data at very fine scales of resolution can make casual linkages even more challenging to discern (European Commission, 2021).

That being said, choosing pragmatic indicators that are relevant and feasible are necessary to support policy and decision-making, monitor implementation, and provide feedback if and how objectives are being met. Still, selecting indicators is a subjective process that traditionally depends on cost-effectiveness, how easy the data is to understand, if its scientifically reliable, and comparable internationally (Dizdaroglu, 2017).

After understanding the resources and capacities of the city to execute monitoring, any results would go on to inform proper management and improve confidence in the quality of results and increasing community acceptance (Carmen et al., 2020). Combined, this tends to increase the likelihood of success and well-balanced implementation of NbS with positive spill over effect for the general benefit of society and the realization of policy goals (Snäll et al., 2016). The selection of indicators must be based on the specific NbS context.

It is highly recommended that the design and implementation team is interdisciplinary and includes natural science professionals such as ecologists (with local knowledge) to assist in the selection of indicators appropriate to the local context and could spur innovative multifunctional solutions (Apfelbeck et al., 2020). Additionally, they may know which trait-based indices to select that may provide greater explanatory power instead of species richness or abundance (Gagic et al., 2015). After understanding the resources and capacities of the city to execute monitoring, any results need to go on to inform proper management and improve confidence in the quality of results and increasing community acceptance (Carmen et al., 2020). For proper monitoring to occur, 'success' benchmarks or threshold for the target species, specific habitat, or project vision should be well-defined in advance along with a realistic time frame for changes to be observed (Apfelbeck et al., 2020). Combined, this tends to increase the likelihood of success and well-balanced implementation of NbS with positive spill over effect for the general benefit of society and the realization of policy goals (Snäll et al., 2016).

One recent development to integrate broad ranges of data to identify landscape structures that protect biodiversity locally and facilitate landscape-level species survival is spatial conservation prioritization (SCP), which uses computational methods and decision analysis to inform protection or conservation actions and fits well into green infrastructure planning and therefore NbS. Using observed or model-predicted occurrences of biodiversity features, including species, habitat types, ecosystems, or ecosystem services as well as relevant costs, opportunity costs, alternative land-use needs, land ownership, and other types of (spatial) restrictions on the conservation solution, SCP strives to highlight crucial trade-offs or synergies between anthropocentric ecosystem services and biodiversity by giving relative weights to the included characteristics (Snäll et al., 2016).

While a specific set of indicators cannot be suggested, the objective is to define broad, interdisciplinary indicators forming a coherent framework that use ecological research and knowledge to better inform design and decision-making at multiple levels from households to regions. With this, urban areas can be more inclusive to ecological elements through the realization of multifunctionality improvement and adaptive capabilities of NbS to produce more innovative solutions for humans' and nonhumans' cities of tomorrow (Childers et al., 2015).

Table 24: Basket of indicators appraise NbS flora, fauna, and habitat (non-) inclusiveness potential

Indicator (metric)	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of integration	Spatial mapping potential
Number of groups/individuals standing in for nature by proxy	Nonhuman representation	Inclusion in design and planning	Representative Procedural	++	-
(Local) Natural science experts consulted for NbS design	Provision of a solid foundation of knowledge on ecosystems, biological processes, nonhuman species	Transdisciplinary design and planning	Representative Capabilities	++	-
Project stage where FFH first included	Target species or habitats are selected at the earliest project stages	FFH-aided design	Procedural	++	-
Criteria used to determine the ecological value and need for protecting certain areas (e.g. intrinsic value versus benefits of humans from nature, species or ecosystem services	Socio-economic & cultural aspects in particular as defining human-nonhuman relationship	Peoples' norms, behaviours, values, and needs, and ecological integrity	Recognitional	++	O

prioritized, attitudes towards pioneering, alien, or invasive species)					
Population, community, and ecosystem well-being (various units)	Common indicators addressing human and nonhuman communities	Habitat or group size, biodiversity, trophic transfer, interconnectedness of habitats	Distributional	++++	○
Spatial distribution of ecosystem services and biodiversity with scenario planning and other tools to identify trade-offs and prioritise conservation potential hotspots (various units)	Linked to variables in relation to air pollution, carbon storage & sequestration etc.	Key focus on protected areas	Distributional Procedural	++++	●
Biodiversity enhancement potential					
Structural connectivity of urban green and blue spaces (various units)	Biodiversity benefits	Physical connectivity of NbS elements	Distributional	++	●
Species diversity within a defined area (number)	Biodiversity benefits	Species diversity	Distributional	++	○
Proportion and size of natural areas within a defined urban zone (% and ha)	Biodiversity benefits	Availability of habitats, aspects of naturalness	Distributional	++	●
Proportion and size of protected areas within a defined urban zone (% and ha)	Biodiversity benefits	Availability of habitats, aspects of naturalness	Distributional	++	●
Number of veteran trees per unit area (No per ha)	Links to neighbourhood age		Distributional	+	●

Note: Level of integration -: no significant integration; some (+) to very high (++++)
Spatial mapping potential -: no significant mapping potential; ○: some; ●: high

3.5 Spatial (in-) justices

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Distribution of environmental amenities and disamenities impacts processes such as socio-spatial segregation, sorting of urban population and gentrification, impacted by the socio-economic context, individual and social vulnerabilities. To be addressed by the balancing socioeconomic development with environmental stewardship.

3.5.1 Definition

Many disciplines have tried to analyse the concept of spatial (in-)justice, and as such not surprisingly no commonly agreed definition exists.

In sociology, the concept of space justice was initially developed in the early 1970s. Spatial justice was placed alongside social justice and the main consequence has been that the concept of spatial justice has often developed in urban processes instead of having a broader character (Babí Almenar et al., 2021). It is precisely because its broader aspect has not been adequately developed that gives rise to spatial justice as a continuous and democratic process of demanding more just and equitable social conditions that aim for a just outcome, in a combination of distributive and procedural aspects (Babí Almenar et al., 2021). These more just social conditions include:

- Avoidance of social-spatial segregation;
- Gender equity;
- Age equity;
- Racial equity;
- (Income) class equity.

The concept of social-spatial segregation refers to the unequal distribution of different social groups, infrastructures, activities or other spatial elements across the territory (Cruz-Sandoval et al., 2020). Segregation is reflected in the separation of different social groups based on social conditions such as gender, age, race, economic condition (income class inequity), and environmental condition (risk areas).

From the geography viewpoint (Soja, 2009), spatial (in-)justice intentionally focuses on the spatial aspects related to justice and injustice. As a starting point, it concerns the (fair and equitable) distribution in space of resources considered socially valuable and the opportunities to use them. In this context, spatial justice should not be considered as a replacement of other forms of justice (social, economic, etc.) but a way of looking at (in-)justice from a critical spatial perspective. Moreover, spatial (in)justice can be seen as both an outcome (distributional patterns that are just/unjust) and a process (that produce these outcomes).

Social and spatial concepts are strictly related to the so-called "socio-spatial dialectic" (Soja, 2009): the spatial shapes the social as much as the social shapes the spatial. Taking this dialectic into account means recognizing that the spaces in which people live can have negative as well as positive consequences on every social aspect.

From the perspective of urban studies, (Bibby et al., 2021) stated that the achievement of spatial justice in a just city (considering the basic elements of justice being the values of equity, democracy, and diversity – as theorised by Fainstein (2010)) depends on boosting participation (diversity) in open political-economic processes (democracy), ensuring at the same time benefits and costs of urban (re/)development are distributed between diverse social groups (equity).

In the modern context, spatial justice is becoming increasingly important especially in urban areas; the influx of people moving to places close to city centres is steadily increasing (Azgomi & Jamshidi, 2018). Today, 54% of the world's population lives in urban areas, and 60% lives within 5 km from urban centres (Azgomi & Jamshidi, 2018; Haase et al., 2017). These continuous social changes due to the movements of people have increased and emphasised the importance of good space management that balances socioeconomic development with environmental stewardship. On the one hand, the increased residential density brought by urbanization affords opportunities to more efficiently deliver goods and services to urban inhabitants at lower environmental cost. On the other hand, higher density brings its own set of challenges, including higher exposure to local air pollutants and more constrained access to greenspace (Frondel et al., 2021).

The need for just and equitable social conditions in the spatial dimension is linked to another modern necessity: to keep cities liveable and sustainable (SDG 11, see Section 3.1.1). The uneven distribution of environmental amenities and disamenities has been shown to cause systematically higher health concerns for particularly vulnerable population. The term vulnerable refers to that part of society that, due to a particular characteristic, whether innate, physical, or related to the life cycle (such as advanced age, gender, pregnancy, childhood, etc.), is in a disadvantaged position (K. Brown et al., 2017). This segment of the population faces disproportionate socioeconomic and environmental stressors due to the uneven distribution of environmental amenities. Indeed, very often people's innate or physical conditions limit (vulnerability) their ability to reach certain parts of the city, such as green spaces, for infrastructural or cultural reasons. For example, women from gender-segregated cultural backgrounds (Sultana, 2014) do not have the possibility to freely use the surrounding spaces, and the proxemic distance from green spaces limits even more their possibility to access these areas and benefit from the positive aspects for psycho-physical well-being (Sultana, 2014).

Box 9: Spatial justice and green gentrification

The **spatial dimension** plays a very important role in the relationships between different systems and social actors. Moreover, the evolution of **spatial inequality** is increasingly taking on the characteristics of other types of inequality that are now more profound, such as social, economic, etc. (Tickamyer, 2000). One phenomenon that can create spatial and other inequalities is gentrification.

Gentrification broadly refers to the increase in home and rental prices that occurs as wealthier people move into a neighbourhood, increasing the local demand for housing. Gentrification can have social impacts that are rooted in spatial injustices. This process often takes the neighbourhood from a situation of degradation and poverty to a situation of high wealth. While gentrification can be highly beneficial to pre-existing homeowners, the new situation sometimes leads to a relocation outside the gentrified neighbourhood of low-income people and renters which cannot afford the higher rental prices (Anguelovski et al., 2018; Colléony & Shwartz, 2019).

With regard to the effects of nature-based solutions in low-income neighbourhoods, some studies have found that features such as newly planted trees, improved the sale prices of houses located nearby (Yang, 2020). In this case, NbS give tangible value for home-owning residents, whose property value is increased by their proximity to urban amenities. Therefore, gentrification and the redevelopment of neighbourhoods is a complex and sometimes controversial topic in both social sciences and urban planning. Drawing conclusions about the social processes that lead to spatial disparities in urban vegetation is not simple without expanding the scope to cross sectoral studies of interlinkages between vegetation, or other NbS, and descriptions of the social environment including its changes through time (Endsley et al., 2018). This is true especially in the contemporary world, where urban greening to address the challenge of climate change is over-emphasized.

This is deemed to be influenced by home ownership and as such housing policy in particular, although its role is often undervalued (Cucca & Ranci, 2019). The analysis of resulting socio-economic spatial disparities is of particular interest to studies in economics. Major aspects that are considered are for example drivers such as i) employment, economic competitiveness and attractiveness of a city or neighbourhood; and ii) housing affordability and development of the real estate market (housing amenities) (Cucca & Ranci, 2021). Housing policy instruments, such as social housing development, public subsidies to associations, rent control or homeownership support, can have a key impact on the 'sorting' of an urban population, also in relation to environmental amenities and urban green infrastructure (Gantioler, 2019).

The general objective of the following sections on spatial (in-)justice is to define the dimensions and factors for analysing the socio-economic spatial disparities within the urban context that should inform decisions on where to place NbS and which NbS is more feasible for a neighbourhood, avoiding spatial injustices.

For several reasons the focus has been put on gentrification (see Box 9). First, gentrification could be a real problem because of the implementation of NbS. Since the activation of NbS is the overall objective of the JUSTNature project, the hypothesis that gentrification is effectively a problem should be explored in order to be able to develop according countervailing measure. Another aspect that makes this phenomenon interesting in the context of spatial (in-)justice is the lack, to date, of a specific method that analyses the risks of gentrification due to the implementation of NbS, and that integrates this knowledge into the design of NbS. Delving into what dimensions and factors to analyse socioeconomic spatial inequalities within the urban context can be linked with respect to NbS implementation.

Table 25: Specific conditions driving spatial (in-)justices

	Key insights	**Key literature**
Environmental conditions	• The distribution of environmental amenities and disamenties impacts processes such as social-spatial segregation or the sorting of an urban population as well as gentrification processes. Variables to consider: Pluvial flooding, Green index, Air pollution, Biodiversity, Green gentrification index	(Certomà & Martellozzo, 2019; Colléony & Shwartz, 2019)
Social and economic conditions	• Social variables: Relationships, Social capital (trust, networks, spatial identity, place meaning) Associationism • Economic variables: Maintenance costs • A pandemic (or other extreme events) causes marginalised groups to lose more opportunities to use public parks or green spaces. Variables to consider: Unemployment, Violent Crime Incidents, Income Inequality, Hardship Index Score • "Classic" socio-economic status measures are not enough to explain inequalities in access to urban vegetation. New measures of socio-economic conditions derived from real estate inventory data would have stronger associations with the distribution of urban vegetation. "Classic" variables considered: Household income and home value	(Babí Almenar et al., 2021; Bixler et al., 2020; Certomà & Martellozzo, 2019; Felipe-Lucia et al., 2020; Fisher et al., 2021; Koprowska et al., 2020; Ronchi et al., 2020; Yang, 2020)
Individual conditions & vulnerabilities	• Gentrification: marginalised and deprived social groups living in disadvantaged areas are also more likely to suffer from exposure to risky and hazardous environmental conditions. Variables to consider: Gender, Age, Education level, Race, Household(composition)	(Endsley et al., 2018; Fisher et al., 2021; Haase et al., 2017; Ronchi et al., 2020)

	• Green spaces and non-material benefits: Spiritual and cognitive development • The design of green spaces should consider social and individual vulnerabilities (e.g., energy vulnerabilities) related to the access of green spaces: Advanced age, gender, particular life course (e.g. pregnancy), childhood, youth, people with disabilities, minority and disadvantaged groups • Green spaces are needed to prevent the negative health conditions that are becoming more common in urban areas. Variables to consider: Diabetes, Lung Cancer, Childhood Lead Poisoning, Adult Obesity, Elevated Blood Lead Levels, Physical Inactivity, Allergic diseases (e.g., Atopy) • Potential disparities in green vegetation density between demographic groups may emerge; variables to consider in this regard are race and migration status.	
Built-environment	• The green index of cities is a built-environment topic, strictly connected with the risk of gentrification. Furthermore, the built environment is a resource to answer urban challenges. • Urban areas give tangible value for residents, whose property value is increased by their proximity to parks. Variables to consider: Severe Housing Cost Burden, Vacant Housing Unit • The housing market and demolition rate measures demonstrate a stronger relationship with changes in vegetation density than the changes in census measures (like income). Thus, the demolition rate can be considered a better predictor of the distribution of urban vegetation. Variables to consider: Sale prices, Tax foreclosures, New housing construction, Demolitions, Balance of construction and demolition	(Babí Almenar et al., 2021; Endsley et al., 2018; Yang, 2020)

3.5.2 NbS contribution

From a social point of view, the literature emphasises the importance of the environment in human life and how NbS would enhance this relationship. NbS could become a new form of cultural heritage from which people could draw the non-material benefits that humans obtain from ecosystems by enriching the spirit, cognitive development, etc. (Ronchi et al., 2020).

As noted above, NbS can also create socially unsustainable outcomes such as green or ecological gentrification. "Paradoxically, the implementation of NbS to address the environmental justice problem can increase a neighbourhood's health and esthetical attractivity, in turn, also increasing housing costs and property values, and therefore strengthening ecological gentrification" (Colléony & Shwartz, 2019). There are many examples of NbS or green infrastructure that have increased social stratification (Fisher et al., 2021). This means that some people (usually minority communities and socially disadvantaged people) are unable to respond to rising prices and this results in less access to green spaces, worsening certain situations of spatial and social inequality. In order to identify the drivers promoting the benefits and reducing the risks of negative outcomes of NbS, it is important to address the social, cultural and political dimensions of NbS (Colléony & Shwartz, 2019). By identifying context-specific needs, synergies and trade-offs resulting from the implementation of NbS, research can maximise the benefits of such interventions (Colléony & Shwartz, 2019). On the other hand, in developing countries NbS help the city in planning for greater environmental sustainability, adapting to increased rain flooding (Bush & Doyon, 2019), and can become places where citizens can explore performative justice actions that challenge social and environmental injustices in everyday life (Ronchi et al., 2020). Within the development of a new city or the redevelopment of a city, NbS emerged to try to bring to life a concept that could provide ecosystem-based solutions to existing social challenges (Bush & Doyon, 2019).

In a more general context, the spatial dimension of NbS has been considered positively in different aspects of society. Natural elements can positively influence the mental health of city dwellers, can increase social cohesion, and have an impact on problems related to socio-spatial inequality (Dushkova et al., 2021). But often urban vegetation is distributed unevenly among residents and neighbourhoods, creating social disparities in the accessibility to these important benefits (Endsley et al., 2018; Yang, 2020). Above all in growing cities, higher household income enables citizens to buy larger residential areas (with gardens, etc.) and live closer to green spaces (Endsley et al., 2018), which are signals of higher social prestige and can further hinder the access to scarce urban green areas among financially disadvantaged households.

In defining NbS contribution and key types to spatial (in-)justices, especially the investigations by Dumitru et al. (2020) were considered. The authors identify some conceptual and some empirical problems in the existing evaluation processes of NbS that can lead to gentrification. From a conceptual point of view, mainly 4 issues are identified:

1) Impacts on social cohesion and well-being in the studies are considered as indirect or secondary to the environmental impacts of NbS.
2) Data that are collected for evaluation are mixed, giving little clarity as to which belong to the process of creating NbS and which belong to the outcomes of NbS projects.
3) There are few studies providing information on how NbS may affect specific aspects, especially human health and social fabric.
4) There is no mapping that can represent how different impact categories are in synergy or can be compromised by the implementation of NbS.

In addition, from an empirical point of view, there is no evidence of how the green areas are used by different social groups. Therefore, it is difficult to assess the outcomes that NbS have on people and inequalities. NbS-related disruptions and the long-term consequences of NbS implementation are often not considered in NbS planning.

Bush et al. (2019) assert that the NbS can play a substantial role in the way the dimensions of social equity are considered, including spatial equity. A key role is given to urban planning and the ability to manage trade-offs and conflicts.

Furthermore, some authors (Certomà & Martellozzo, 2019; Haase et al., 2017) affirm the existing relationship between the co-benefits of NbS, in particular how the implementation could facilitate the development of different types of cultures by facilitating their integration and inclusion (related to SDG 11) (Haase et al., 2017). NbS also contribute to economic development by increasing employment through the implementation of infrastructures and work in green areas (thus fostering the SDG 8) (Outcault et al., 2018). From an environmental point of view, NbS are an important element to be able to fight the impacts of climate change (SDG 13) through the reduction of urban heat islands, urban surface flooding, and groundwater flooding. For a deeper insight on SDGs see Section 3.1.3.

In relation to the types of NbS, it is very important to consider the where, for whom and the how (Babí Almenar et al., 2021) when activating NbS (Haase et al., 2017). First, it is important to consider existing recreational areas when situating NbS, to avoid those socially important areas for the community being replaced (*where*?). Second, NbS should open the possibility to include different social groups (*for whom?)* within the new infrastructure plan at every stage of the project (*how*?).

From an economics or preference-based perspective, in incorporating the interrelationship between humans and ecosystem services in the evaluation of NbS, it is critical to comprehensively assess the direct use values, such as recreational opportunities, that such services provide. Many urban interventions that run counter to NbS, such as road construction, are essentially irreversible, at least over the medium term. Hence, the concept of option value – the ability to maintain alternative development options for the future – assumes central importance. In addition, it is also important to consider passive use values. These include existence value – e.g., the satisfaction derived from simply knowing that a park is nearby – as well as bequest value, the satisfaction derived from passing this amenity to future generations (Arrow & Fisher, n.d.; Bastien-Olvera & Moore, 2021). About different concepts of value however also see Box 2 in Section 3.2.1. These considerations point to the need for both economic and social approaches, reflected in the efforts made in recent years to make urban-planning more interdisciplinary (Bush & Doyon, 2019).

