Development of a large-scale spatially explicit approach to enable the uptake of Nature-Based Solutions in Italy

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1. Introduction

Today society is facing the long-standing global environmental crises of climate change and biodiversity loss. Global biodiversity and climate targets will require ambitious national and regional actions to protect and sustainably manage remaining areas of high ecological integrity and restore degraded areas to improve biodiversity (O'Brien et al., 2023). In Europe, many ecosystems are being lost or degraded as a result of the long-time anthropogenic pressures (Kuemmerle et al., 2016; Schulp et al., 2019). The drivers of loss and degradation vary according to the ecosystem and location, but the key pressures include urban expansion, agricultural intensification/abandonment, grey infrastructure expansion, air and soil pollution, hydrological modifications to water bodies, and the intensification/abandonment of forestry practices (Ellis et al., 2013; European Commission, 2015). Accordingly, Land Use and Land Cover Changes (LULCC) are recognized as the main drivers affecting biodiversity and Ecosystem Services (Verburg et al., 2015) as well as global warming (Zhu et al., 2019). Recent investigations showed that the biophysical variability of territories, combined with socioeconomic aspects, strongly affect the spatial location of different LULCC along both latitudinal and altitudinal gradients (Blasi et al., 2017; Di Pirro et al., 2021; Kuemmerle et al., 2016), leading to different impacts. LULCC affect the ecosystems' functions as well as their ability to deliver Ecosystem Services and meet other challenges, such as carbon sequestration, water and air purification, soil erosion protection, flood damage control, and the provision of livable and safe places with recreational opportunities that contribute to human well-being. According to European Commission (2015) the annual damage measured as GDP loss stands currently around €450 billion due to loss of biodiversity, while, due to climate change, could be estimated from €20 billion for a 2.5°C scenario to €65 billion for a 5.4°C scenario. Furthermore, between 2002 and 2012, numerous extreme events generated 80,000 fatalities and €95 billion in economic loss, mainly due to extreme temperatures, pollution, and floods (D'Ippoliti et al., 2010; Khomenko et al., 2021; WMO and WHO, 2015). In addition, the health condition of populations is strongly affected by complex interactions among factors (e.g., air pollutants and heatwaves), which are interconnected and evolve through time (Brousmiche et al., 2020; Cramer et al., 2019; Klompmaker et al., 2020). As human populations and activities are concentrated in exposed areas, such as cities and along the coasts, the damages could reach unsustainable levels due to the persistence of these phenomena.

Indeed, 73% of Europe's population lives in urban areas and this percentage is projected to increase to 82% by 2050 (European Commission, 2015). Some of the most harmful environmental challenges such as urban heat islands, poor air and water quality, waste-water inefficiencies, high energy consumption, and loss of biodiversity, are exacerbated by an increasing urban population and urbanized land. The shift to sustainable planning and management of urban ecosystems, in harmony with the policy actions at all levels, could minimize the environmental impact of cities and increase human health and well-being of inhabitants. It could also contribute to improving ecosystem conditions both in urban contexts and in other ecosystem types, i.e., agroecosystems, fresh-water ecosystems, grassland and wetlands located in peri-urban areas (Zulian et al., 2022).

Both urban and rural communities still rely on 'conventional' measures and systems for water supply, heating, lighting, drainage, cooling, and other services such as recreational facilities (Kolokotsa et al., 2013; Pappalardo and La Rosa, 2020). Unfortunately, several of these systems may no longer be suitable for purpose due to the over mentioned challenges and hazards whose impacts are increasing both in severity and frequency (Wild et al., 2020).

Extending legally binding policies and actions to multiple challenges could help reduce risks and vulnerability for exposed populations and improve the resilience capacity of most populated areas (Darrel

Jenerette et al., 2011; Flacke and Köckler, 2015; Maes et al., 2019). Accordingly, this requires a paradigm shift from an economy based on the overexploitation of natural resources and the use of fossil fuels towards a regenerative bio-based, and nature-positive economy (European Union, 2021; Palahí et al., 2020; Sica et al., 2021) . Massive and rapid decarbonization actions are not enough and need to be coupled with the restoration and sustainable management of ecosystems and natural carbon sinks and reservoirs (Burrascano et al., 2016; UNEP and IUCN, 2021). Indeed, growing recognition of the value of ecosystem services and the wider socio-economic benefits provided by nature has encouraged a shift in policy and planning discourse, aiming to integrate these considerations into decision-making processes (Davis et al., 2018; Mendes et al., 2020).

At the European level, between 2019 and 2022, the European Commission promoted several initiatives to protect the environment and minimize hazards related to climate change and pollution for human health and biodiversity, setting ambitious goals. For example, the European Green Deal, including a set of proposals to shape European's climate, energy, transport, and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels. Then, European Climate law translated these goals into law, setting a legally binding target of net zero greenhouse gas emissions by 2050. Afterward, the Biodiversity Strategy for 2030, the Environmental Action Program, and the Proposal for a Nature Restoration Law have enriched with several goals the strategic and legislative framework linked to the path of a more sustainable, safe, and equitable world (Zulian et al., 2022). In this context, the central role of nature is not limited to its protection and safeguarding but all nature-based approaches have emerged as a key instrument to face different challenges across sectors of society and business, also offering multiple cost-effective benefits to ecosystems and human well-being (Chausson et al., 2020; Naumann et al., 2011; Seddon et al., 2020). In recent years, several nature-based approaches have become a key topic of contemporary research on sustainable development of urban and rural areas (Albert et al., 2019) such as ecological restoration, ecological engineering, green and blue infrastructure, ecosystem services, urban forestry, ecosystem-based management and adaptation, and eco-disaster risk reduction (Castellar et al., 2021; Escobedo et al., 2019). Since 2015 (European Commission, 2015), the concept of Nature-Based Solutions (NBS) has included all these approaches under its 'umbrella' that work with and enhance nature to help address multiple challenges and reach Sustainable Development Goals. Research on and innovative applications of NBS are supported by many policy initiatives, especially in the European Union that aims to become a world leader on this topic (Faivre et al., 2017). Indeed, it invested in the Horizon 2020 research and innovation program, catalyzing research–practice partnerships (Frantzeskaki et al., 2019), and providing insights regarding NBS performance, impacts assessments, and cost-effectiveness (Raymond et al., 2017). Concurrently, a growing number of private businesses identified NBS as a strategic frame to meet the Paris climate goals, offsetting their greenhouse gas emissions. The rationale behind NBS implementation - as an alternative or in combination with more conventional measures - is that they provide a wide range of co-benefits while limiting negative impacts, thus resulting cost-effective on a medium-to-long-term perspective and at multiple spatial scales (Cortinovis et al., 2022). NBS are tested in front-runner cities and urban living labs proving their capacities to experts, decision-makers, and stakeholders (Dumitru and Wendling, 2021; Sarabi et al., 2021) in facing extreme events related to climate change, by adaptation and mitigation actions (Veerkamp et al., 2021), contemporarily able to preserve human health (van den Bosch and Ode Sang, 2017), psychosocial well-being (Bratman et al., 2019), improve air and water quality (Barboza et al., 2021), increase landscape connectivity (Staccione et al., 2022) and provide new jobs (Maes and Jacobs, 2017). Despite all these projects highlighting multiple NBS advantages to reach national and international goals, some shortcomings deserve further attention, to

allow NBS to move from demonstration areas to their full-scale deployment.
Currently, NBS projects are limited to scattered case studies, often at local and municipal levels, scarcely showing the complicated real-life contexts of practice (Schröter et al., 2022; UNEP, 2021). Usually designed to provide supportive decision-makers and flexible governance (Sarabi et al., 2021) they may hide the difficulties to spread the gained knowledge to other contexts and scales, increasing the issues related to planning silos (Mendes et al., 2020). Furthermore, policy instruments for NBS implementation are mainly conceived for the municipal level (i.e., urban planning (Cortinovis et al., 2022)) and not for the landscape, country, or higher levels (Mendonça et al., 2021). The analysis proposed by Davis et al. (2018) revealed that while multiple European and member states' policy instruments explicitly acknowledge NBS-related approaches, they rarely contain quantitative objectives relating to NBS deployment and quality.
Given the planned investments to reach global and European targets as well as the high NBS capacity to help in this path, room remains to enhance knowledge regarding NBS inclusion at national and regional policy and planning levels (Naumann et al., 2011; UNEP and IUCN, 2021). Particularly, at the national level there is a significant need to strengthen the degree of awareness regarding the multifunctional potential and support cross-sectoral policy instruments to optimize existing NBS interventions and implement new ones. Furthermore, the availability of the budget and the space are recognized as the main barriers to enabling the uptake of NBS, maximizing their multifunctionality, and to ensuring their equitable distribution across the territory (Mendonça et al., 2021; Sarabi et al., 2019).
Therefore, providing coordinated legislative and financial support for NBS implementation would allow for an increase in both the cost-effectiveness of interventions and environmental justice.
Several methodologies are proposed in the literature that can help in this path. Ecosystem Services frameworks are mainly employed for assessing the Ecosystem Services supply of the proposed NBS