Another important role is given to NbS as a solution to environmental disasters and climate change; in particular the contribution that is highlighted is not only environmental but also of systems defined as biophysical that include an interaction between environment and society (Bush & Doyon, 2019; Certomà & Martellozzo, 2019).

Table 26:: Overview of the contribution of NbS and key types

	Key insights	Key literature
NbS contributions	• NbS can affect, reinforce, or reduce neighbourhood or city characteristics in terms of socio-economic spatial inequalities e.g., the existence of inequalities such as gender and age inequalities, social-spatial segregation, social vulnerability to urban violence, affordable housing the cultural context and the current land uses. • NbS could influence social cohesion and social well-being (social and individual (in-)justice). • (Socio-economic) Spatial impacts of NbS and related conflicts or improvements in the quality of life may arise after the introduction of NbS, such as the increase of the presence of homeless people in green areas. • NbS must be able to create places that bring together different types of populations through, for example, the inclusion of natural and infrastructural elements that are of importance and value to multiple types of cultures (social (in-)justice). • The decrease of traffic or the access to footpaths or cycle routes (ecological (in-)justice). • NbS potentially leading to commodification of nature, and exploitative human-nature relationships. • NbS applied at a broader scale (not only isolated interventions) creates a connected green network. • Ecosystem services contribute to mitigation of natural disasters and of climate change, as well as to adaptation and recovery from disasters and crises, for both the biophysical and social systems. • NbS can provide societal benefits in a fair and equitable way and in a manner that promotes transparency and broad participation. NbS contribute to: • Environment: protecting water quality through the filtration of nutrients, reducing runoff from impervious surfaces, limiting soil erosion, cooling neighbourhoods, reducing stormwater runoff, cleaning the air. • Built environment: reducing heating and cooling costs in buildings. • Economy: tangible value for residents. • Health & well-being: making people feel relaxed mentally, and physically able to lead more active lifestyles that can help lower rates of cardiovascular disease, diabetes, and obesity; improving quality of life for urban residents.	(Babí Almenar et al., 2021; Bush & Doyon, 2019; Certomà & Martellozzo, 2019; Endsley et al., 2018; Haase et al., 2017; Outcault et al., 2018; Yang, 2020)

NbS categories and measures	Different relationships exist between the characteristics of social groups and the types of NbS: where, how, and for whom. • Urban green spaces (different types of urban park). • Urban vegetation in the form of lawns, parks, and tree canopy.	(Babí Almenar et al., 2021; Endsley et al., 2018; Yang, 2020)

Table 27: Types of action and justice principles

	Key insights	Key literature
(Remove) Protect, Manage, Restore, New	New and manage Citizens and stakeholders' preferences, which can be more effectively and comprehensively understood through strong collaboration between NbS promoters and citizens (and stakeholders). Therefore, citizen participation in NbS planning and implementation is important: does it exist? Is it planned? Restore It is important to consider that the population is not a homogeneous entity and to understand that there may be potential conflicting values related to the benefits and benefit distribution of NbS, the characteristics of people living in the neighbourhood or city, such as the age, the educational level, the health conditions (social justice). New • Concerning social capital, the quality of neighbourhood or city governance affects the likelihood of seeing a new green area (social justice). • It is important to assess the existing spatial inequalities in the availability of green spaces to find where NbS can most benefit vulnerable communities and strata of society. Manage It is suggested to analyse space-time data on crime, because crime is one of the major factors negatively affecting the quality of green spaces or public parks.	(Babí Almenar et al., 2021; Brink et al., 2016; Endsley et al., 2018; Fisher et al., 2021; Yang, 2020)
Distributive, Procedural, Recognition, Contributive,	Procedural justice: Empowering all citizens to participate in the decision-making and creation phase of the NbS is relevant to ensure social justice outcomes. Recognitional justice: Facilitate the practices related to different cultures through NbS that reflect the needs of the population Contributive justice: Ensure that NbS are useful spaces not only for the residents of that specific neighbourhood but also a meeting place for neighbouring population. Distributive justice: Unequal spatial distribution of urban parks and green areas can contribute to distributive injustices. Accessibility to NbS: Consider ecological and socioeconomic inequalities in green space access. Distributive justice: Urban vegetation is often distributed unevenly among residents, creating social inequalities. Availability of NbS: the availability of NbS links social with biophysical conditions.	(Babí Almenar et al., 2021; Bush & Doyon, 2019; Endsley et al., 2018; van der Jagt et al., 2021; Yang, 2020)

3.5.3 Interlinkages with other key challenges

One aspect arising from the uneven distribution of services and environmental conditions is the different level of air pollution in different neighbourhoods (see also Section 4.1). Furthermore, zoning policies in the Unites States, intended to protect the public health, safety, and welfare, have often been proven to be exclusionary and relegating low-income individual or households and discriminated people to the least desirable locations, shaping current disparities within urban areas (Maantay, 2001) (see Section 4.6). Local discrimination, created through the prejudices imposed on certain populations because of their geographical location, is central to the production of spatial injustice. The three best known forces shaping spatial and locational discrimination are class, race, and gender (Soja, 2009).

Recent research (Musterd et al., 2017) shows a growing trend in socioeconomic segregation also in European cities even if it's difficult to identify specific nationality, race or ethnicity that have been excluded everywhere in Europe, and conditions of particular groups may vary a lot between cities and countries (Silver & Danielowski, 2019) (see again Section 4.6). At the European level, social disparities have been marked by isolation, ghettoization, and marginalization processes with increase targeting of immigrant population (Wacquant et al., 2014). This often occurred through land use policies and allocation of certain facilities, e.g. incinerators or other waste facilities, with major impact on immigrant and low-income households (Schönach, 2016). The concept of marginalization is defined as "an involuntary position and condition of an individual or group at the margins of social, political, economic, ecological, and biophysical systems, that prevent them from access to resources, assets, services, restraining freedom of choice, preventing the development of capabilities, and eventually causing extreme poverty" (Gatzweiler et al., 2011).

Table 28: Overview interlinkages with other key challenges

	Key insights	Strength and effect	Key literature
Air quality (in-)justice	• Improving air quality and controlling wind and temperature • Urban vegetation cleans the air	↗↑	(Hominick, 1993) (Endsley et al., 2018)
Thermal (in-)justice	• Reducing heating and cooling (costs) in buildings. • Urban vegetation cools neighbourhoods	↗↑	(Endsley et al., 2018; Yang, 2020)
Carbon (in-)justice	Spatial patterns and socioeconomic factors play important roles in the creation of ecosystem services (e.g. carbon sequestration, etc.)	↗↑	(Jiang et al., 2021)

FFH-inclusive	• Protecting water quality through the filtration of nutrients, reducing runoff from impervious surfaces, limiting soil erosion. • Urban vegetation reduces stormwater runoff. • Integrating natural elements into urban development could provide co-benefits such as biodiversity.	↓↗	(Endsley et al., 2018; van der Jagt et al., 2021; Yang, 2020)
Temporal (in-)justices	Land-use policies have led to processes of isolation of low-income households.	↓↗	(Schönach, 2016)

Note: Strength and effect ↓: strong negative interlink; ↘: partial negative interlink; –: no correlation; ↗: partial positive interlink; ↑: strong and positive interlink

3.5.4 Basket of indicators

The selected literature has considered several indicators and variables, which are summarised in the following table with reference to the different types of ecological justice mentioned above (e.g., recognitional, contributive, etc.). The last two columns in the table refer to our personal evaluation of how the different metrics (e.g., socio-demographic, socio-economic etc.) open the possibility to integrate different types of variables and inform our future analysis on the socio-spatial disparities profiles to be used in designing NbS. In the last instance, it is assessed, again according to our perception, whether these variables can be mapped and/or georeferenced.

Table 29: Basket of indicators to appraise NbS spatial (in-) justices potential

Indicator (metric)	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of integration	Spatial mapping potential
Socio-demographic Education, age, gender, race, cultural diversity index, income, population density	Existence of inequalities based on socio-demographics	Build NbS that reflect the community's characteristics Build NbS that avoid reinforcing existing social and spatial inequalities	Recognitional	++++	o
Socio-economic Job creation	Potential for economic opportunities and green jobs	All NbS measures and categories	Contributive	+	-
Social capital Relation	Offer new meeting places or consolidate existing ones, where there is a need	Parks and recreation; Allotment and community gardens	Recognitional	-	-

Organization Participation, social network	Engage stakeholders during NbS design	All NbS measures and categories	Procedural	+	-
Distribution of NbS Accessibility to useable NbS, NbS land cover, spatial distribution of environmental risk, transportation, cultural services	Improve the distribution of NbS	All NbS measures and categories	Distributive	+	○
Operates at multiple spatial scales / Place-based approaches Fine-grained spatial socio-economic, demographic, jurisdictional, biophysical and ecological data	Not creating larger problems somewhere Else	All NbS measures and categories	Recognitional	+	○
Accessibility (walkability index)	Reasonable walking distance or easy to access by public transportation	Urban parks	Distributive	+++	●
Demolition rate / Construction-demolition balance	Demolitions are a link between neighbourhood's social and biophysical conditions	All NbS measures and categories	Distributive	+	○
Foreclosure rate	Foreclosures may be seen either as drivers of vegetation change or as driven by vegetation change	All NbS measures and categories	Distributive	-	●
Housing cost burden, vacant housing units	Housing conditions to investigate spatial disparities	All NbS measures and categories	Distributive	+	○

Note: Level of integration -: no significant integration; some (+) to very high (++++)
Spatial mapping potential -: no significant mapping potential; ○: some; ●: high

The successful design and implementation of NbS is a multistage process that requires connecting and understanding in which specific stages green infrastructures bring positive values by reducing spatial (in-) justice, and identifying opportunities for increasing procedural and distributive justice. One aspect that should not be underestimated, however, is that most of this information related to the positive or negative influence of NbS on the increase or decrease of (in-) justice is often personal and therefore related to the perception that the community has through its own experience and knowledge. It is of utmost importance to know the context and how the changes (e.g., the introduction of a new NbS) are perceived locally. Involving the community itself, but also the municipality and commercial services, in this process would facilitate the collection of information on specific perceptual and experiential aspects. The organization of meetings that allow for an exchange of information is necessary to avoid unintended adverse outcomes such as gentrification.

3.6 Temporal (in-) justices

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Temporal justice refers to the interrelations between past, present and future conditions of injustices and inequalities, considering lock-ins and path dependency processes occurring in cities as well as the consequences of today's actions on future generations.

3.6.1 Definition

The concept of temporal justice is strongly related to the concepts of intergenerational- and climate justice. Intergenerational justice is defined as the transgenerational respect for the rights and the fulfilment of duties with regard to future and past generations (Meyer, 2012 in J. Taylor, 2013). In this sense, future or past generations can be viewed as "holding legitimate claims or rights against present generations, who in turn have correlative duties to future or past generations" (Meyer, 2012 in J. Taylor, 2013). Among these duties are ensuring a stable climate. In turn, climate justice acknowledges that people living in the future will suffer more from climate change than currently living people, who are responsible for today's greenhouse gas emissions.

Temporal perspectives on justice recognize that present manifestations of past and historic inequalities have an immediate bearing on efforts to ensure just outcomes for today and future generations (Meyer, 2017). From an intergenerational and climate perspective, the question of justice concerns the duties of present generations towards future generations in view of the fact that present emissions affect future environmental conditions.

The complex interrelation between past, present and future conditions determines the need for a more systemic view and understanding of the dynamics of socio-ecological systems; it defines the need to account for the way in which outcomes are shaped over time and how present conditions have their roots in historic realities that create trajectories for the future (Schönach, 2016).

Drivers of temporal injustices can be identified in past distribution patterns of environmental burden that persist over time, shaping current disparities and inequalities. The uneven distribution of environmental amenities and disamenities has been shown to cause systematically higher health concerns for particularly vulnerable populations that face disproportionate socioeconomic and environmental stressors. Air pollution has been shown to be a determinant of neighbourhood dynamics over longer time frames. Questioning why the east sides of formerly industrial cities are more deprived, for example, (Heblich et al., 2018: 1509) show "*that the east-west gradient is partially a remnant of the distribution of the atmospheric pollution that affected cities during the Industrial Revolution*." The influence of initial environmental conditions on current disparities has also been investigated through the analysis of house prices over time; a positive relation has been found between the increase in house prices and the distance from the historical location of environmental disamenities (Villarreal, 2013). Other such studies show how the effects on uneven distribution of environmental burden and benefits due to environmental conditions tend to persist over time, even after the obsolescence of the original conditions.

Social disparities can also be traced back to historical urban development and land-use patterns, and are related to the presence of particular discriminatory policies in the past. Discrimination and segregation phenomena have been shown to be the basis of certain land use policies in the United States (Maantay, 2001). Zoning policies, intended to protect the public health, safety and welfare, have often been proven to be exclusionary, often relegating low-income individual or households and minorities to the least desirable locations, thereby shaping current disparities within urban areas (Maantay, 2001). Such policies have often been accompanied by business practices referred to as redlining (Maantay, 2001; Lane et al., 2022), which withheld certain services like banking and insurance from potential customers who resided in neighbourhoods classified as "hazardous".

The location of noxious facilities in certain areas, contrasted with the restoration of others, is another result of zoning policies in the US that led to discrimination based on racial or ethnic background. Although segregation patterns in European cities are less pronounced than in the US, evidence of neighbourhood effects on life outcomes can be detected (Silver & Danielowski, 2019). Whereas black/white segregation is persistently the highest in the US, it is difficult identifying specific nationalities, races or ethnicities who have been systematically excluded in Europe, and conditions of particular groups may vary a lot between cities and countries (Silver & Danielowski, 2019). Nevertheless, recent research (Musterd et al., 2017) shows a growing trend in the socioeconomic segregation in European cities.

Compared with the explicit discriminatory intent of zoning policies in the United States, discriminatory measures in Europe have been less overt but have nevertheless led to isolation, ghettoization and marginalization processes with increased targeting of immigrant populations (Wacquant et al., 2014). This often occurred through land use policies and the discriminatory siting of certain facilities, e.g. incinerators or other waste facilities, with a major impact on immigrant and low-income households (Laurian & Funderburg, 2014; Schönach, 2016). Schönach, (2016) in particular, shows that burdensome activities persistently accumulate in certain neighbourhoods, through institutionalized patterns of decision-making and self-reinforcing sequencing of events. Such accumulation is also accompanied by the tendency to shield certain areas from burdensome facilities, further exacerbating disparities across neighbourhoods.

The concept of path dependence used in urban environmental studies refers to a form of dependence on initial conditions and the influence of previous decisions and choices on future ones (Liebowitz & Margolis, 1995). Previous decisions may restrict the available options in the future and lock-in the decision-making process to certain possibly unjust choices (Schönach, 2016). Inequalities may also occur with the exclusion from sustainability initiatives and greening interventions in historically deprived areas (Kotsila et al., 2021). Such pathways of exclusion are rooted in barriers that discourage the development of certain infrastructures in some areas, instead favouring investment in others where propitious circumstances already exist, e.g. where costs are lower due to pre-existing infrastructures (Gantioler, 2019).

Temporal justice issues inevitably deal with future climate change related questions, but the answers are often fraught with uncertainty, starting with the fundamental question of how much CO_2 will be emitted in the coming decades. Even if this quantity could be pinpointed, there remain uncertainties regarding follow-on effects, including the resulting increases in temperature, sea-level, and extreme weather events, as well as the associated impacts on human populations (Pindyck, 2021). Notwithstanding these uncertainties, the IPCC's latest projections on future climate (IPCC, 2022a) predict that global surface temperature will continue to increase until at least mid-century under all emissions scenarios considered (SSPs). Higher temperatures will be accompanied by an increase in the intensity and frequency of hot extremes, including heatwaves and heavy precipitation. Some regions will see an increase in the frequency and intensity of hydrological droughts. A warmer climate will intensify very wet and dry weather and climate events and seasons, with implications for flooding and droughts. The ocean and land carbon sinks are projected to be less effective at slowing the accumulation of CO_2 in the atmosphere under scenarios with increasing CO_2 emissions. Many changes due to past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level.

Increases in average global temperatures and related impacts will likely disproportionately affect vulnerable populations, and a range of vulnerabilities can be expected to increase in the future. Climate change impacts such as natural disasters and extreme weather events will likely exacerbate physical and mental health conditions of marginalized populations (Benevolenza & DeRigne, 2019); age, pre-existing medical conditions, social deprivation (Paavola, 2017) and language (due to barriers in accessing resources or understanding alert messages during disasters) (Nayak et al., 2018), have been found to be key factors that make people vulnerable to climate change impacts and vulnerability is expected to increase in the future due to an aging population.

The interaction between climate change and pre-existing patterns of cumulative inequalities raises questions about the extent to which adaptation and mitigation strategies in cities will reduce or increase the inequalities already being experienced (Klinsky & Mavrogianni, 2020).

Temporal considerations of justice are gaining increasing interest within studies of ecosystem services, particularly referring to the distributional effects determined by changes in provision and demand of specific ecosystem services on current and future societies, but also in relation to the role for current and future societies of unequal distribution, recognition and participation in the past (Anguelovski et al., 2020). Climate change, socio-demographic changes, and other drivers not only modify the provision of ecosystem services, but may also affect their future demand. Provision and demand for specific ecosystem services might have distributional effects both within the current society and in future societies. The adaptability and response to such changes is likely to depend on pre-existing socioeconomic and individual conditions. (Derkzen et al., 2017) show how individual circumstances, such as land tenure or financial capital, affect households' ability to adapt to changes in ecosystem services provision.

It is thus essential to consider the historical background to increase our understanding of existing environmental injustices, and how these injustices are sustained through path-dependent development patterns.

Table 30: Specific conditions defining temporal (in-)justices

	Key insights	Key literature
Environmental conditions	• Conditions such as air pollution, exposure to pollutants and other environmental disamenities are related with neighbourhood segregation and residential sorting processes. • The consequences of such environmental factors persist over time even after the obsolescence of the initial conditions.	Heblich et al., 2018 Lane et al., 2022 Villarreal, 2013

	• Changes in environmental conditions may determine changes in provision of ecosystem services.	
Social and economic conditions	Marginalized populations have higher vulnerability and are likely disproportionately affected by impacts related to climate change, e.g. extreme temperature, natural disasters	Musterd et al., 2017 Benevolenza & DeRigne, 2019
Individual conditions & vulnerabilities	Some individual circumstances might determine higher vulnerability to shifts in ecosystem services, occurrence of extreme weather events and natural disasters, and adverse health outcomes related to climate change: • Low income • Language • Age • Per-existing medical conditions • Social deprivation In the future, climate change and aging population may coalesce to aggravate the inequality of health outcomes related to climate change.	Derkzen et al., 2017 Nayak et al., 2018 Paavola, 2017
Built-environment	• Urban environment choices, e.g. siting of waste facilities, have often preserved certain areas from environmental burden, resulting in the accumulation of environmental disamenities in poorer neighbourhoods. • Path dependency tends to lock-in certain circumstances especially in the context of the built environment, due to the longevity of the building stock and infrastructure. • In the context of climate change, decisions about the built environment e.g. in housing, the siting of industrial centres and neighbourhood design, result in commitments to particular forms of energy and ways of life that are difficult to shift and thus result in a diversity of social, economic, energy, resource and physical path dependencies.	Maantay, 2001 Schönach, 2016 (Klinsky & Mavrogianni, 2020)

3.6.2 NbS contribution

NbS interventions in cities can affect urban society by reconfiguring values, benefits, services and uses of spaces (Kabisch et al., 2016). The potential of NbS to produce co-benefits depends on the socio-ecological context; this affects the capacity of NbS to restore ecological flows, enrich biodiversity and provide social co-benefits to the local community (Gómez Martín et al., 2021). In order to understand the potential and opportunities of NbS to produce such co-benefits, the consideration of historical conditions and path-dependencies in urban planning play a major role in the planning process (Kabisch et al., 2016). Path-dependencies, cultural legacies and planning paradigms determine current urban planning, and specific factors rooted in past decisions can inform future opportunities for the implementation of different kind of NbS, enabling or hindering their potential (Zwierzchowska et al., 2021).