interventions and support urban planning (e.g., Cortinovis and Geneletti, 2018; Grêt-Regamey et al., 2017); Spatial analysis using data-overlay and/or aggregated indices are employed to defining priority areas for interventions while maximizing different co-benefits and environmental justice (e.g., Bodnaruk et al., 2016; Hansen et al., 2022; Kato-Huerta and Geneletti, 2023; Meerow and Newell, 2017; Vail Castro, 2022); cost-effectiveness and cost-benefits analysis are well investigated to evaluate the economically most efficient way to meet an objective and in turn target investment decision (e.g., Le Coent et al., 2021; Qiu et al., 2020; Valatin et al., 2022).

However, these methodologies are still generally proposed at the municipal scale, and often focused on single challenge addressing, revealing their intrinsic limitation given also by the use of administrative boundaries in i) environmental challenges spatial distribution and addressing, and ii) Ecosystem Services assessments (Baró et al., 2019, 2015).

Scientific evidence and approaches at national scale are still lacking to support and guide the implementation of environmental policies at lower levels. Especially, the possibility of supporting national governments in optimizing funds allocation through maximizing the return for people and ecosystems is almost unexplored. Indeed, this Ph.D. research thesis aims to fill this gap using Italy as a case study, where the well-being of the human population is strongly threatened by multiple environmental challenges and the national government is currently struggling to enhance environmental sustainability in urban areas.

The possibility to overcome the project/municipal scale and apply project outcomes and advanced methodologies to the national scale was the primary objective of this research thesis. Particularly, the proposal of an evidence-based spatially explicit framework was conceived to provide a strategic level at the national scale. This level could help to connect the supranational objectives and the operational level with a comprehensive and coordinated approach to i) identify and map hazardous challenges for human well-being and health, ii) provide a set of cost-effective solutions to address these challenges, iii) identify the budget potentially dedicated to fulfilling the objectives.

Italy was identified as a meaningful case study, as it is experiencing the adverse effects of climate change, such as heatwaves, floods, and drought events, combined with exposure to the three most harmful air pollutants in the European Union (Cramer et al., 2019; European Environment Agency (EEA), 2020; Fischer and Schär, 2010). Furthermore, issues related to ecological connectivity, biodiversity, and ecosystem services loss are exacerbated by the highly sealed surface and urbanized territory (Capotorti et al., 2012; Sallustio et al., 2015). Indeed, the Italian sealed surface reaches one of the highest relative national coverages (7.1%) among European countries (Sallustio et al., 2016), showing a fragmented pattern that increasingly smoothed boundaries between urban and rural area (Amato et al., 2016).

The Italian national government has envisaged different urban sustainability strategies and policies and set ambitious tree-planting objectives to address the over mentioned challenges (Marchetti et al., 2019; Salbitano and Sanesi, 2019). Italy is also one of the leading countries, among the Mediterranean countries (Krajter Ostoić et al., 2018) in research focused on urban forestry, and on Nature-Based Solutions among European countries (Mendes et al., 2020).

Therefore, this Ph.D. thesis is based on the premise that the Italian national government could benefit from scientifically-sound support to coordinate the implementation of NBS at lower levels for reaching multiple national targets related to different environmental policies, with the final scope to improve the state of ecosystems and human health as a whole. At the same time, this approach could be replicated in Europe or by other Member States which need to effectively leverage investments provided by the Green Deal/Recovery and Resilience Plans, developing strategies to generate gains for adaptation, mitigation, disaster risk reduction, biodiversity, and health (European Union, 2022; Veerkamp et al., 2021).

This Ph.D. thesis was developed according to four main stages, as presented in the following workflow,
Stage I: Harmful areas to human health were mapped with a spatial resolution of 1 Km^2, based on three environmental challenges, air quality, climate adaptation and mitigation, and water management, which exceed specific Environmental Quality Standards (EQS). The greater the EQS exceedance the greater the population's exposure to challenges in that portion of the territory. A spatial multi-criteria analysis assessed the cumulative occurrence of factors by combining them into a single Aggregate Index of Challenge (AIC), a hotspot analysis identified the spatial aggregation of AIC through the territory, and the product of the AIC and the population density provided the Risk Index AICpop; Stage II: the overlay of the three challenges (i.e., areas in exceedance of Environmental Quality Standards) allows the identification of portions of territory threatened simultaneously by the same challenges (i.e., spatial groups). These groups serve as functional areas where 24 NBS were ranked and mapped according to their performance to address challenges occurring within the groups (Ecosystem Services supply); Stage III: three different NBS selection scenarios were designed combining data related to their performance and their implementation costs. Once selected, the NBS allocation through the territory was prioritized following the Risk Index AICpop, and the relationship between the costs and effectiveness was investigated for the three scenarios; Stage IV: the NBS embeddedness in the Italian policy discourse of the Recovery and Resilience Plan was investigated to assess how NBS are considered to meet environmental targets as well as the dedicated investments.

These four stages eventually conducted to the publication of four scientific articles in SCI journals here presented as four different chapters.

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2. Urgence and priority to address environmental challenges

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This chapter explores the spatial priority of interventions based on the intensity of multiple environmental challenges and population density. The approach proposed in this chapter allows the identification and quantification of areas considered under health hazards through using common thresholds (i.e., Environmental Quality Standards) and aggregated indices to monitor the impacts of the interventions and compare different contexts and scales.

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Strengthening the implementation of national policy agenda in urban area to face multiple environmental stressors: Italy as a case study

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ABSTRACT

Multiple environmental stressors threaten the environmental quality in urban areas.S everal policies were implemented in Italy to improve environmental quality, following the rationale that the more populated municipalities need high intervention priority and funds. Nevertheless, this approach not necessarily ensures to address real environmental challenges. This study aims to provide an innovative approach to explore interventions' priority at the national scale, based on Environmental Quality Standards (EQS) of five factors related to three environmental stressors, air pollution (O_3, PM_{10}, NO_2), thermal stress (heatwave days), and hydraulic vulnerability (flooding events). A multi-criteria analysis assessed the cumulative effect of factors by combining them into a single Aggregate Index of Challenge (AIC), and a hotspot analysis identified AIC spatial aggregation through the territory. Finally, the spatial mismatch between Italian environmental policies and the co-occurrence of factors was explored. Results evidenced EQS exceedances in the national territory of O_3 for 89%, PM_{10} for 8%, NO_2 for less than 1%, heatwaves for 45%, and hydraulic vulnerability for 10%. AIC highlighted that 43% of the national surface shows the coexistence of at least two factors in EQS exceedance. Results highlighted that administrative boundaries are not sufficient to delimit an area of analysis and intervention as opposed to an evidence-based approach which seems promising for enhancing the cost-effectiveness of funds allocation as well as their return in terms of human wellbeing. This study provides a novel approach to enhance environmental policies and planning, giving insight for future research, especially for Nature-Based Solutions implementation, performance, and multifunctionality.

KEYWORDS

Urban sustainability; Human well-being; Air pollution; Thermal stress; Hydraulic vulnerability; Multi-criteria analysis

1. Introduction

Today societies are facing the long-standing global environmental crises of climate change and biodiversity loss. Currently, 73% of Europe's population lives in urban areas and this percentage is projected to increase to 82% by 2050, posing a range of challenges for urban contexts, including resource availability, equitable economic growth, and population health (European Commission, 2015; van den Bosch and Ode Sang, 2017). Air pollution and the extreme events related to Climate Change (e.g., heatwaves and floods) are the environmental stressors of main concerns in the European Union (EU) (European Commission, 2015), and the policies to face them might be coupled in the political agenda (Raymond et al., 2017). Air pollution is a major EU public health issue, leading to half a million premature deaths in 2016 (Sicard et al., 2021; van den Bosch and Ode Sang, 2017). The European summer of 2021 was marked for great heatwaves episodes leading to regional fires and heavy rains, which brought devastating floods (WMO, 2021). Therefore, the total health risk already reported in the literature (D'Ippoliti et al., 2010; Menne and Murray, 2013; Pyrgou and Santamouris, 2018) is amplifying with the increase in frequency and intensity of extreme events related to Climate Change. In urban areas, both the hazard severity and people's vulnerability are exacerbated. Sealed surfaces reduce the ability to intercept, store and infiltrate rainwater (Livesley et al., 2016; Malaviya et al., 2019), and their low albedo combined with large thermal admittance cause Urban Heat Island effect (Fini et al., 2017). Furthermore, the health condition of populations is strongly affected by complex interactions among factors (e.g., air pollutants and heatwaves), which are interconnected and evolve through time (Sarkar and Webster, 2017).