A fundamental issue in the implementation of NbS that has consequences in terms of temporal justice concerns the lack of evidence regarding their long-term impacts (Dumitru et al., 2020). This regards specific complex impacts of NbS that reveal themselves over the long run: benefits in climate change mitigation; social impacts and outcomes, like increases in social cohesion or place attachments; certain health-related impacts such as in life expectancy or the prevalence and incidence of certain diseases, or due to behavioural changes such as increases in exercise. It also relates to questions of effectiveness but also the fairness of biodiversity offsetting measures, a conservation tool for balancing biodiversity losses (Maron et al., 2016).

Further complicating this issue is the fact that the costs and benefits of NbS occur over different time frames, with the costs generally incurred over the short run while the benefits accumulate more slowly and into the more distant future. In assessing whether to implement a given NbS, one is therefore confronted with how to weigh future benefits against immediate costs, an inherently intergenerational question. In the context of formal cost-benefit analysis (CBA), where the aim is to determine the net benefits of an intervention, this question is usually resolved through the application of discounting, which assigns lower values to costs and benefits that occur in the future. This practice is justified by the notion of time preference (Schelling, 2000): People generally place a higher value on gratification enjoyed now than gratification in the future (see Box 10). However, discounting is also highly controversial owing to the perception that it short-changes the future. In particular, the use of high discount rates in a CBA tends to mitigate against implementing projects whose benefits are accrued in the long term because these are assigned lower values relative to the costs that are incurred in the here and now. Applying a low discount rate or none at all is also problematic, however, because this fails to adequately recognize that resources invested today have an opportunity cost, which may lead to investments in ill-advised projects.

Box 10: Using discount rates

One measure of time preference is the interest rate in private investments, which is effectively a discount rate. For example, given an annual interest rate of 5%, the discounted value of 100 euros obtained in one year would be 100/(1 + 0.05) = 95.24 euros in today's value, just as 95.24 euros invested today would be worth 100 euros in a year. As this example illustrates, discounting translates future sums of money into equivalent current sums (Goulder & Stavins, 2002), which makes it highly useful in deciding whether to undertake a project whose costs and benefits arise at different points in time.

There is a fundamental difficulty of how to settle on the correct discount rate to apply in any given cost benefit analysis. As there is no clear answer to this question, it is often prudent to apply different discount rates to explore the sensitivity of net benefits calculations to the level chosen. For example, the

US Environmental Protection Agency typically employs two rates of 3% and 7%, with the former regarded as the "social" rate of discount and the latter the "business" rate to reflect public and private perceptions in decision-making.

CBA is predicated on ascribing a monetary value to as many of the relevant cost and benefit categories as possible. This serves to translate the value of disparate elements into comparable units, which in turn allows reaching a calculation of the net benefits. Some cost and benefit categories, however, such as those related to certain health impacts or ecosystems services, are difficult to monetize accurately, but nevertheless substantially impact welfare and should therefore be considered in the analysis. Doing so requires input from allied fields such as epidemiology and ecology to at a minimum quantify the impacts of the NbS, even if these ultimately defy monetization. In order to plan NbS in a way that ensures equitable distribution of benefits throughout their lifecycle, an interdisciplinary approach is thus needed to analyse the potential long-term outcomes in addressing the initial challenges, and to understand multiple additional benefits or trade-offs (Kabish et al. 2022).

Given the variety of temporal scales over which an NbS is implemented, any assessment should consider the length of time for particular actions to become effective in relation to the challenge to be addressed. Ideally, NbS effectiveness should be assessed in reference to different time thresholds to evaluate short-time effects (5 years), medium-time effects (5-10 years), and long-time effects (over 10 years) (Sowińska-Świerkosz & García, 2021). A proper evaluation of NbS over time would allow to identify potential additional interventions, guaranteeing NbS functionality over time through continual adjustments in implementation and maintenance (Dumitru et al., 2020).

Long-term monitoring of NbS becomes particularly important in a climate changing context, where changes in mean temperature, species distribution or precipitation patterns are highly likely to alter ecosystem functions and thus NbS functionality. The long-term capability of NbS to deal with extreme weather events such as droughts may not be sufficient in a climate change context (Gómez Martín et al., 2021). Climate change, socio-demographic changes and other drivers indeed, not only modify the provision of ecosystem services but may also affect their future demand.

Ensuring a just implementation of NbS from a temporal perspective requires to understanding the ecosystem service- (or NbS functions) that different groups require for their flourishing in the future, and how the flow of such ecosystem services can be maintained in the future (Langemeyer & Connolly, 2020). To do so, taking into account the uncertainty of future conditions when planning and implementing NbS is crucial.

The SSP-RCP framework (see Box 11) is supporting research on future scenarios across different thematic areas and spatial scales. To use global scenarios in local studies, several extensions of the SSP-RCP framework have been developed to include information on climate and societal conditions at scales relevant for decision-making. Climate projections downscaled to the regional and local level, consistent with projected trends related to land-use change, would provide a better understanding of the implications of variations in land-use and regional climate across SSPs, improving the understanding of future resilience (O'Neill et al., 2020).

Top-down and bottom-up approaches have been used to integrate global scenarios in local studies. In top-down studies, the scene for potential future developments in specific contexts are developed by experts within the scientific community, using as boundary conditions the global SSPs. Bottom-up studies, by contrast, engage stakeholders as a key part of the methodology to include local-specific knowledge (Nilsson et al., 2017). Expanding the participation of several stakeholders through an interactive interfacing process between experts and society would make scenario products more widely known and accessible (O'Neill et al., 2020).

Gómez Martín et al. (2021) used a participatory approach applied to the SSPs framework in the evaluation of the long-term effectiveness of NbS under different climate scenarios. They engaged stakeholders in the model development, and analysed the NbS suitability in the light of the development pathways depending on different policy measures. They demonstrate that proper communication and management of this uncertainty through the stakeholder engagement process provided multiple advantages, contributing to the identification of barriers and the limitations of NbS implementation. Their approach also revealed complex interconnections among system elements, helping to anticipate possible policy resistances or rebound effects, and to promote awareness and collective learning.

Box 11: Socioeconomic and Climate Scenarios

In the late 2000s, multiple-communities have collaborated in the development of the so-called Shared Socioeconomic Pathways (SSPs) – Representative Concentration Pathways (RCPs) framework.

The RCPs were published in 2011 with the purpose of providing time-dependent projections of atmospheric greenhouse gas concentration. The SSPs, developed in 2017 provide modelling of possible changes in socioeconomic factors over the next century, including population, economic growth, education, urbanization and the rate of technological development. The SSPs are based on five narratives describing alternative socio-economic developments, including sustainable development (SSP1), Middle of the Road (SSP2), Regional Rivalry (SSP3), Inequality (SSP4) and Fossil-fuelled Development (SSP5).

The two efforts were designed to be complementary. The RCPs set pathways for greenhouse gas concentrations and, effectively, the amount of warming that could occur by the end of the century. Whereas the SSPs set the stage on which reductions in emissions will – or will not – be achieved.

The SSP do not include mitigation and adaptation responses themselves, nor do they include the impacts of climate change. This design choice was made so that integrated studies can assess the effects of policies or magnitude of impacts included in their own studies by comparing outcomes to those in the SSPs.

Stakeholders' engagement would also provide useful information for understanding the implications of policies and interventions on populations, in order to avoid exacerbating existing vulnerabilities and creating unfavourable outcomes.

Actions to increase knowledge and understanding of historical conditions and development patterns, inclusion of non-human actors into consideration as well as future generations needs in decision-making processes, could help addressing future risks and ensure that future living conditions under the impacts of climate change are as bearable as possible and unnecessary harm is avoided (Fünfgeld & Schmid, 2020).

Table 31: Overview of the contribution of NbS and key types

	Key insights	Key literature
NbS contributions	NbS in cities can affect the urban environment reconfiguring values, benefits, services and uses of spaces, with effects over the long period. The contributions of NbS that affect the cities in the long run concerns • Benefits in climate change mitigation • Social impacts and outcomes, e.g. increases in social cohesion or place attachments; • Health-related impacts e.g. life expectancy, prevalence and incidence of certain diseases, impacts related to changes in behavior • Restore ecological flows, enrich biodiversity • Protection from extreme weather and natural disasters When considering long-term contribution of NbS some aspects need to be taken into account: • The effect of historical conditions and path-dependencies to inform future opportunities for the implementation of different kinds of NbS that can enable or hinder their potential. • The need for long-term monitoring of NbS to - Understand multiple additional benefits or trade-offs - Ensure NBS effectiveness in the long period - Provide adjustments and additional interventions to guarantee NbS multifunctionality over time. • The impacts of climate change, socio-demographic changes and other drivers that can modify the provision and demand of	(Dumitru et al., 2020; Kabisch et al., 2016; Langemeyer & Connolly, 2020; Zwierzchowska et al., 2021)

	ecosystem services, affecting the effectiveness of nature-based solutions over time	
NbS categories and measures	Mitigation of extreme weather events, key focus on • Green walls and roofs, trees and parks, blues infrastructure • Rain gardens, floodplains, bioswales, permeable pavements Major impacts on social outcomes comes from: • Urban parks • Allotments and community gardens Health impacts: • Urban trees • Green corridors	(Seddon et al., 2020)

Table 32: Types of action and justice principles

	Key insights	Key literature
(Remove) Protect, Manage, Restore, New	• Increase knowledge and understanding of historical conditions and patterns of disparities to inform measures that address the unequal distribution of vulnerabilities • Monitoring and evaluation over the long term in order to identify and provide required additional intervention in the future that could avoid reduction of nature-based solutions performance over time. • Consideration of nonhuman actors and future generations in the decision-making process. • Increasing stakeholder engagement and awareness can enhance the potential of NbS to deliver certain co-benefits over time and to - Identify barriers and limitations of NbS implementation - Integrate local knowledge - Reveal complex interconnections among system elements and help to anticipate possible policy resistances or rebound effects and suitable NbS to act on the system - Promote awareness and collective learning. • Take into account uncertainty when considering future climate scenarios. Proper communication and management of this uncertainty represent an opportunity for NBS decision-making.	(Fünfgeld & Schmid, 2020; Gómez Martín et al., 2021)
Distributive, Procedural, Recognition, ?	Distributive/Recognition: Take account of different outcomes on different groups depending on their social and individual vulnerabilities in order to mitigate long-term potential trade-offs related to NbS implementation; Recognition of youth and children as legitimate voices in NbS planning; Procedural: Include in the decision-making process individuals who will be personally affected by mid- and long-term outcomes of NbS implementation and inclusion of future generation and nonhuman stakeholders' needs. Corrective: actions that aims at ensuring the mitigation of future loss and risks, related to climate change impacts, could have effects in terms of corrective justice, within a process of re-establishing equality through the recovering of original conditions or ensuring actions undertaken today have the least possible impact on future generations	(Fünfgeld & Schmid, 2020)

3.6.3 Interlinkages with other key challenges

Temporal justice shows strong relationships with all the other considered justice challenges, as temporal concerns and the associated distribution, recognition and procedural challenges crosscut all the relevant justice aspects identified in the context of NbS potential. Temporal implications must be acknowledged both in their legacies determining present conditions as well as in the future implications of the actions undertaken today. The main temporal considerations for the different justice components are discussed below.

Air quality conditions have been proven to shape spatial disparities, producing conditions of inequality and neighbourhood dynamics that shapes our cities over the long term. This e.g. can also be linked to impacts in relation to decisions on air monitoring systems (see Chapter 3.3 on air quality in-justices). Moreover, actions to improve air quality conditions may require long timeframes to be evaluated in their beneficial effects, and may produce effects that persist over time with consequences on intergenerational justice.

Considerations of temporal scale are inextricably linked with thermal justice issues, as green planning to improve thermal outdoor comfort in cities and reduce urban heat island effects must take account of projections of future climate scenarios, especially in relation to raising temperature and increasing extreme weather events such as heat waves during summer seasons.

Temporal justice is also strictly related to carbon justice given the disparities between the sources of carbon emissions – people in the present – and those who incur the costs, as people living in the future will suffer disproportionately more from climate change than currently living people, who are responsible for greenhouse gases emissions. It also takes into consideration historical responsibilities for emissions. Moreover, when it comes to climate mitigation measures, urban development patterns can create obstacles in the implementation of NbS: urban infrastructure and built environment are long-lived assets, particularly prone to carbon lock-ins due to interactions between infrastructure, technological and behavioural systems which create inertia and path dependency that are difficult to break (IPCC, 2022b). An example is the interrelation between highway and energy infrastructure and social and cultural preferences for individual mobility options, which determine the dominance of car and their supporting infrastructures (IPCC, 2022b). Another example is the development of underground infrastructure systems (e.g. water, ICT) or the use of defined street and road material, which affect the space available for the siting and growth of trees. When it comes to designing NbS for carbon reduction, such as restoring an ecosystem, taking account of potential impacts from climate change is critical; NbS must be designed for longevity, paying closer attention to their long-term carbon sink potential, as well as their impacts on biodiversity (Kopsieker, L., et al., 2021).

Spatial disparities and conditions of inequalities occurring in cities and the uneven distribution of environmental amenities and disamenities, are rooted in past decisions and choices and in the historical urban development. The distributional justice effects related to changes in environmental conditions and infrastructures' allocations slowly modify the spatial configuration of socioeconomic conditions, with important implications in terms of intergenerational justice.

Temporal justice also has a strong relationship with FFH inclusion given that exploitation of resources, pollution emissions, and land-use changes have historically caused a decline in biodiversity and ecosystem functions. Climate changes, with the increased intensity of extreme weather events and fires, floods and droughts, have contributed to expanding this negative impact in several respects, including species distribution, phenology, population dynamics, community structure and ecosystem function. Moreover, scenarios on future impacts of global environmental change show how biodiversity and regulating ecosystem services provided are projected to decline, exacerbated by the compounding effects of land-use change, overexploitation of resources, pollution and invasive species (IPBES, 2018). By contrast, reducing the pressures affecting ecosystem function (pollution, invasive species, habitat loss and fragmentation, over-exploitation, and enhancing genetic, species and functional richness, could minimize ecosystem sensitivity to future global changes (Seddon et al., 2021).

Table 33: Overview interlinkages with other key challenges

	Key insights	Strength and effect	Key literature
Air quality (in-)justice	• Historical patterns of distribution of air pollution have been shown to generate neighbourhood dynamics of segregation that persist over time • Impacts of NbS implementation on air quality may require a longer timeframe to be evaluated	↓↑	(Heblich et al., 2018; Lane et al., 2022)
Thermal (in-)justice	• Green planning to improve thermal outdoor comfort in cities and reduce UHI must take account of projections of future climate scenarios, especially in relation to raising temperature and increasing extreme weather events such as heat waves during summer seasons.	↓↑	(R. D. Brown et al., 2015)
Carbon (in-)justice	• Past and current GHG emissions will have disproportionate effects on future generations • Urban development and path dependency create an obstacle to overcoming carbon lock-ins and can hinder the implementation of GHG emissions reduction strategies	↓↑	(IPCC, 2022b; Kopsieker, L., et al., 2021)

	• In the context of carbon reduction strategies, NbS must be designed for longevity considering climate change impacts, paying attention to the long-term carbon sink potential and their impacts on biodiversity		
Spatial (in-)justice	• Urban greening projects might cause shifts in ecosystem services across socio-economic groups that happen over the mid- and long-term scales, producing effects that have implications for intergenerational justice (e.g. future generation of socially vulnerable groups are excluded from improvement)	↓↑	(Langemeyer & Connolly, 2020)
FFH-inclusive	• Historically, exploitation of resources, pollution and land-use changes have caused a decline in biodiversity and ecosystem functions • Climate changes and the compounding effects of land-use change, overexploitation of resources, pollution and invasive species are likely to exacerbate the negative impacts on nature. • Ecosystem sensitivity can be minimized by reducing the pressures affecting ecosystem function and enhancing genetic, species and functional richness	↓↑	(IPBES, 2018; Seddon et al., 2021)

Note: Strength and effect ↓: strong negative interlink; ↘: partial negative interlink; –: no correlation; ↗: partial positive interlink; ↑: strong and positive interlink

3.6.4 Basket of indicators

When it comes to defining relevant indicators in terms of temporal justice, a few aspects need to be taken account:

- Identification of those aspects that, rooted in the past, affect the potential of NbS interventions
- Identification of areas of vulnerability and exposure to climate change where NbS can provide benefits
- The definition of the monitoring timeframe to ensure the proper management and the mitigation of potential negative impacts and the maintenance of benefits over time

The spatial configuration of socioeconomic as well as environmental conditions across the city and the modification over time can provide information on areas where particular conditions of exposure and vulnerability exist and might be exacerbated by future climate changes. This can also provide information on particular aspects to consider when implementing NbS as well as information on what kind of NbS to implement, in light of the characteristics of the neighbourhood, households and their specific needs and preferences.

Identification of areas of exposure and vulnerability, through indicators of air pollution, indoor and outdoor thermal discomfort exposure, socio-demographic characteristics that may represent vulnerable conditions (e.g., income, education level, age, gender, race), and their monitoring over time not only provide information on areas at particular risk to exposure and the correct interventions to undertake, but also provide information on those aspects that require particular attention during the lifetime of the project.

The necessity of long-term monitoring systems has been persistently emphasized. However, the common method envisages the evaluation of single assessments to assess the pre-NbS and post-NbS conditions, whereas some metrics require more frequent and continuous monitoring. Such real time or near-real time acquisition of data would be particularly useful in terms of stakeholder engagement, contributing to support educational and learning opportunities.

The above considerations are applicable for the various baskets of indicators that are introduced in the various chapters of the ecological (space) justice components, and not necessarily limited to only one thematic area (e.g. siting of monitoring systems over time). The table below presents a few that are particularly pertinent to temporal (in-) justices considerations, as outlined above.

Table 34: Basket of indicators to appraise NbS temporal (in-) justices potential

Indicator (metric)	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of integration	Spatial mapping potential
Land use and land use change indicators					
Land use and land use change	Land use changes	na	Distribution/ Procedural	++++	● (Satellite and aerial imagery)
Green space configuration and variations over time	Land use change	na	Distribution/ Procedural	+++	●
Location of facilities (waste facilities, incinerators…)	Land use	na	Distribution/ Procedural	++	●
Proportion of natural areas	Land use change impacts on natural heritage	na	Distribution	++	●
Proportion of protected areas	Land use change impacts on natural heritage	na	Distribution	++	●
Neighbourhood age (usually determined by average building age and land use change)	Correlated to the distribution of green spaces and tree canopy	Urban green areas and urban tree canopy	Distribution	+	○

Indicators of vulnerable areas and areas exposed to risks					
Urban/residential/ productive area exposed to risks	Climate change impacts	Green walls and roofs, trees and parks, blues infrastructure; rain gardens, floodplains, bioswales, permeable pavements	Distribution	++++	●
Vulnerable population (e.g. elderly, disable) exposed to risks	Climate change impacts	Green walls and roofs, trees and parks, blues infrastructure; rain gardens, floodplains, bioswales, permeable pavements	Distribution	+++	○
Urban/residential/ productive area exposed to flood risks	Climate change impacts	Rain gardens, floodplains, bioswales, permeable pavements	Distribution	+++	●
Buildings and infrastructures exposed to flood risks	Climate change impacts	Rain gardens, floodplains, bioswales, permeable pavements	Distribution	+++	●

Note: Level of integration -: no significant integration; some (+) to very high (++++)
Spatial mapping potential -: no significant mapping potential; O: some; ●: high

4 INSIGHTS FROM THE COMMUNITY OF PRACTICE

4.1 Insights from consulting the involved city partners

A community of practice is formed by people who have engaged in a process or a network of collaborative learning in a shared domain, whereas '*practice is about meaning as an experience of everyday life*' (Wenger, 1998). The city partners as part of the City Practice Labs (CiPeLs) are inherently part of JUSTNature's Community of Practice (CoP), which engages in the common activity of testing, designing, activating, implementing, questioning and evaluating the various project results. As part of this CoP, several activities have been carried out to inform the development of the conceptual and action framework (see Chapter 1.2.1).