One of the recognized methods to measure the multiple effects of the stressors is the use of composite indices obtained by combining multiple factors usually evaluated separately (Brousmiche et al., 2020). A deeper comprehension of the interactions between environmental stressors and human health will help define policies and design effective interventions towards minimizing environmental risk exposures (Sarkar and Webster, 2017). Therefore, policies that establish clear thresholds and limits, such as EU Air Quality Directive (2008)/50/EC), are crucial for monitoring factors (e.g., air pollutants) in space and time and to track the progress of countries (Sicard et al., 2021). The extension of legally binding policies and actions (mitigation and adaptation) to multiple stressors could help reduce risks and vulnerability for exposed populations and improve the resilience capacity of urban areas (Maes et al., 2019; van den Bosch and Ode Sang, 2017). Moreover, the calculation of composite spatially-explicit indices further support the implementation of strate- gies and policies to enhance environmental health (Flacke and Köckler, 2015).

Recent studies showed that the link between natural environments and public health is robust and economically significant (McDonald et al., 2017). Indeed, the maintenance and enhancement of ecosystem services (ES) is proved as a valid approach to face environmental challenges and ameliorate human health and well-being (Babí Almenar et al., 2021, 2018). In this context, Nature-Based Solutions (NBS), along with biodiversity conservation, can help in addressing these challenges (Escobedo et al., 2019; Seddon et al., 2020; Wendling et al., 2018), providing multiple ES (Babí Almenar et al., 2021; Wild et al., 2017). Literature poses particular emphasis to the NBS capacity in the mitigation of factors (e.g., Particulate Matter, Ozone, Nitrogen Dioxide, Heatwaves, Flooding and run-off) and their related environmental stressors (e.g., Air pollution, Thermal Stress, Hydraulic Vulnerability) (Fusaro et al., 2017; Gatto et al., 2020; Keesstra et al., 2018; Malaviya et al., 2019; Morabito et al., 2021; Semeraro et al., 2020; Sgrigna et al., 2020).

This scientific evidence sparked the interest in policy worldwide, encouraging ambitious tree planting initiatives (FAO, 2018; McDonald et al., 2017) as the "Trillion Tree Campaign" (Seymour, 2020) or the "Great Green Wall" (Goffner et al., 2019). Under the European Green Deal, one of the commitments of the Biodiversity Strategy2030 is the pledge to plant at least 3 billion trees in the EU by 2030 (European Commission, 2021a). Industrialized countries (e.g., EU member states) are experiencing land abandonment, followed by forest expansion in the mountain and economically marginal areas (Graham et al., 2017; Munteanu et al., 2014; Malandra et al., 2018; Sallustio et al., 2015), counterbalanced by the urban expansion in lowlands and along the coasts (Romano and Zullo, 2014). This spatial polarization has triggered the need to set planting-objectives aiming to improve the connectivity of ecosystems in lowlands while addressing urban challenges (Di Pirro et al., 2021; FAO, 2018; Kremer et al., 2016). Therefore, starting from the protection of existing forests, additional trees will be planted in urban and peri-urban areas (European Commission, 2021a).

For this purpose, different methodologies were developed to define priority planting areas (e.g., Bodnaruk et al., 2016; Locke et al., 2013; Morani et al., 2011), and the ES framework was broadly recognized for its support in urban planning (Hamel et al., 2021). A wide scientific literature presented tools to map and assess the ES demand arising from current critical conditions and the expected ES supply of the proposed interventions (Grêt-Regamey et al., 2017). These assessments are promoted as a way to estimate the mismatch between supply and demand (Baró et al., 2015), to develop performance-based planning approaches (Cortinovis and Geneletti, 2020), and to investigate alternative planning scenarios (Cortinovis and Geneletti, 2018) aiming to strengthen urban planning initiatives (Cortinovis and Geneletti, 2019). However, these studies are generally carried out at the municipal scale, revealing their intrinsic limitation given the use of administrative boundaries in ES assessments (Baró et al., 2015). The high ES demand within cities could not always be fulfilled by enhancing the supply just within their administrative boundaries (Baró et al., 2014; Larondelle et al., 2014). Indeed, the ES supply-demand dynamic is usually influenced beyond the cities' boundaries, namely by the peri-urban and rural hinterland (Alonso et al., 2011; Baumgardner et al., 2012; Larondelle and Haase, 2013). Accordingly, urban policies allocating funds for NBS implementation based on administrative boundaries might not necessarily i) be more efficient than investments in surrounding areas excluded a priori from budget allocation, ii) guarantee their spatial match with environmental challenges through the Country, iii) align with other policies and national targets.

When the boundaries of the ecological process do not match with the boundaries of its management strategy, this is called "scale mismatch" and it can contribute to a decrease in social-ecological resilience and human well-being (Cumming et al., 2006; Guerrero et al., 2013). This issue is pronounced when ES are applied in urban policies and plans (Wilkinson et al., 2013), especially in the management and implementation of urban green spaces as isolated units from urban matrix and surroundings (Borgström et al., 2006). Despite the resolution of scale mismatches remains a frontier for research and policy (Cumming et al., 2006), a multi- and cross-scale approach for institutions seems promising to address environmental challenges (Borgström et al., 2006; Guerrero et al., 2013). Particularly, Borgström et al. (2006) proposed to adopt an integrative view of the whole social-ecological landscape and introduce a missing level (i.e., mesoscale) of planning that could connect strategic (e.g., EU) and operational levels (e.g., municipality).

Despite the governments are allocating funds to the municipalities for the mitigation of environmental stressors, scientific evidence at the national scale is still lacking to support and guide the implementation of policies at lower levels, and in turn helping to reduce the scale mismatch. We question if administrative boundaries can be overcome, resuming this lack with a national spatially explicit assessment to identify hazardous areas for people based on their exposure to single and cumulative stressors. We contribute to address this gap using Italy as a case study, where population is strongly affected by multiple environmental stressors and the government is allocating funds to municipalities to enhance the environmental sustainability in urban areas.

Consequently, this work aims to provide a spatially-explicit methodology to explore the spatial priority of interventions based on Environmental Quality Standards (EQS) and policy goals. We used EQS (Baró et al., 2015) to indicate the desirable common threshold (e.g., EU Air Quality Directive, 2008/50/CE) that should be reached by the environmental factors (e.g., air pollutants) to ensure human well-being. Thus, EQS allow to determine where the exceedance for each factor is problematic for human health, how the different factors interact each other across the national territory, and hence where interventions for their reduction and mitigation should be prioritized. We proposed a pixel-based approach to monitor the whole national territory and allowing to support: i) the identification and quantification of areas in EQS exceedance, hence considered as health hazard; ii) the identification of interventions priority based on the intensity of environmental challenges; iii) an efficient and evidence-based funds allocation by national policies; iv) the spatial agreement among health hazard areas and funds' allocation related to the Decree on Climate (2019).

2. Introducing the case study

In Italy, built-up areas increased during the last decades despite the generalized negative national demographic trend (SNPA, 2019), reaching one of the highest relative coverages (7.1% of the national territory) among EU countries (Sallustio et al., 2016). The urban mosaic appears highly scattered and fragmented (Romano et al., 2017) thus smoothing the demarcation line between urban and rural areas (Amato et al., 2016). Furthermore, Italy is the second country in Europe to show the largest population exposed to all three pollutants in exceedance for the standards set in Air Quality Directive (EEA, 2020) and, being situated in the Mediterranean region, it is consistently experiencing the effects of Climate Change (Fischer and Schär, 2010).