The second CiPeL workshop took place on 27th of January 2022 in order to collect information on pre-existing knowledge about justice issues and perceived socio-ecological disparities and injustices in the different CiPeLs contexts. Building on the activities of WP2, each CiPeL had been provided the following questions in anticipation of the meeting:

- What are the biggest perceived ecological injustices in their area/city? Can you provide examples of issues and concerned neighbourhoods?
- Are there any environmental conditions/characteristics perceived as the most disproportionately or evenly disturbed?
- Who or which groups are perceived to be more welcomed/loudest or excluded/silent and should be more included in the design and distribution of ecological space, urban and peri-urban green areas and nature-based solutions?
- How much weight should be given to nonhuman stakeholders in the decision-making process?

The main perceived ecological injustices mentioned were regarding

- Presence of overbuilt areas in the cities
- Inaccessible land and housing prices
- Land-use conflicts
- High sealing levels
- Urban heat islands

The latter in particular influenced the decision to have the thematic cluster of thermal (in-) justices included in the action framework.

Various participants also mention the lack of green and accessible open spaces in city centres and in low-income neighbourhoods, considered key part of spatial (in-)justices considerations. The environmental conditions referred to as being disproportionately distributed were:

- Limited access to recreational areas and green public spaces for low-income neighbourhoods
- Disparities between private and public gardens
- Unbalanced distribution between real estate and nature features
- Air pollution issues
- Heat islands perceived to have greater impacts in some parts of the cities.

Groups mentioned by the CiPeLs to have a perceived louder voice in decision-making processes were local industry representatives, business owners (e.g., touristic, hotelier and restoration businesses), car owners or private investors; whereas groups generally perceived as less listened include elderly and young population, migrant and refugees, homeless; a gender imbalance in participation is also mentioned. It needs to be noted that beyond these general patterns, each site is very specific and what might be a predominant group in a CiPeL can be completely ignored in another. Finally, all participants strongly agreed on the importance of considering nonhuman stakeholders in the decision-making processes. These results of the workshop have also further informed the stakeholder mapping process as part of the activities of WP4 and outlined in D4.1.

While building the conceptual and action framework, a condensed version of the developing scientific knowledge base in the form of a concept note was created and distributed in advance of the biannual project meeting, at the beginning of May 2022 (see Annex 4). In it, the commonly used justice frameworks were introduced along with innovative, new frames that could be considered when related to 'greening' and NbS. The final section of the concept note began to introduce the central action components of ecological (space) justice that JUSTNature would be exploring.

In response to feedback received, a third CiPeL workshop was held on the 20th of June 2022 called, "*Justice of what? Navigating ecological (space) justice and Low carbon-High air quality NbS potentials – Insights from WP2*". While this workshop was much less interactive, it was important to share the synthesised scientific knowledge base that informs the action framework to ensure clarity as we move into the next project phases aligned with our city partners. On top of that, pertinent updates and next steps were shared across multiple work packages.

One request that was made to the CiPeLs was to complete the same survey that was devised by EURAC and distributed by ISOCARP to urban planners about NbS activation as discussed more in-depth in the following section (4.2.3).

4.2 Feedback from urban planning practitioners community

4.2.1 Overview of the survey and respondents' information

A survey was devised to understand how urban planners and practitioners address the following questions referring to the importance they attribute to activating Low carbon | High air quality NbS:

- What role do environmental justice considerations play in urban planning practitioners' daily work?
- What key aspects do urban planning practitioners think need to be considered for the planning of low carbon AND just cities?

The survey includes 14 questions to test the concepts and assumptions on different identified justice challenges, including air quality, thermal and carbon (in-)justices, flora fauna habitat (non-)inclusiveness) as well as spatial and temporal (in-) justices. It entails six additional questions to collect information on the respondent's occupation and personal information (e.g., occupation, field of specialty, years of experience, location, age, and gender).

A link to the survey (google form) was shared through various channels, including ISOCARP Society members' channel (Monthly newsletter and WhatsApp group) and social media of ISOCARP Institute and the JUSTNature project (e.g., LinkedIn and Facebook). The link was shared beyond the project group to get more reactions from the general urban planning community. It was shared with Crowdhelix, the Urban Planning Group on LinkedIn, and the Facebook group of the Institute for Housing and Urban Studies (IHS) Alumni, etc. The survey was opened on 7th of June.

Until the finalization of the input to this report, the number of respondents was 16. Among the respondents, 63% (10) was female, while 31% (5) was male. The age of respondents ranges from their 20s to 40s (Figure 9).

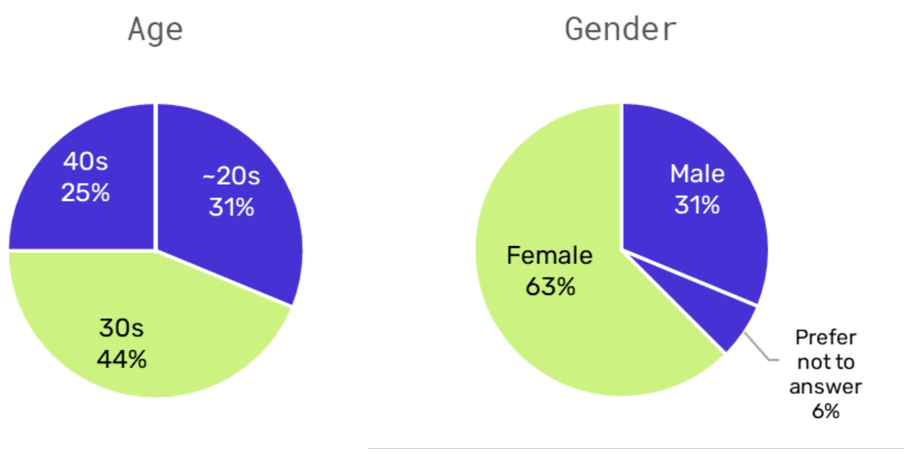

Figure 9: Age and gender of respondents (urban practitioners)

Thirteen respondents provided information on their occupation: five from research institute, three from universities, two from NGO, two from private industry, and one from civil society initiatives. The years of experience are more than 3 years. Seven respondents answered with '3~5 years', six answered with 'more than 10 years,' two with '5~7 years,' and one with '7~10 years.' Fourteen respondents provided their field of specialty: seven people as 'urban planning and governance,' four as 'environmental management,' two as 'green infrastructure,' and one as 'architect.'

4.2.2 Responses

The five most frequently chosen solution areas for the right to ecological space in the city are:

1) Biological diversity conservation (10)
2) Implementation of environment-friendly mobility (9)
3) Improvement of urban climate (7)
4) Improvement of water management (7)
5) Promotion of clean air (6)

Respondents were asked to rank from 1 (not important) to 4 (very important) for statements regarding various aspects of environmental justice. A 4-scale score was calculated based on the rank score (1~4) and their frequency as a weight. First, regarding the importance of distributional considerations on environmental justice in the planning of a city, the highest scored statement was "*Low-income households are more exposed to environmental burdens than others* (3.7)," followed by "*Environmental resources (e.g. green areas or nature reserves) are distributed evenly across the city*. (3.6)," and "*The distribution of environmental burdens and resources supports habitat conservation and urban* *flora/fauna*" (3.4). When considering the distributional aspect, attention is needed for socially disadvantaged groups like low-income households. The distribution of environmental resources (or burdens) needs to be even and fair, as well as considering urban flora and fauna.

Second, related to governance consideration on environmental justice in the planning of a city, the highest scored statement was "*Governance occurs as part of planning processes that involve the large participation of different actors (e.g. citizens, civil society organisation, and business representatives)*" (3.7), followed by "*The main focus of environmental justice is on low-income, disadvantaged, and excluded population groups*" (3.5). This shows urban practitioners understand governance as a process, also importance of involving various actors. In addition, attention is given to the socially vulnerable people.

And finally, when asked about different aspects of justice in the planning of urban NbS, the most important (highest scored) statement was "*Distribution of access and proximity to a defined quality of green and blue space shared among citizens*" (3.9) and "*Recognition of local knowledge and social needs*" (3.9). Both quality and accessibility are important aspects of environmental justice. Also, local-specific contexts need attention in considering justice in the planning of urban NbS.

The respondents were asked to choose the thematic justice blocks that they were interested to know more about regarding NbS (Figure 10). The most frequently chosen block was '*spatial justice: balancing socio-economic development with environmental stewardship, and address gentrification* (12).'

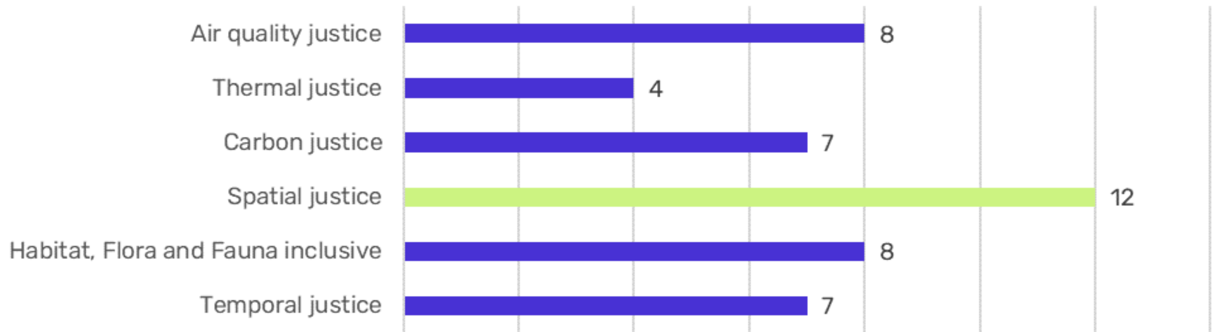

Figure 10: The most interesting thematic justice blocks for NbS

The following table shows the three most frequently chosen NbS categories that have the most potential to address one or more of the thematic justice blocks. Several NbS categories were chosen the most in multiple thematic justice blocks. For example, '*Parks and recreation areas*' were in the top 3 choices in all thematic justice blocks except for carbon justice and temporal justice. '*Allotments & community gardens*' was in air quality justice, spatial justice, habitat, flora & fauna inclusive, and temporal justice.

Table 35: Potential of NbS categories for each thematic justice block

Rank	Air quality justice	Thermal justice	Carbon justice	Spatial justice	Habitat, Flora & Fauna inclusive	Temporal justice
1	Parks & recreation areas (13)	Green buildings (13)	Agricultural land (13)	Parks & recreation areas (14)	Allotments & community gardens (12)	Natural, semi-natural & derelict or vacant land (8)
2	Private, Commercial, industrial, & institutional urban green space (12)	Parks & recreation areas (11)	Natural, semi-natural & derelict or vacant land (11)	Allotments & community gardens (13)	Agricultural land (12)	Riverbank green (8)
3	Allotments & community gardens (12)	Private, Commercial, industrial, & institutional urban green space (10)	Blue infrastructure (11)	Natural, semi-natural & derelict or vacant land (10)	Parks & recreation areas (11)	Allotments & community gardens (7)

Respondents were asked to indicate from 1 (do not agree at all) to 4 (completely agree) about statements regarding thematic justice blocks. Using the number (1~4) as score and frequency of responses as weight, a 4-scale score was calculated. First, about air pollution justice in the city, the respondents mostly agreed with "T*here are big disparities in exposure to air pollutants"* (3.3). Second, two statements regarding thermal justice scored the highest: "*The excessive built surface is one of the major causes of higher air temperature in cities compared to rural areas (i.e. urban heat island effect)*" (3.8) and "*People living in areas with less access to urban green infrastructure, and reduced ability to maintain and develop* private green *space are more exposed to heat-related burdens"* (3.8). Third, when asked about ecological justice, the highest score was given to the statement: "*My clientele have diverse opinions, preferences, and values about nature and natural elements*" (3.1). Finally, the highest scored statement for the aspect of gentrification as effect of the NbS was *"People with disabilities can encounter accessibility problems to neighbourhood green spaces*" (3.4).

Respondents were asked to rank from 1 (the most important) to 5 (least important) for interventions for the planning of carbon just city. Assigning 'the most important' as score 5 and 'the least important' score 1, the 5-scale score was calculated. The most important (highest score) intervention was "*Development of NbS for increased urban resilience to risks* *such as droughts, floods and heatwaves*" (3.8), while the least important intervention was "*Proper management of urban soil to increase carbon capture potential*" (1.9).

When asked about the most important phases to consider socio-economic, cultural and socio-demographic characteristics of the neighbourhood to reduce the potential gentrification where NbS will be placed, "*Design phase: Creating the project plan*" (8) and "Initiation phase: Project study (8)" were most frequently chosen (Figure 11).

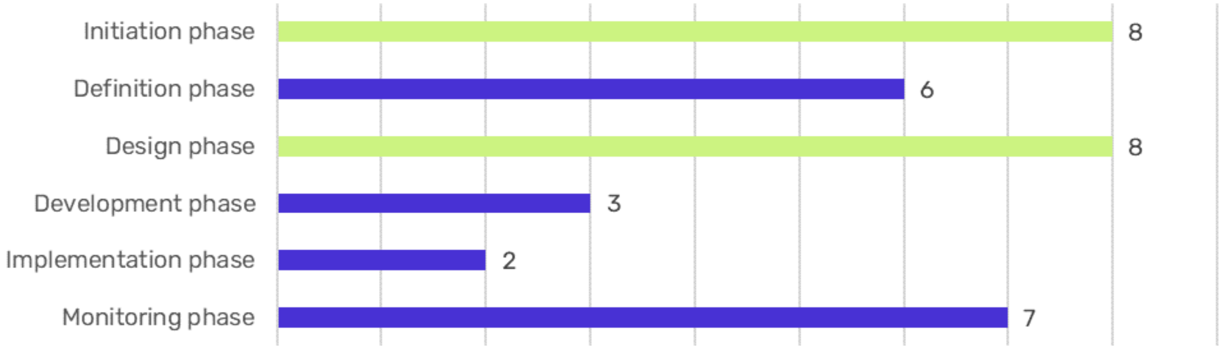

Figure 11: The most important phases in considering decreased gentrification

Finally, respondents were asked to rank from 1 (the most important) to 7 (the least important) on actions regarding ecological (space) justice in the city (Figure 12). Giving score 7 to 'the most important' and 1 to 'the least important,' a 7-scale score was calculated. The most important action was "*Considerations of impacts on future generations in NbS implementation*" (4.8) while the least important action was "*Include youth in the decision-making process as stakeholders that will be personally affected by mid- and long-term outcomes*" (3.1).

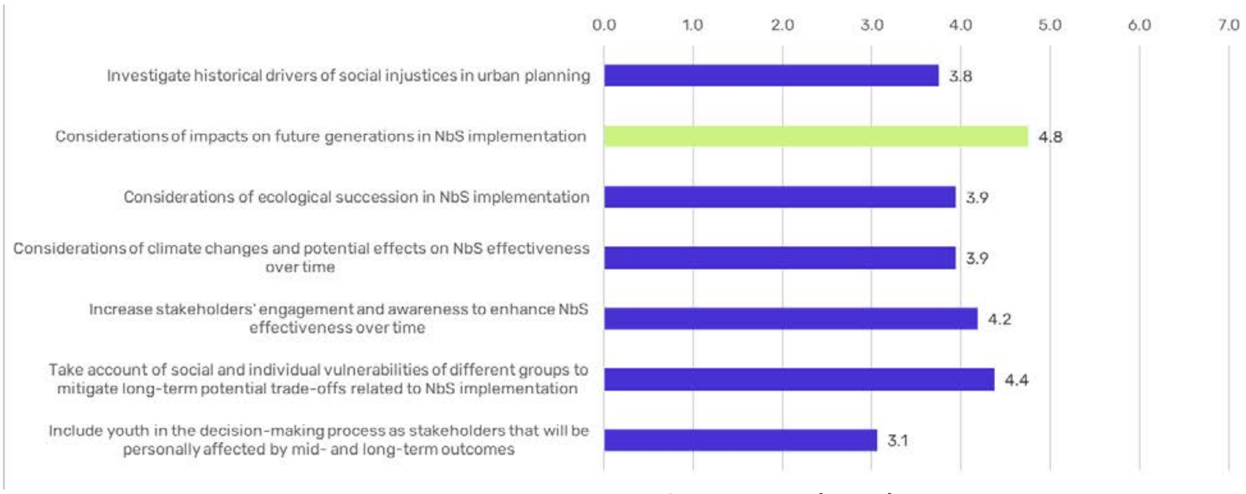

Figure 12: The most important action for ecological (space) justice

The detailed responses are included as part of Annex 3 of this report. The results of the survey, which is still expected to engage additional respondents, are expected to further inform the shaping of the handbook on identifying Low carbon | High air quality NbS potentials in cities (D2.4) (see Conclusions).

4.2.3 Survey result - CiPeLs

The same survey was distributed among CiPeLs. In total, there was 9 respondents from the CiPeLs, five of them are male and four were female. The age ranged from 30s to 40s and one person in 60+ (Figure 13).

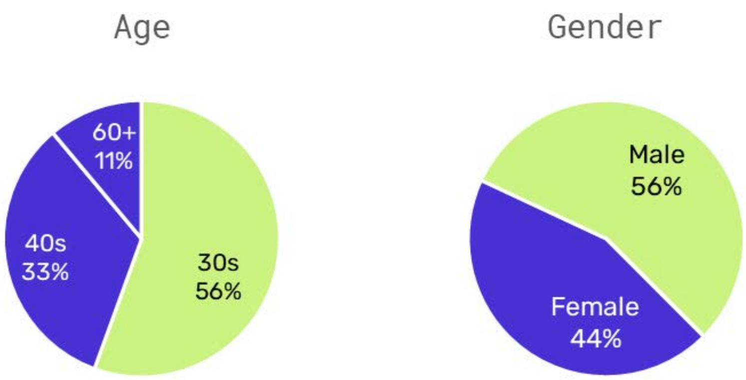

Figure 13: Age and gender of respondents (CiPeLs)

Six respondents, who provided their occupational information, all indicated they work in 'government organization.' Their fields of specialty were specific including 'nature-based solutions and green infrastructure,' 'urban heat islands,' 'sustainable mobility,' 'water management,' 'cities,' and 'green project development.' The years of experience varies: four for 'less than 3 years,' one for '3~5 years' and four for 'more than 10 years.'

The five most frequently chosen solution areas for the right to ecological space in the city are:

1) Improvement of urban climate (6)
2) Promotion of clean air (5)
3) Reduction of urban soil sealing (5)
4) Implementation of environment-friendly mobility (4)
5) Biological diversity conservation (3), Improvement water management (3), Promotion of urban gardening (3), Conserving and restoring urban agricultural land and forests for carbon capture and storage (3), and Protection from natural disasters or disease (3)

The most important statements for distributional considerations on environmental justice in the planning of a city for CiPeLs were "*Environmental burdens (e.g. air pollution, noise heat, or water pollution) are concentrated in defined urban areas*" (3.7) and "*Low-income households are more exposed to environmental burdens than others*" (3.7). The highest scored statement of governance consideration for CiPeLs was "*Governance occurs as part of planning processes that involve the large participation of different actors (e.g. citizens, civil society organisation, and business representatives)*" (3.4). When asked about different aspects of justice in the planning of urban NbS, the highest scored statement for CiPeLs was "*Distribution of access and proximity to a defined quality of green and blue space shared among citizens*" (3.8) and "*Recognition of local knowledge and social needs*" (3.8).

CiPeLs wanted to know more about 'thermal justice (7)' than any other thematic justice blocks (Figure 14).

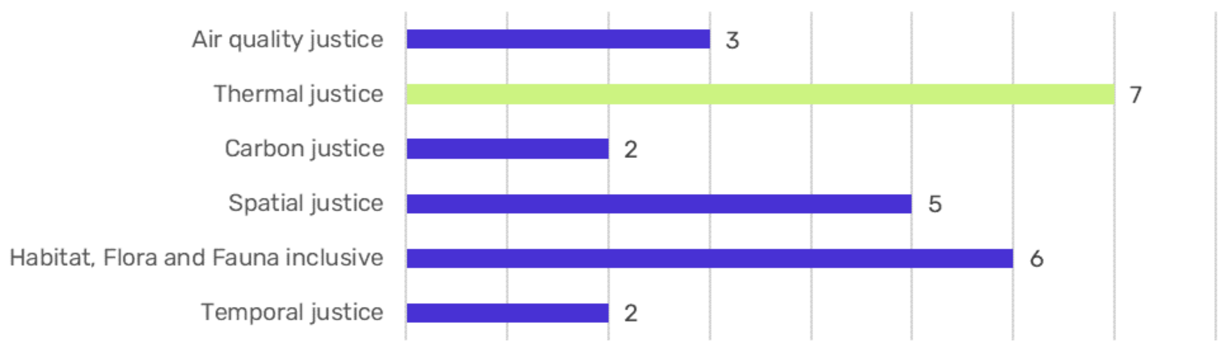

Figure 14: The most interesting thematic justice blocks for NbS (CiPeLs)

The top three highest potentials of NbS categories for each thematic justice block are shown in the following table. '*Parks & recreation areas*' are chosen in multiple blocks, including air quality justice, thermal justice, carbon justice, and spatial justice. '*Allotments & community gardens*' was also chosen in thermal justice, spatial justice, habitat, flora & fauna inclusive, and temporal justice.

Table 36: Potential of NbS categories for each thematic justice block (CiPeLs)

Rank	Air quality justice	Thermal justice	Carbon justice	Spatial justice	Habitat, Flora & Fauna inclusive	Temporal justice
1	Parks & recreation areas (6)	Green buildings (9)	Green buildings (6)	Allotments & community gardens (7)	Allotments & community gardens (6)	Allotments & community gardens (4)
2	Private, Commercial, industrial, & institutional urban green space (6)	Parks & recreation areas (8)	Private, Commercial, industrial, & institutional urban green space (6)	Green buildings (5)	Blue infrastructure (6)	Blue infrastructure (4)

3	Riverbank green (5)	Allotments & community gardens (7)	Parks & recreation areas (6)	Parks & recreation areas (5)	-	-

A 4-scale score was given to level of agreement (1 – do not agree at all to 4 – completely agree) for statements in each justice block. For air pollution justice in the city, CiPeLs mostly agreed with "*There are big disparities in exposure to air pollutants*" (2.9). Regarding thermal justice, two statement scored the highest: "*The excessive built surface is one of the major causes of higher air temperature in cities compared to rural areas (i.e. urban heat island effect)*" (4.0) and "*People living in areas with less access to urban green infrastructure, and reduced ability to maintain and develop private green space are more exposed to heat-related burdens*" (4.0). For ecological justice, the highest score was given to the statement: "*My clientele have diverse opinions, preferences, and values about nature and natural elements*" (3.4). The highest scored statement for the aspect of gentrification as effect of the NbS was "*People with lower incomes may be forced to change neighbourhoods*" (3.2).

CiPeLs were asked to rank from 1 (the most important) to 5 (least important) for interventions for the planning of carbon just city (Figure 15). The most important (highest score) intervention was "*Development of NbS for increased urban resilience to risks such as droughts, floods and heatwaves*" (4.9), while the least important intervention was "*Proper management of urban soil to increase carbon capture potential*" (2.0).

"*Initiation phase: Project study*" (5) was chosen as the most important phases to consider socio-economic, cultural and socio-demographic characteristics of the neighbourhood to reduce the potential gentrification where NbS will be placed,

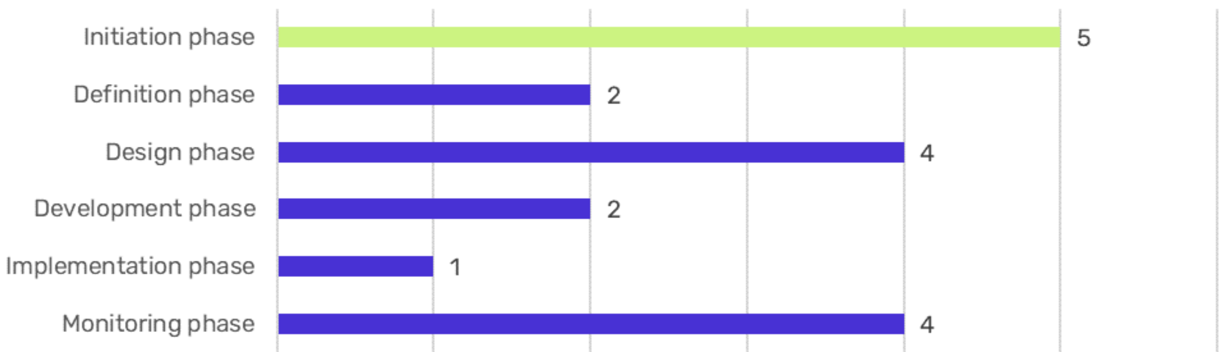

Figure 15: The most important phases in considering decrease gentrification (CiPeLs)

Finally, CiPeLs were asked to rank from 1 (the most important) to 7 (the least important) on actions regarding ecological (space) justice in the city. The most important action was "Considerations of impacts on future generations in NbS implementation (5.8)" while the least important action was "Investigate historical drivers of social injustices in urban planning (1.8)."

The results are expected to inform how CiPeLs or city specific considerations are to be integrated on identifying Low Carbon | High air quality NbS potentials (see Conclusions).

5 CONCLUSIONS

The previous chapters setting out the conceptual and action framework provide rich insights and an expanded knowledge base on how to link key justice concepts and in particular ecological (space justice) to the activation of NbS, to simultaneously address several societal challenges, and to the framing of action on Low carbon | High air quality NbS. This especially regards the identified 6 key challenges or visions to be claimed by the identification (and expected activation) of Low carbon | High air quality NbS potentials: Air quality, thermal and carbon (in-)justices, flora fauna habitat (non-)inclusiveness, as well as spatial and temporal (in-)justices.

As outlined in the introduction and methodological part of the report, the work is far from finished, but according to an abductive logic presents intermediary results. In particular, the knowledge base for the 6 key challenges aimed at generating meaning rather than collecting data or evidence, and this sense- or meaning-making is considered inherently influenced by the researchers and what knowledge they call upon. It is expected to be further informed by the activities linked to the creation of ecological & socio-economic status and disparities profiles (Task 2.2) as well as for visualizing future NbS development trajectories according to different scenarios (Task 2.3). In line with interpretive research, it needs to be put up to further scrutiny, especially in practice, to generate actionable knowledge, which means not only relevant for the practice but used by people to transform their city.

In order to further transform the findings accordingly, it has been decided that in a subsequent step, the created knowledge base informs the development of an ecological (space) justice strategic planning game toolkit. The idea builds on a planning toolkit developed in the framework of netWORKS 4 – Resilient Networks | Contributions of urban supply systems to climate justice, a project financed by the German Ministry for Education and Research and involving research partners such as the Institute for socio-ecological research (ISOE), the German Institute for Urbanistic (Difu) or the Berlin Municipal Department for Environment and Climate Protection (netWORKS 4, 2022). The planning toolkit aims to support the integrative planning of green, blue and grey infrastructure and has developed a set of information cards and tokens to be applied in a collaborative planning process, which can be applied at multiple scales.

The aim is to create an own set of cards and tokens, building on the findings of the D2.1 conceptual and action framework. An example how such a game card as well as tokens could look like, building on the 4-tier system of NbS activation, is illustrated in Figure 16.

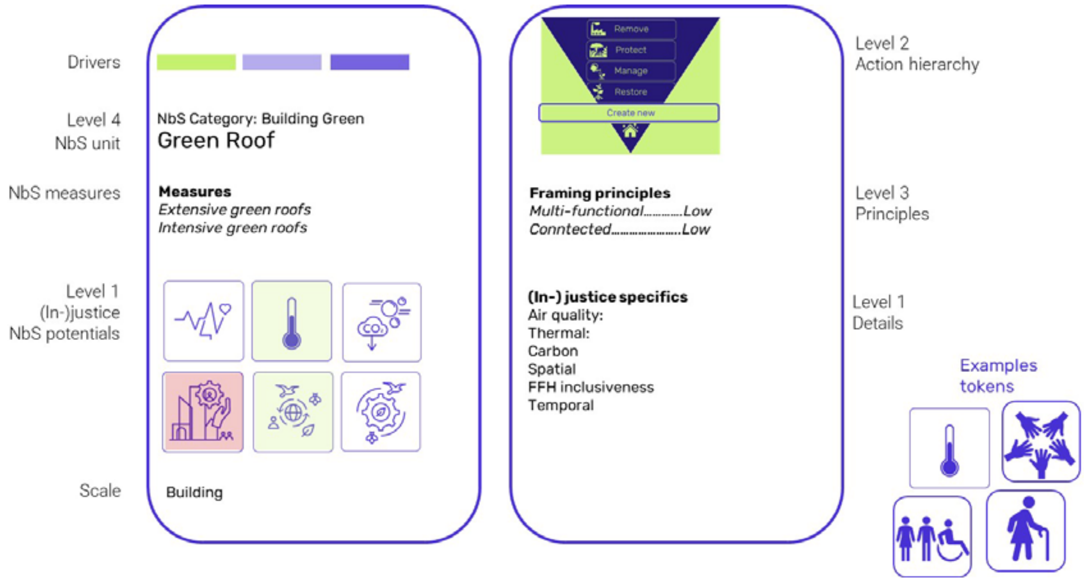

Figure 16: Example of a game card and tokens of an ecological (space) justice strategic planning toolkit

The game cards and tokens are to be applied as part of a structured collaborative planning process, and in relation to JUSTNature to be tested and further developed (see Figure 17).

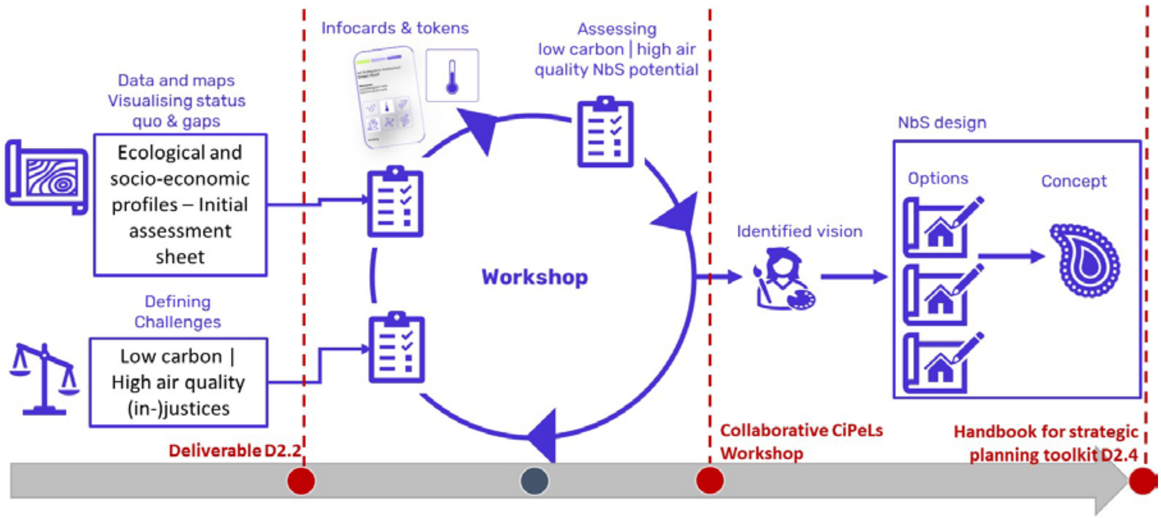

Figure 17: Example of a game card and tokens as part of the ecological (space) justice strategic planning toolkit

This report lays out the basis for one of the first steps in applying the toolkit as part of a collaborative process: the identification of the (in-) justice challenges (action framework) to be addressed in a city. An according template or form will be developed that structures the step of defining these challenges in a collaborative workshop setting. In addition, it is expected that the activities of Task 2.2 on the development of ecological and socio-economic profiles on the one hand provide information on the current status quo in the CiPeLs and on the other hand indicate where there may be gaps in data and maps to assess the Low carbon | High air quality NbS potentials. The application of the game cards and tokens shall then support a collaborative assessment of potentials to further generate knowledge for taking action. This can be applied at various planning scales, at the site, neighbourhood, and city-wide scale, and as such consider the different stages of NbS development in a city. An expected result is the creation of a common vision of (in-)justices to be addressed and to inform the development of various NbS options and the overall concept as part of NbS design activities (e.g. WP 5).

The development of the game cards and tokens and the preparation of the collaborative strategic ecological (space) justice planning process represents an opportunity to re-discuss the action framework. It is expected not to be a straightforward process, in particular to strike the balance between recognising the normative nature of the various (in-)justices, taking into account the complexity of ecosystem functionings sustained by NbS and how to provide an accessible guidance to put all into practices for a just transformation of cities. However, this is what actionable knowledge is also about – negotiating meaning or also making sense together.

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ANNEX 1 - THE USE OF LAYERS AND LIST OF TAGS IN ZOTERO

Layer 0: Refers to important **features** of a publication.

0_KEY CONCEPTS;

0_H2020 NBS PROJECT PUBLICATION;

0_META-RESEARCH STUDY;

0_CASE EXAMPLE

0_DATA AND MONITORING

Layer 1: Refers to the **thematic clusters** identified as key for defining Low carbon | High air quality NBS potentials. The following have been initially identified:

1_ECOLOGICAL SPACE AND DISPARITIES

1_SOCIO-ECONOMIC SPACE AND NEEDS

1_RETHINKING BUILT ENVIRONMENT

1_TEMPORAL SCALE CONSIDERATIONS

Layer 2: Includes tags that refer to more **specific key words** considered relevant for the thematic clusters. Based on keyword suggestions for the thematic clusters, the following initial list was selected:

2_Green infrastructure elements

2_NbS typologies

2_Urban green & urban land use categories

2_NbS and/or urban green & air pollution

2_NbS and/or urban green & climate change mitigation

2_NbS and/or urban green & climate change adaptation

2_Spatial disparities & NbS

2_Neighbourhood segregation & NbS

2_NbS & gentrification

2_City & climate change mitigation

2_City & climate change adaptation

2_City & air quality

2_Built environment & inequality

2_ NbS & climate change scenarios

2_Historic impact urban planning

2_Urban planning cultures & spatial disparities

Layer 3: Layer 3 refers to a **tag suggested by a partner**, in addition to the already identified tags. It was recommended to add only what are considered strictly necessary tags, as they add a new feature, thematic cluster or key specific key word.

3_[my_proposed additional tag]

The contributing partners are asked to add **10 to 15 items** to the group library, tagging them using the different layers. Tags of one to four layers can be added to a publication, the exception being layer 0 tags as they require at least one additional tag from one of the other layers (no standalone layer 0 tag). Although **no maximum number of tags** is established, especially for layer 2 avoid using too many tags, but focus on the key topics addressed by the paper and how it informs the development of the conceptual and action framework.

Items can be added to the group library by either dragging and dropping pdf-files, using the "Save to Zotero" button (by installing the Zotero connector to be added to the web-browser) or using an identifier (e.g. DOI, ISBN). The quality of the retrieved **meta-data** (e.g. title, authors, journal, publisher, abstract) varies accordingly. Where limited meta-data is available, besides information on title, authors, date, publisher, also a **short abstract** should be added.

Besides tags, also **notes** can be added to an item. This function should be used to very briefly explain why an item was considered important or a new 3_[my_proposed additional tag] was added.

ANNEX 2 – TEMPLATE TABLES FOR DEFINING THE 6 KEY JUSTICE COMPONENTS

Definition

	Insights	Literature reference
Environmental conditions		
Social and economic conditions		
Individual conditions & vulnerabilities		
Built-environment		

NbS contribution

NBS contribution	NBS type	Types of action	Justice dimension
Literature reference			
Literature reference			
Literature reference			

Interlinkages with other key components

	Insights	Literature reference
Air quality (in-)justice		
Thermal (in-)justice		
Carbon (in-)justice		
Spatial (in-)justice		
FFH-inclusive		
Temporal (in-)justices		

Basket of indicators

Indicator (metric)	Drivers of (in-) justices	NbS contribution	Justice Dimension	Level of integration	Spatial mapping potential
Literature reference					
Literature reference					
Literature reference					

ANNEX 3 – SURVEY RESULTS

Survey Introduction for Urban Practitioners

Dear Community of Practice,

What role do environmental justice considerations play in your daily work?
What key aspects do you think need to be considered for the planning of low carbon AND just cities?

As part of the EU HORIZON project, JUSTNature, we are conducting a survey to understand how urban planners and practitioners address these questions. This in particular refers to the importance you attribute to activating low carbon and high air quality nature-based solutions (NbS)*. As part of the survey, we would like to test some of our concepts and assumptions on different identified justice components (e.g., air quality injustice, thermal injustices, carbon injustices, spatial injustices, flora, fauna, and habitat inclusive, temporal injustices) in NbS. There are no right or wrong answers. Every input is important.

The overall objective of JUSTNature is the activation of nature-based solutions (NbS) by ensuring a just transition to low-carbon cities, based on the principle of the right to ecological space. This encompasses the right to clean air and indoor/outdoor thermal comfort for human health and well-being, as well as thriving biodiversity and ecosystems. It also entails the duty of not constraining the ecological space of others, in particular in relation to the mitigation of climate change and measures required for reducing GHG emissions. JUSTNature will contribute to this vision of shaping low-carbon cities by developing a set of typical Low carbon | High air quality NbS in seven European city practice labs.

The survey should take approximately 20 minutes. Your responses are completely anonymous and the data we collect will be used only for this research.

If you want to be informed about the results of this survey and receive other news from JUSTNature project, please visit our project website (https://justnatureproject.eu/) or send an email to Yirang Lim at lim@isocarp-institute.org

*Nature based solutions (NbS): Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". They are just one of a range of concepts used to frame nature's contributions to people (NCP). Others refer to ecosystem-based adaptation, green infrastructure or ecosystem services.

Sources:

Cohen-Shacham, E., Walters, G., Janzen, C., & Maginnis, S. (2016). Nature-based Solutions to address global societal challenges. International Union for Conservation of Nature and Natural Resources.

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R. T., Molnár, Z., ... & Shirayama, Y. (2018). Assessing nature's contributions to people. Science, 359(6373), 270-272.

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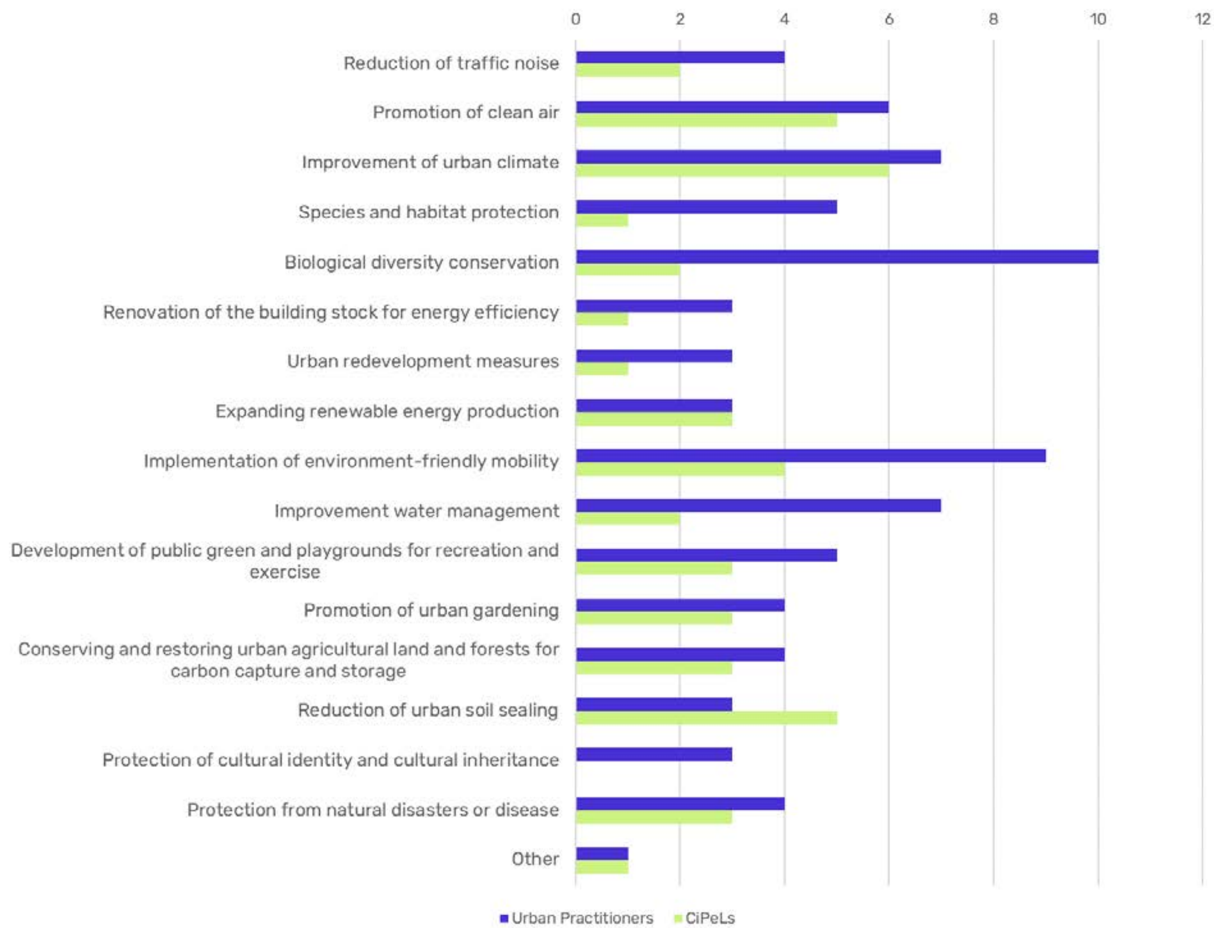
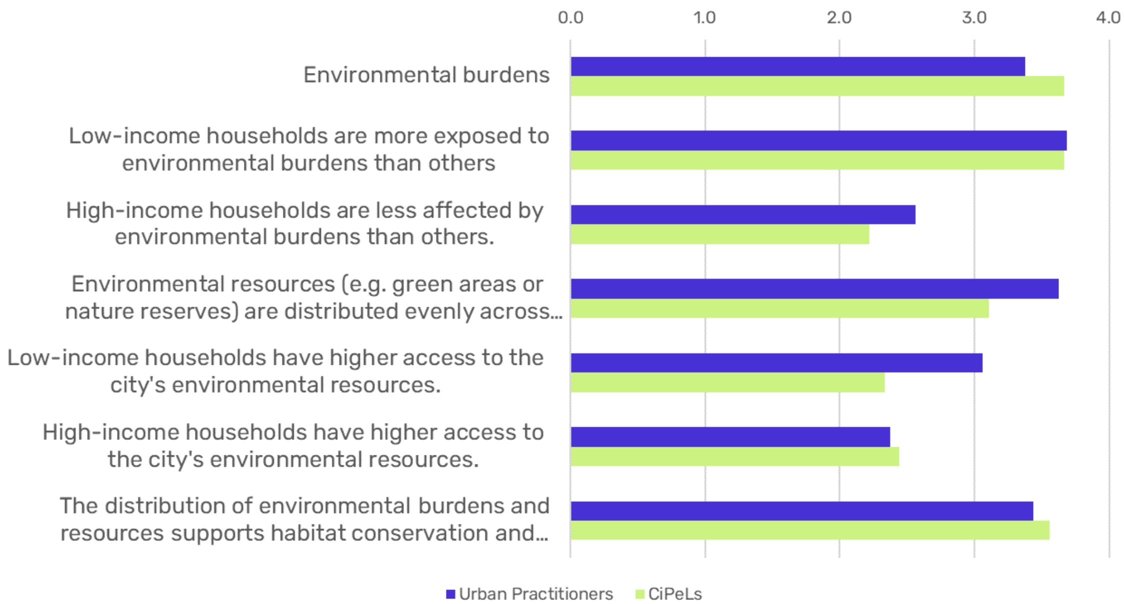
Survey Questionnaires and the Responses

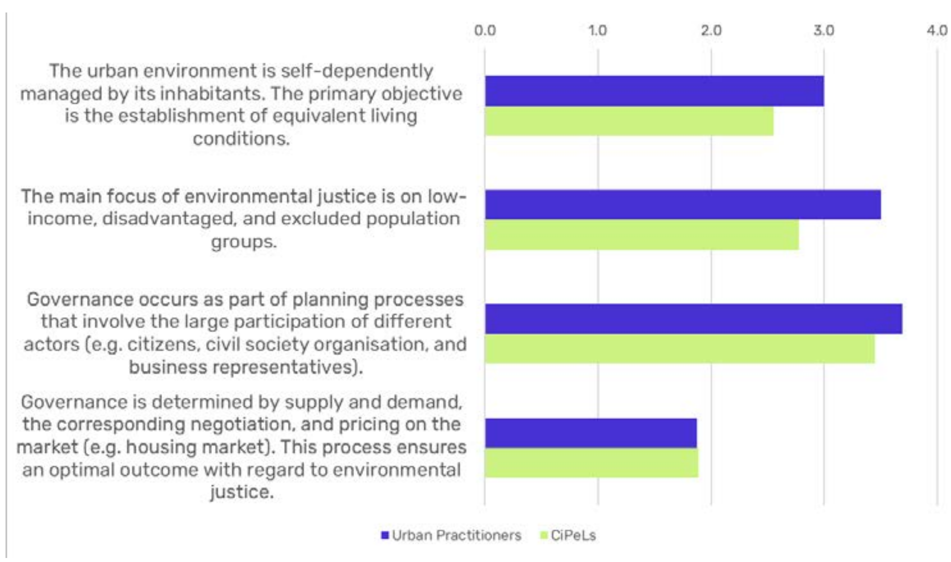
1. Which do you think are the 5 most important solution areas for the right to ecological space in the city? (If you find other solution areas not in the list, please specify in "Others" option)



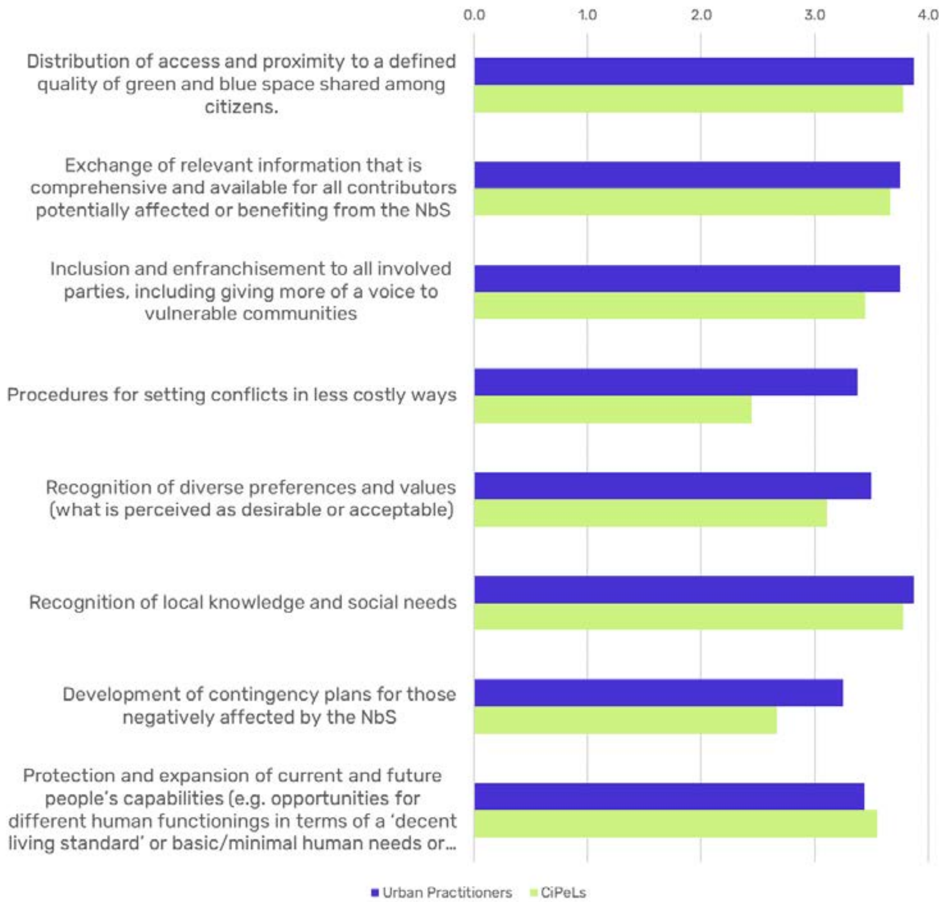
2. What importance would you attribute to the following distributional considerations on environmental justice in the planning of a city? Please rate from 1 (Not important) to 4 (Very important).



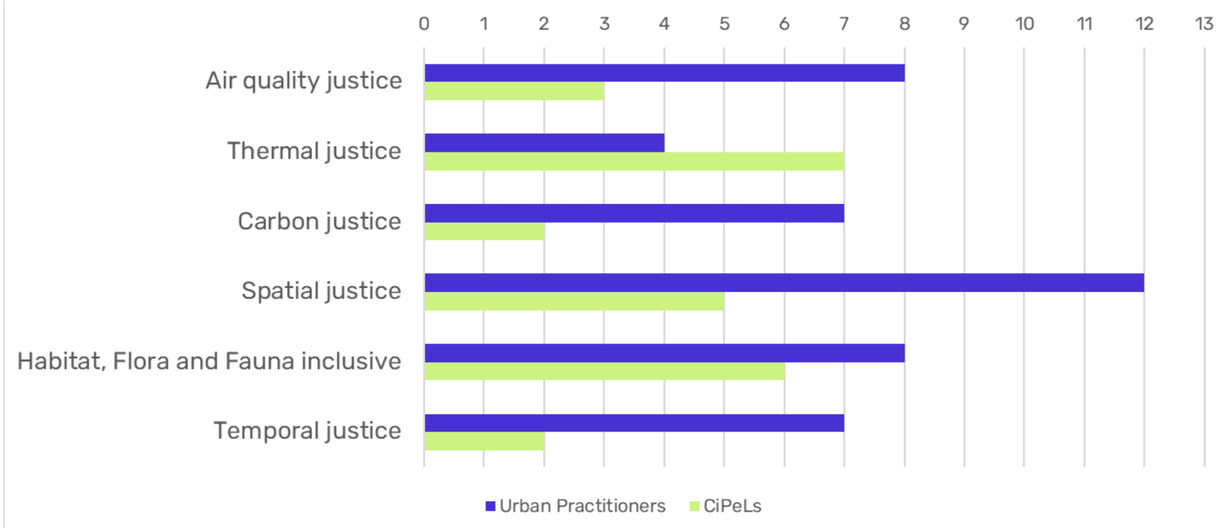
3. What importance would you attribute to the following governance considerations on environmental justice in the planning of a city? Please rate from 1 (Not important) to 4 (Very important)



4. What importance do you attribute to the following aspects of justice in the planning of urban nature-based solutions? Please rate from 1 (Not important) to 4 (Very important)



5. Which of the following thematic justice blocks would you be interested to know more about with regard to NbS? (If you find other thematic justice block not in the list, please specify in "Others" option)

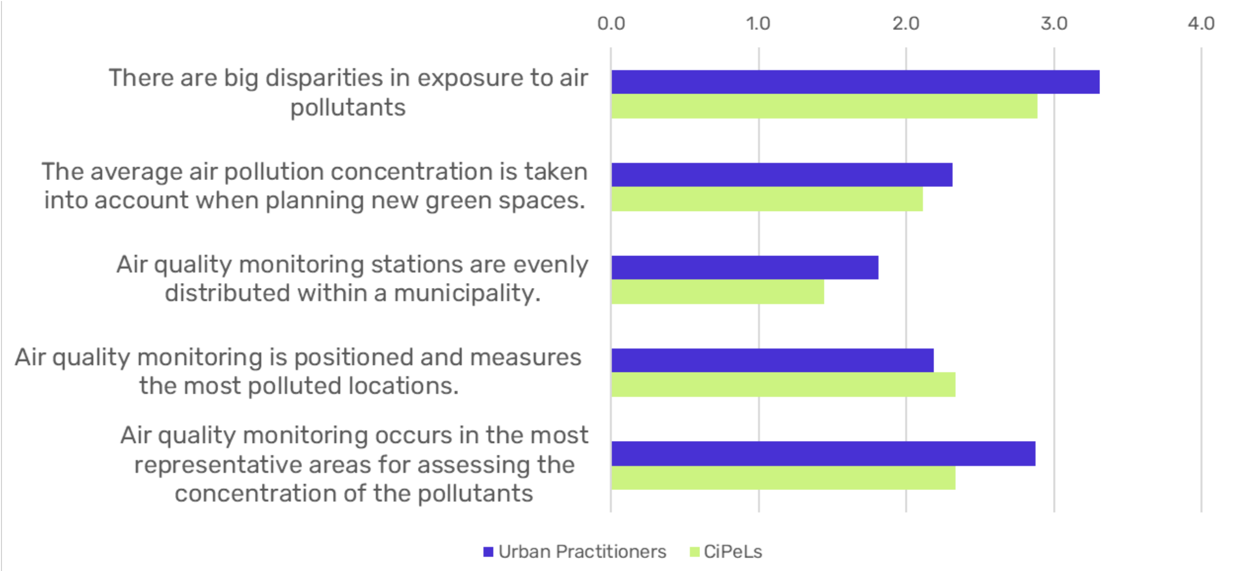


6. Which NbS categories have the most potential to address one or more of the thematic justice blocks according to your professional opinion?

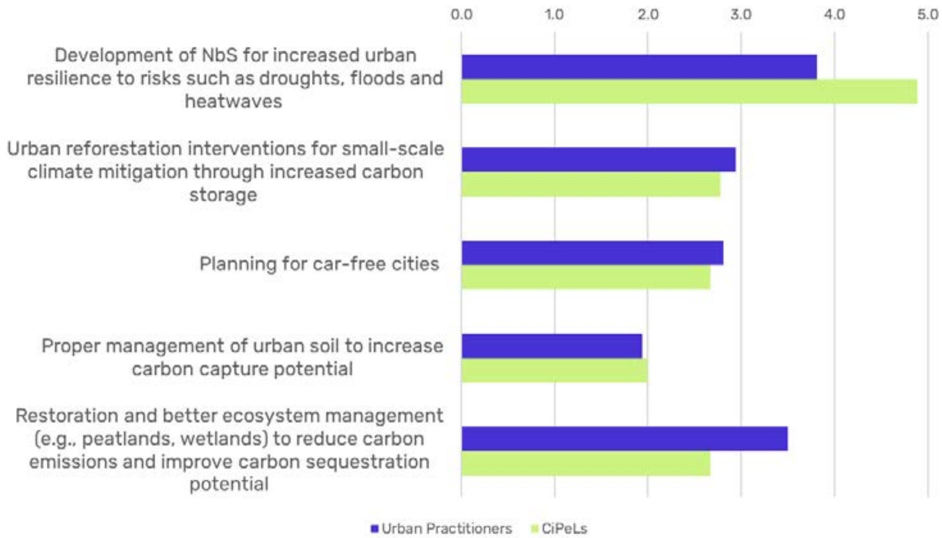
Urban Practitioners	**Air quality justice**	**Thermal justice**	**Carbon justice**	**Spatial justice**	**Habitat, Flora and Fauna inclusive**	**Temporal justice**
Greening buildings (e.g. roofs, walls)	11	13	10	5	7	4
Private, Commercial, Industrial, and Institutional urban green space	12	10	10	5	10	6
Parks and Recreation Areas	13	11	10	14	11	5
Allotments and community gardens	12	9	9	13	12	7
Agricultural land	8	5	13	8	12	6
Natural, semi-natural, and derelict or vacant land	9	7	11	10	10	8
Riverbank green	11	9	11	9	9	8
Blue infrastructure	9	9	9	5	10	6
CiPeLs	**Air quality justice**	**Thermal justice**	**Carbon justice**	**Spatial justice**	**Habitat, Flora and Fauna inclusive**	**Temporal justice**
Greening buildings (e.g. roofs, walls)	4	9	6	5	4	1
Private, Commercial, Industrial, and Institutional urban green space	6	6	6	4	5	3

Parks and Recreation Areas	6	8	6	5	5	1
Allotments and community gardens	4	7	3	7	6	4
Agricultural land	2	1	1	2	0	3
Natural, semi-natural, and derelict or vacant land	4	3	5	2	5	1
Riverbank green	5	6	3	4	5	2
Blue infrastructure	2	6	2	4	6	4

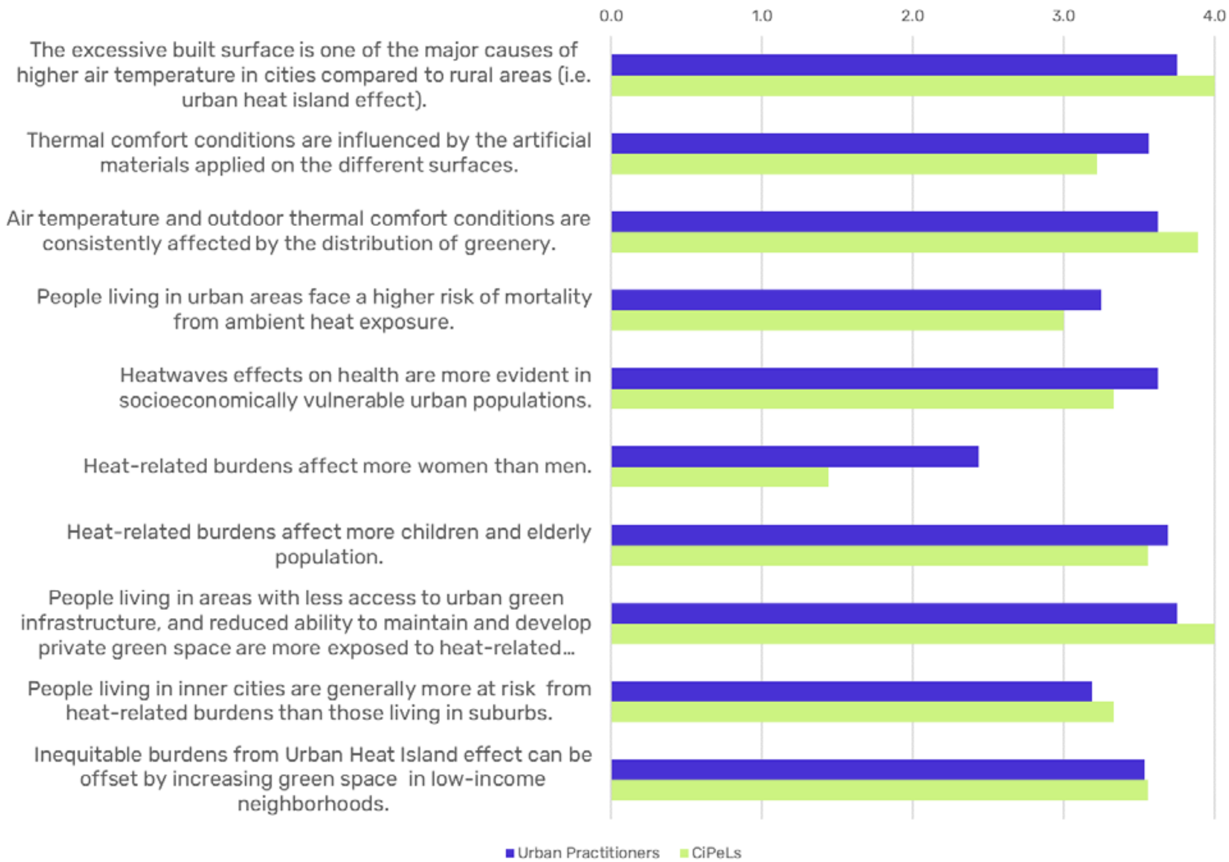
7. To what extent do you agree with the following statements on air pollution justice in the city? Rating from 1 (Do not agree at all) to 4 (Completely agree)



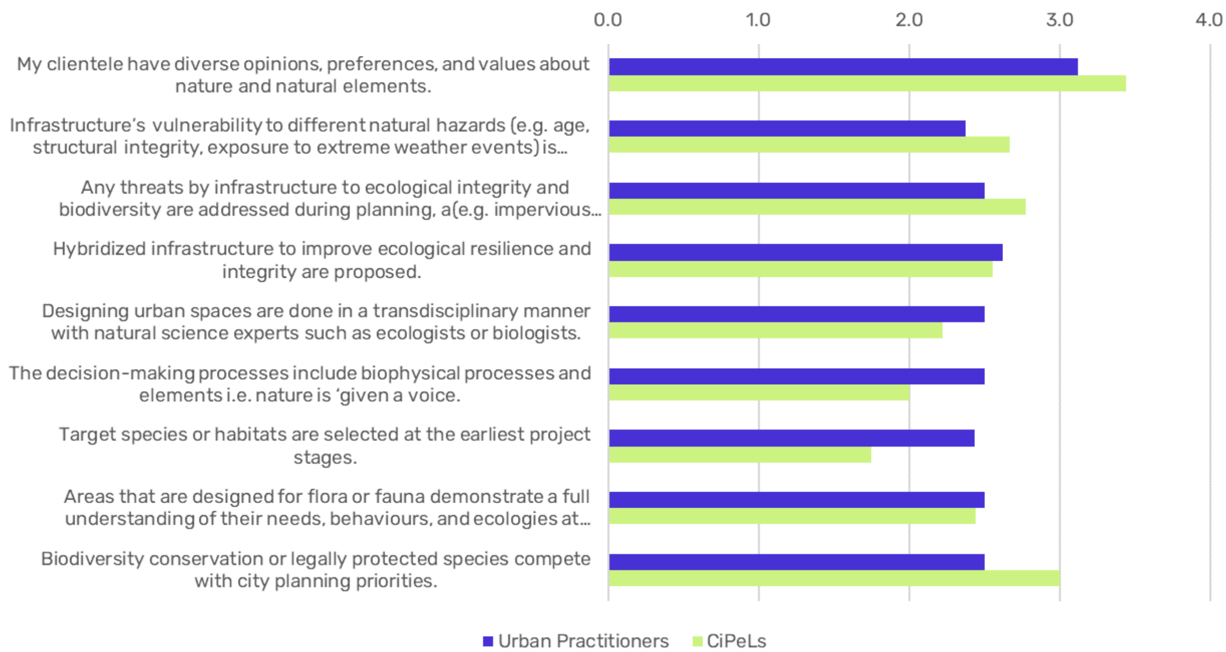
8. What importance do you attribute to the following interventions for the planning of carbon just city? Please rank in order of importance from 1 to 5 (1 being the most important) Please choose one rank for each intervention.



9. To what extent do you agree with the following statements on thermal justice in the city? Please rate from 1 (Do not agree at all) to 4 (Completely agree).

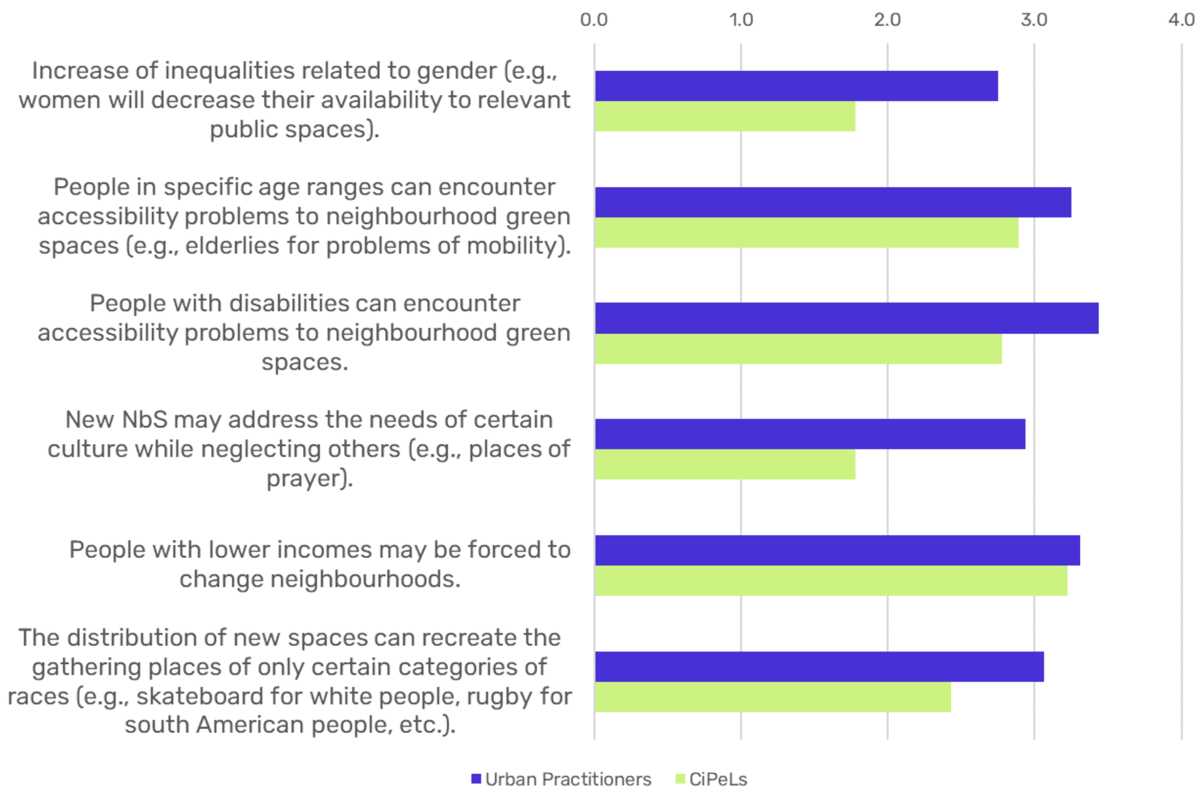


10. To what extent do you agree with the following statements on ecological justice in the city reflecting your current planning in your city? Please rate from 1 (Do not agree at all) to 4 (Completely agree).

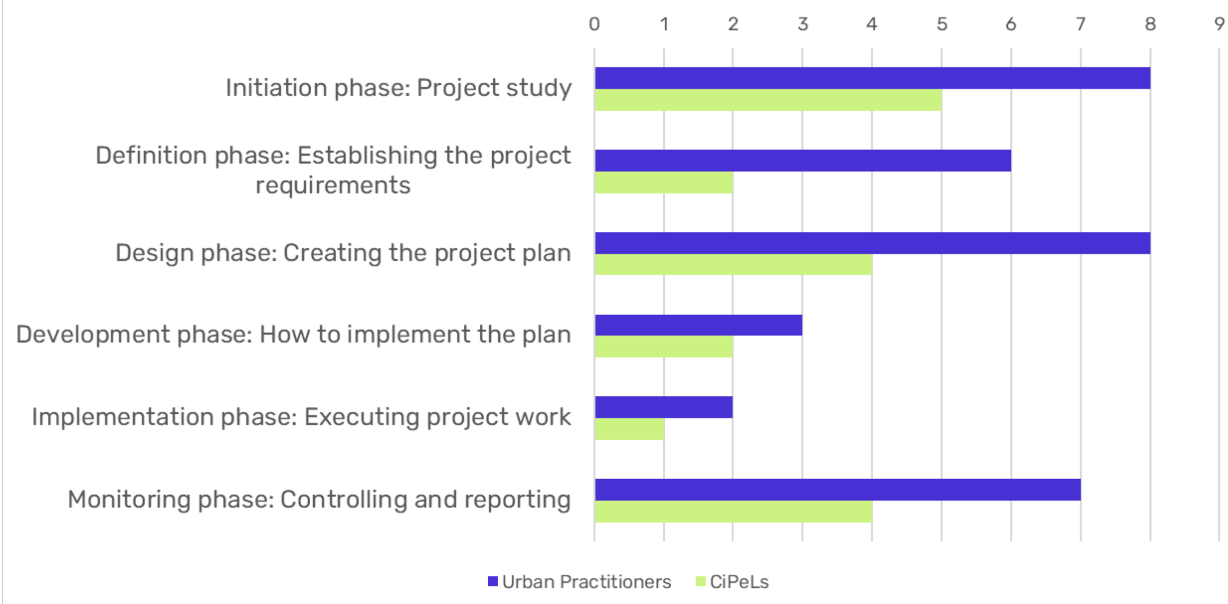


11. According to your experience, which aspects of gentrification* could grow as effect of the NbS? Please rate from 1 (Do not agree at all) to 4 (Completely agree).

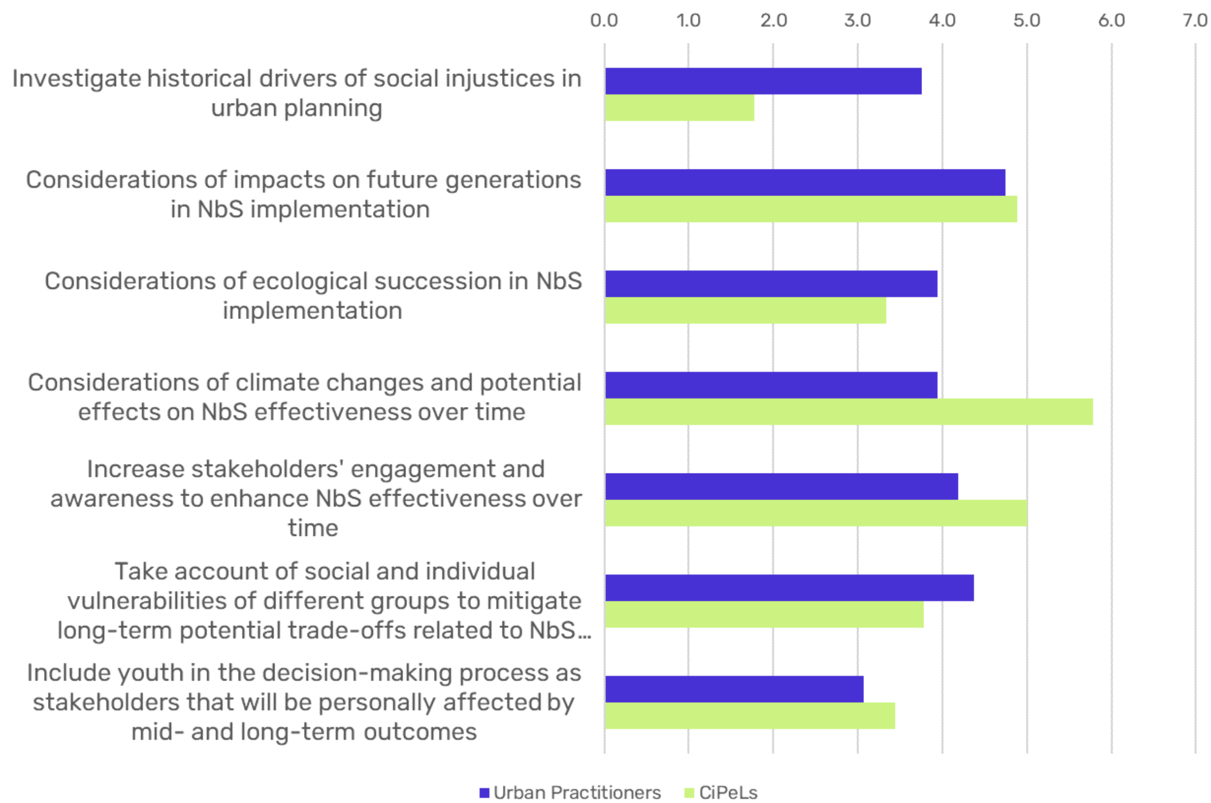
*Gentrification is a phenomenon that indicates some issues-problems due to the inclusion of an NbS within a neighbourhood. Problems and issues that may be encountered are for example the increase of real estate costs, or the reallocation of the less well-off.



12. In order to decrease the potential gentrification where NbS will be placed, how important is it to consider the socio-economic, cultural and socio-demographic characteristics of the neighbourhood in the different stages of the design and implementation process?

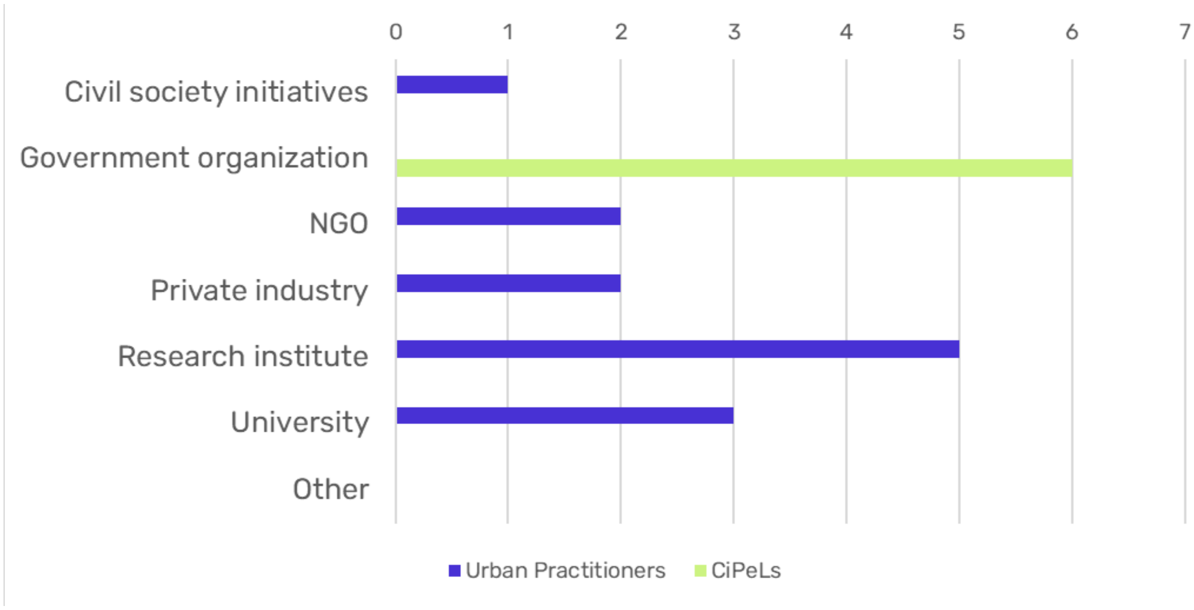


13. What importance do you attribute to the following actions regarding ecological (space) justice in the city? Please rank in order of importance from 1 to 7 (1 being the most important). Scores are assigned, 7 as "the most important"" to 1 as "the least important. The sum of the scores multiplied by the frequency of responses are divided by the total number of responses in the selected action.

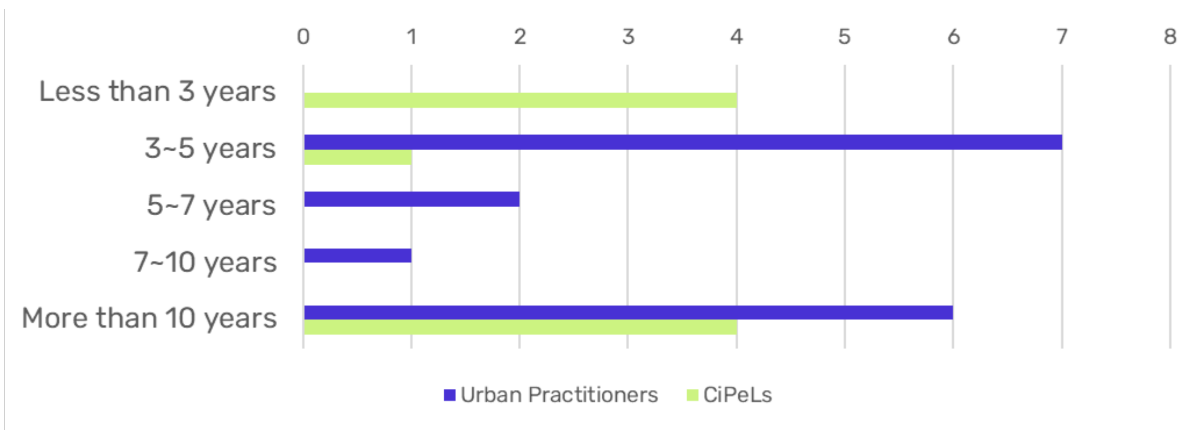


Personal Information

14. Which category best fits your occupation?



15. How many years have you worked in your field?



16. What is your field of specialty? (e.g., urban planning, environmental management, nature-based solution, etc.)

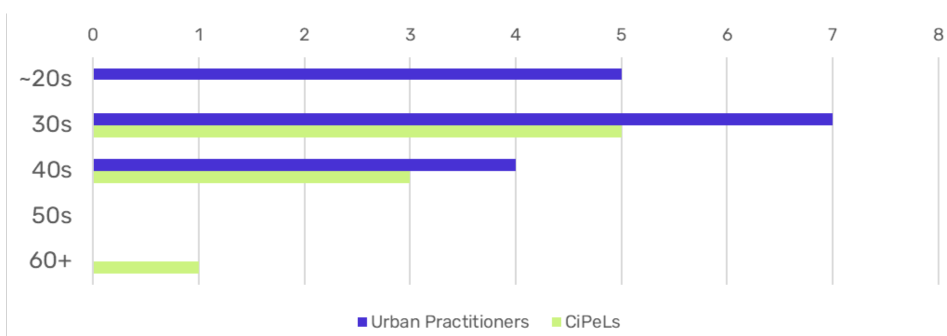
Urban Practitioners	No.
Urban Planning & governance	7
Green infrastructure	2
Environmental Management	4

Architect	1
Total	14
CiPeLs	**No.**
NbS & green infrastructure	2
Urban heat island	1
Sustainable mobility	1
Water management	1
Cities	1
Green project development	1
Total	7

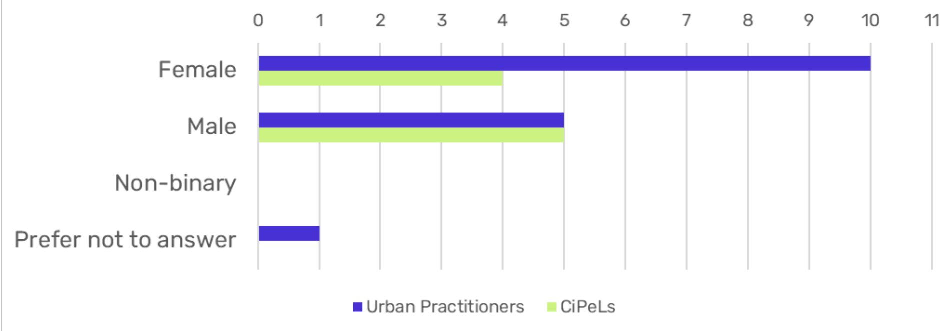
17. What city and country do you mainly work in (Urban Practitioners)?

Country	No.
France	1
Germany	2
Italy	1
Netherlands	3
Nepal	1
Indonesia	1
Ecuador	1
Central African Republic	2
Total	12

18. Age



19. Gender


0
1
2
3
4
5
6
7
8
9
10
11
Female
Male
Non-binary
Prefer not to answer
Urban Practitioners
CiPeLs

ANNEX 4 – THE CONCEPT NOTE

Concept Note |
Ecological (Space) Justice and
Low carbon | High air quality NbS potentials

WP 2 Task 2.1 Determining the scientific knowledge base and developing a framework for assessing Low carbon | High air quality NbS potential and possible spatial disparities

Project meeting 2-4 May 2022, Munich

Authors:

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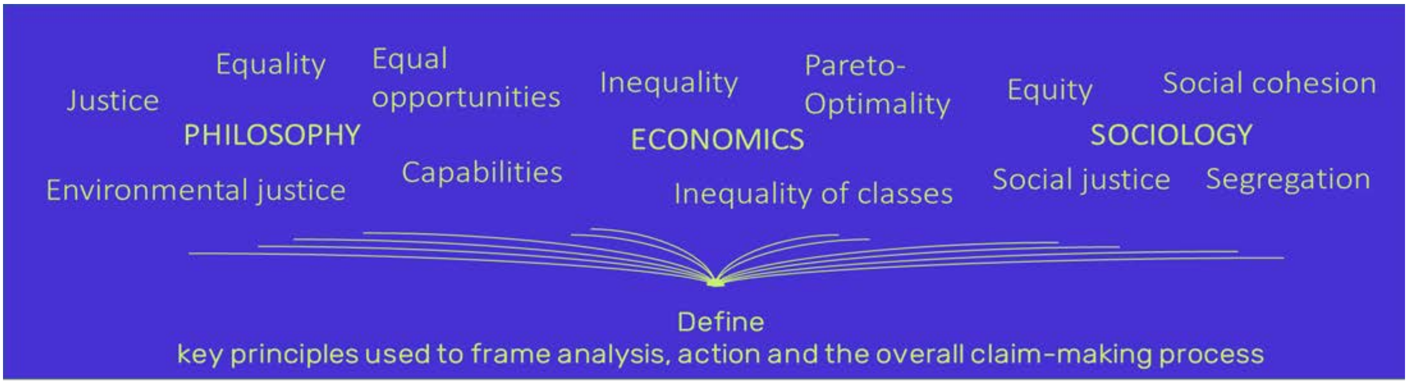
Justice
A question of values and ethical doctrines

- While **notions of equality, inequality, equity, justice and injustice** are often used interchangeably, different scholarships have had different reasons for adopting a defined notion. It influences key components or principles to **frame analysis**, **action** and the overall **claim-making process**
- Ideas of **equality** are in the domain of philosophy, and rather than becoming equal, are a consideration of being of **equal worth**. Disputed aspects:
  - **Egalitarians** (what should be equalized), and **non-egalitarians** (what is the moral significance of equality)
  - **Formal theories** (focus on processes that lead to equality) and **content** (focus on characteristics of what equality to be achieved)
  - **Ways of achieving equality**, whether everyone is brought up to the level of the best off, everyone is brought down to the level of the worst off or the worst and best off are brought to a level where they meet



- Aristotle (350 BC) introduces **justice**, focusing on merit: justice to be achieved when equals are treated equally and unequals unequally, and thus some receives what is '**deserved**' (proportional equality)
- Rawl's '**theory of justice**' (70s) questions the role of merit and argues for justice as a social contract to be achieved by **bargaining parties** discussing its fundamental terms behind 'a veil of ignorance'
- Often ignored, **indigenous American influences**: From each according to their abilities, to each according to their needs (e.g. Kandiaronk, Graeber & Wengrow 2021)
- **Equal opportunities** is central to the development of policies. Today basic interpretation of opportunity to **compete** in a given market or society, rather than a matter of **equal life chances** according to specific criteria
- Sen's **theory of capabilities** (70s): Attention is shifted to basic entitlements, to make people capable to do and, influenced by goods & services, social context and individual choices
- Introduced in psychology, mostly in opposition to equality interpreted as equal opportunities, **equity theory** is mostly associated with the (perceived) **fairness** of amounts received

Examples of how justice and equity have been interpreted differently and can be widely disputed.

From the perspective of a geographer:

- **Inter-generational equity**, referring to the respect of the needs of future generations
- **Intra-generational equity**, addressing contemporary equity and social justice, not merely focused on redistributive questions
- **Geographical equity**, giving consideration to external impacts outside the jurisdictional domain, whether at a neighbourhood or global level
- **Procedural equity**, developing a framework of democratic political processes and responsibilities using multiple democratic and participative forms and channels
- **Inter-species equity**, highlighting the critical importance of preserving ecosystem integrity and maintaining biodiversity

Source: Haughton 1999:235 in Gantioler 2019

From the perspective of an economist/urban planner, arguing for the futility of the endeavour as justice a too much disputed notion:

- **Elitist or libertarian justice**, promotes the 'strong' and is based on the main norm of maximising liberty (e.g. Friedrich A. Hayek)
- **Utilitarian justice**, promotes the 'most' and is based on the main norm of maximising happiness (e.g. Jeremy Bentham, John Stuart Mill, and contractualists such as Hobbes)
- **Social justice**, promotes the 'poor' and is based on the main norm of minimising pain (e.g. John Rawl)

Source: Davy 1997:256-257 in Gantioler 2019

Why focusing on environmental/ ecological (space) justice?

- Environmental justice (EJ) debates increasingly inform **sustainability transformations** scholarship as the notion requires discussions on important drivers such as **values, norms and ethics,** and call for **community action** rather than individual action **.**

- Long **history of EJ scholarship and activism** focused on
  - Unequal distribution of **environmental ills** and racism in the US (70s)
  - Distributional effects of environmental policy (e.g. who bears the costs, 80s)
  - More recently focused on process of distributing **environmental qualities** (e.g. spatial and urban planning)

- New emerging concepts of **energy justice (EyJ)** and **climate justice (CJ),** with define key focus:
  - **EyJ:** considering the social impact of transitioning to low-carbon sources & energy poverty
  - **CJ:** consequences of rapid CC for vulnerable groups, impact on future generations and global accountability

- **Just transition** has been introduced as joint conceptual space for reflection and to unite justice scholarship foci, especially by applying the re-occurring **triumvirate of tenets** (distributional, procedural and restorative). (McCauley and Heffron 2018) ,

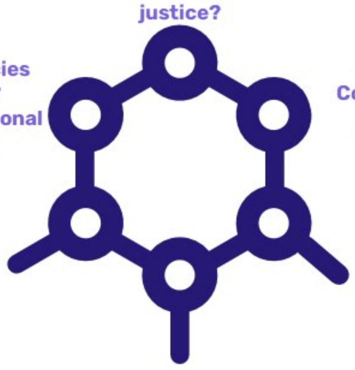
- The concept of **ecological space** brings principles of ecology to bear on the concept of space, as a particular 'way of seeing'. The concept adopts the definition of ecological niche, to hint at its 'functional' rather than physical nature. It is used to emphasise that **humans as other species are not exempt from ecological constraints** (e.g. temperature, food, air quality, water quantity and quality, or interactions biosphere).

- The notion of **ecological (space) justice** weaves ecological considerations into ethical considerations of justice: of the finitude and vulnerability of ecological niches and biosphere's diversity and the **adequate distribution** of ecological space for a diversity of species (incl. humans/non-humans) to thrive.

What frames of justice to consider?

1. Commonly used justice frames in **relation to NbS**

- **Recognitional:** NbS planners need to acknowledge the **individual or communal capacities** such as local knowledge, the resources or services needed to improve living conditions, diversity of preferences, values and perspectives on governance. Recognizing these characteristics and values could enhance **place-based attachment** and **connection** with NbS. A more inclusive NbS should also **recognise non-human life** found in urban areas and it's needs, capacities, and limits.
- **Procedural:** Co-creation and co-design of NbS with urban populations that is **inclusive** to and **representative** of all potentially benefited or affected communities, inviting diverse professional opinions such as by ecologists or biologist on, and by enhancing deliberative spaces for conflict resolution and ongoing reevaluations.
- **Distributive:** Most widely addressed dimension of EJ focused on characteristics of NbS such as location, typology, form, and size and how these characteristics will influence **ecosystem services**, **functionality**, and **ecosystem integrity**.



2. Suggested new frames or tenents to be considered for low carbon | high air quality NbS

- **Interspecies:** Embracing a duty to not encroach on nonhuman's interests has the potential to radically change NbS design when included or prioritized early in the decision-making process; Can lead to solutions to environmental or social problems that are more sustainable and multifunctional
- **Intergenerational:** NbS implementation can be more inclusive to future generations of people by conserving their right to access the same quality of natural and cultural environments and to conserve resource diversity to that options are available to solve problems and satisfying the needs of humans not yet born.
- **Corrective:** An approach to rectify or compensate for a different action i.e. the damage to natural systems by GHG emissions; Can NbS directly consider what protections or assistance is conceptually owed to those displaced by climate change?
- **Contributive:** Within a broader community, judgements should be made about what kinds of work are worthy of recognition and esteem but also what we owe one another as citizens and how these moral judgements are reflected in the economy of societies. What role can NbS have in rewarding what is valuable to the common good?
- **Capabilities Approach:** Addressing the integral aspects of the living process I.e. vulnerabilities and needs, adaptive capacity, and ecosystems' integrity can be achieved by spatially depicting these needs and vulnerabilities to ensure more inclusive NbS by ensuring everyone and everything's consideration and management.

Systemic monitoring and evaluation

NbS monitoring and evaluation is particularly relevant to capturing and addressing the ecological space (in-) justices.

GAPS in NbS Monitoring and Evaluation

- **Lack of systematic monitoring** and evaluation across challenges and impact areas, being focused on environmental impacts. → Need for a systemic monitoring and evaluation approach to systematically capture the **NbS socio-ecological impacts, synergies, trade-offs and disservices** (Charoenkit & Piyathamrongchai, 2019; Dumitru et al., 2020; Veerkamp et al., 2021).
- **Lack of extended monitoring data** that capture the potential of NbS through **time**, especially in relation to impacts that can be observed in the long term i.e., climate change, social and health impacts (Dumitru et al., 2020).
- NbS impact evaluation ought to account for **diverse social groups** (Dumitru et al., 2020) and expand on **equity impacts** (Hunter et al., 2019).

EU funded projects' contribution:

(i) EKLIPSE impact evaluation framework (C. Raymond et al., 2017)

(ii) Handbook produced by the NbS Task Force 2 (EU, 2021)

(i) + (ii) are the state of the art on monitoring and evaluation of NbS. Both frameworks are inclusive in the recognition of social challenges that can be addressed by NbS, and can be linked to three pillars of the sustainable development agenda **people-planet-prosperity** (EU, 2021, p118).

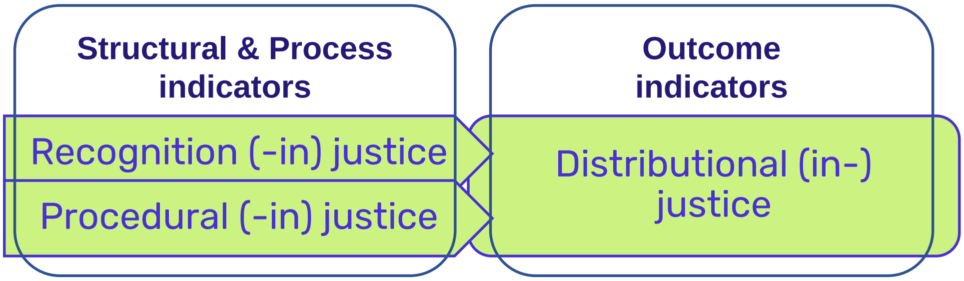
GAP: Both frameworks are far from capturing socio-ecological (in-) justices through the proposed indicators.

! If monitoring is not designed so as to capture the complexity of socio-ecological systems within urban ecosystems and reveal socio-ecological injustices, then a false picture is obtained, which can result in interventions not properly addressing the needs and possibly perpetuate injustices. !
(Biernacka et al., 2020; Dumitru et al., 2020).

Monitoring and evaluation efforts need to be directed towards capturing **distributional** (-in) justices as well as **recognition and procedural (-in) justices**, that are the **underlying causes** of distributional (-in) justice (Zuniga-Teran et al., 2021).

A mapping can be identified among the types of indicators – i.e. structural, process, outcome indicators (EU, 2021) – and the dimensions of justice:

- The structural and process indicators are those related to evaluation of resources and procedures for planning and decision making, and can reveal recognition and procedural (-in) justices for example in participatory planning and co-creation.
- The outcome indicators are related to impacts and results of NbS and can be linked with distributional (-in) injustices.



BOX: Key urban ‚greening' concepts

(Urban) Green Infrastructure (U-GI) | Planning:
Green infrastructure is the **network** of natural and semi-natural areas, features and green spaces in rural and urban, and terrestrial, freshwater, coastal and marine areas, which together enhance **ecosystem health and resilience**, contribute to biodiversity conservation and **benefit** human populations through the maintenance and enhancement of ecosystem services. Green infrastructure can be strengthened through **strategic and co-ordinated initiatives** that focus on **maintaining, restoring, improving and connecting** existing areas and features as well as creating new areas and features. UGI comprises both **privately, institutionally, and publicly owned urban green spaces**, such as designed green spaces, gardens, remnants of natural areas, farmland on the fringe, derelict land, and street trees.

Urban Green Spaces or Areas (UGS) | Management:
Denotes the management of a specific part of UGI, defined as urban **publicly** accessible areas with natural vegetation, such as trees, grass, and plants

Nature-based solutions (NbS) | Development: NbS are defined by the International Union for Conservation of Nature (IUCN) as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". It follows 8 core principles, including nature conservation norms, singular to integrated features, site-specific and cultural context, fair and equitable societal benefits, biological and cultural diversity, different spatial scales, multi-functionality, integrative part of policies.

NbS defined by:

1) **Constituting elements**, following a classification of UGI (e.g. green roofs & facades, urban trees and forests)
2) **Application of core principles,** e.g. connectivity or co-creation
3) **Distinguished hierarchy of actions**, from removal of disturbances to creating new features (NEW)

For **Low carbon | High air quality NbS potential**

4) **Cutting across justice components:** air quality, thermal, carbon, spatial, temporal justices and flora/fauna/habitat inclusiveness (NEW)

I. AIR QUALITY (in)JUSTICE

Definition: The air quality (in-)justice, has been applied for several air pollutants with a focus on the exposure to **NO_2, O_3, SO_2, CO and Particle Matter (PM_{10} and $PM_{2.5}$).** Key issues:

- Distribution of respiratory **diseases and hospitalizations** that are linked with **higher average values of air pollutants** among different groups of the populations considering urbanicity levels, social categories, income, race, age and sex;
- Distribution of Air Quality Monitoring Network (AQMN) that tend to monitor areas that are on average, relatively clean compared to the surrounding are.

NbS contributions: Key focus on urban trees, due to the short growing season in the northern region seems to be limited, the most relevant features are canopy density, foliage longevity and emission potential, the contribution may vary based also on the local conditions (e.g. canyons). Green walls and roofs on building envelopes can also be used as effective air pollution abatement measures.

Interlinkages (synergies/tradeoff): Spatial justice: low income are generally closer to air pollutant emissions sources like traffic roads, industrial sites, etc. Carbon justice: often exists an overlap between the distribution of greenhouse gas emission sources and the air pollution sources.

Indicators: Basket of socio-environmental indicators to define low/high emission zones, distance from network roads.

II. THERMAL (in)JUSTICE

Definition: Within a city, the uneven distribution of buildings, other heat-absorbing artificial surfaces, and vegetation is the reason why some areas are more affected by overheating than others. These differences results from disparities in the planning, development and maintenance of urban areas. Thermal justice refers to the reduction of the **inequitable distribution of extreme heat conditions and related risks** across different areas within the same city and vulnerable population.

NbS contributions: vegetation at street level plays a key role in mitigating high temperatures through evapotranspiration and, in the case of **trees and urban forests**, the provision of shade. **Horizontal greening** also contributes to the improvement of thermal conditions, albeit with more limited effects at pedestrian level.

Interlinkages (synergies/tradeoff):

- Spatial justice: the population most vulnerable and with less ability to adapt to the effects of extreme heat generally lives in low-income areas, lacking access to social and economical resources, green spaces, and technological solutions to cope with heat (e.g. air conditioning);
- Air quality justice: the higher density of particulates emissions is among the major factors causing the increase of temperatures in urban areas and exacerbating heatwaves.

Indicators: local climate parameters (e.g. air temperature and relative humidity), human thermal comfort indexes (e.g. PET, UTCI, etc.), land surface temperature, and heat risk indexes (e.g. Urban Heat Risk Index).

III. CARBON (in)JUSTICE

Definition: Considers 2 major aspects :

1) Accountability for the **distribution of the environmental ill of greenhouse gas emissions** (carbon dioxide emissions equiv.) of individuals, population groups, and various sectors.
2) Considerations of the **climate change mitigation potential** of different **ecosystems** and their distribution across a city. It links to discussions on the capacity (and duty) to bear mitigation costs.

NbS contributions: Key focus on trees (new), urban and peri-urban forests (protected & managed), grasslands and peatlands (restored & managed). Indirect impact of green roofs and facades on the energy consumption and thus GHG emissions of buildings, as well as of pocket-gardens and mini-forest on slowing down traffic

Interlinkages (synergies/tradeoff): Urban densification leading to emission reduction synergies though increasing risks of loss of habitats and biodiversity. Indirect impacts on air quality related to regulation of car traffic and alternative forms of mobility.

Indicators: Basket of socio-environmental indicators to define low carbon/high carbon zones

IV. SPATIAL (in)JUSTICE

Definition: Good space management that balances socio-economic development with environmental stewardship.

→ Focus on **gentrification** (increase in home and rental prices that occurs as wealthier people move into a neighborhood, increasing the local demand for housing) as a risk due to NbS implementation.

NbS contributions: NbS can play a substantial role in the way the dimensions of social equity are considered, including spatial justice.

→ A key role is given to **urban planning** and the ability to manage trade-offs and conflicts, considering the space as a social area.

Interlinkages: air quality improvement, wind and temperature controlling; reducing heating and cooling (costs) in buildings; reducing runoff, limiting soil erosion; biodiversity growth.

Indicators: socio-demographic (e.g. education, age, gender, race, etc.), socio-economic (income, job creation, etc.), linked to social capital (relation), NbS distribution (accessibility).

V. HABITAT, FLORA & FAUNA (non)INCLUSIVE

Definition: Justice for nature i.e. an extension of justice considerations to non-humans that prioritizes the environment at the species-, individual-, or the ecosystem level in contrast to the anthropocentrism embedded in most environmental justice discourse.

NbS contributions: An NbS framework inclusive to HFF in and for cities builds upon on the equitable **distribution of environmental goods and bads, social–ecological interconnectedness, nature's agency and capabilities**, and the broadening of representative and procedural justice principles. High importance given NbS's dominance as the interface of direct human-nature interactions.

Interlinkages: In some ways, it can positively influence all other injustices given the interdependencies and multidirectional linkages of human-nature systems at varying temporal, spatial, and social scales. Potential conflicts exist when selecting which habitats or species are targeted, as well as with humans when their needs are secondary. The manifold ways that nonhumans are valued affect how their inclusion is manifested in NbS.

Indicators: Nonhuman representation (by proxy) in design and decision process, environmental and/or population integrity and functioning, and ecological space (habitat type, quality, connectedness/fragmentation, legal protections or land ownership)

VI. TEMPORAL (in)JUSTICE

Definition: Temporal justice considers the interrelations between past, present and future conditions of injustices and inequalities, recognizing the lock-in and path dependency processes occurring in cities, the consequences of historical socio-environmental conditions as well as responsibility towards future generations

NbS contributions: Properly planned and managed NbS provide co-benefits, contributing to adjust historical trajectories of injustices and provide socio-environmental benefits that persist over time;

→ Key focus on long-term monitoring schemes and stakeholders' engagement and awareness to ensure effectiveness of NbS over time

Interlinkages: actions to enhance genetic, species and functional richness can minimize the ecosystem sensitivity to future climate change; implications of climate projections for thermal justice; long-term monitoring affects spatial injustices in its intergenerational component

Indicators: land-use patterns, historical location of environmental amenities (e.g. green spaces and types) and disamenities (e.g. air pollution distribution patterns, waste facilities location) linked to neighborhood isolation and marginalization indicators (e.g. dissimilarity index, isolation index, households characteristics)

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Driving a just transition toward low carbon cities

Everyone has the right to ecological space and the duty of not constraining that of others; to live and help live, work and play in climate-resilient and sustainable cities and beyond.

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