To address these challenges, Italy, as many other countries, set ambitious planting objectives (e.g., the Laudato Si' communities proposed to plant 60 million trees) (Marchetti et al., 2019). Concurrently, several policies were implemented aiming to improve environmental sustainability and resilience in urban areas, allocating funds from the government to the municipalities. Indeed, the Italian Ministry of Environment, Land and Sea Protection recently approved the "Decree on Climate" (2019) as a national strategic policy adopted to tackle the climate emergency and achieve the objectives related to the Air Quality Directive (2008)/50/CE). This policy follows the rationale that the more populated municipalities coincide with the areas where the quality of life is mostly threatened and consequently deserve high priority of interventions (e.g., sustainable mobility, urban forestry). For example, the "Mobility Voucher" program (Bonus Mobilità-Art.2 Decree on Climate, 2019) aims to reduce pollution within urban contexts, providing a tax refund to citizens buying bikes as well as electric propulsion vehicles for private mobility. Similarly, the recently launched "Urban Forestry Program" (Azioni per la riforestazione-Art.4 Decree on Climate, 2019) allocates funds for implementing and managing urban and peri-urban forests, and for reducing impervious surfaces (i.e., de-sealing interventions) as key components to address urban challenges (Salbitano and Sanesi, 2019). Both programs have particular emphasis to mitigate air pollution while the "Urban Forestry Program" also evaluates the mitigation capacity on heatwave and flood hazard.

According to the aim of this work, we focused our analysis on three administrative domains to which a decreasing emphasis (e.g., funding opportunities) is currently given by national policies related to environmental urban sustainability (i.e., Decree on Climate, 2019). These three geographic domains (Fig. 1) are represented by: i) the fourteen Metropolitan Cities (hereafter, MC) involved within both the "Urban Forestry Program" and the "Mobility Voucher"; ii) the regional and provincial capitals and the municipalities with more than 50,000 inhabitants (hereafter Large Cities, LC), to which only the "Mobility Voucher" is extended to, and excluding those already included in MC; iii) the rest of Italian municipalities (hereafter, "NoFund") currently excluded by both the funding initiatives. MC represents the administrative domain to which more emphasis on urban sustainability is recognized by national policies. The fourteen MC identify the biggest Italian cities and their surrounding areas having great socio-economic relevance in the National context. Together, MC covers approximately 46,600 km^2 hosting about 22 million inhabitants. Municipalities falling into LC have a lower emphasis on the national political framework if compared to MC, and they cover 22,500 km^2 hosting about 26 million inhabitants (ISTAT, 2021). The rest of the municipalities - "NoFund" - that are currently excluded by the two policies analyzed in this work, covers approximately 234,000 km^2 and host about 12 million inhabitants.

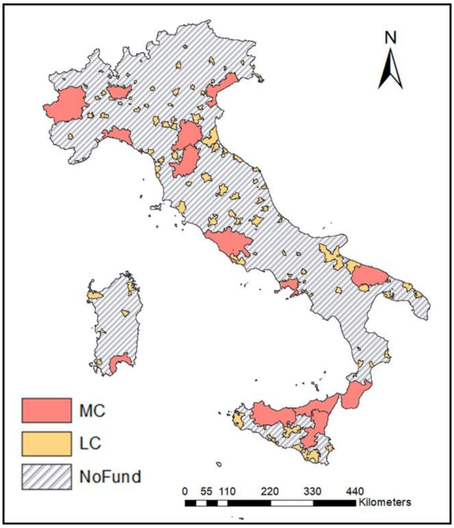

Fig. 1. Administrative domains investigated, Metropolitan Cities (MC) in pink, Large Cities (LC) in orange and the remaining municipalities excluded from the Decree on Climate (NoFund) represented with the striped pattern.

3. Materials and methods

We selected five factors frequently altering people's mortality: NO_2, PM_{10}, O_3 concentrations, number of days of annual heatwaves and flood hazard, representative of three environmental stressors: air pollution, thermal stress and hydraulic vulnerability. After that, for each factor, we identified Environmental Quality Standards (EQS) according to thresholds given by European Union directives, national reports or scientific papers in literature. A spatially-explicit assessment of areas where the single EQS thresholds are exceeded, as well as the magnitude of such overshoot, allows to locate and quantify harmful areas for human health. The greater the exceedance (the difference between the current value and EQS value for each factor) the greater the challenges the population is exposed to in that portion of territory. We performed a multi-criteria analysis (MCA) to assess the intensity of environmental challenges resulting from the co-existence of multiple factors. MCA enables the production of a detailed Aggregate Index of Challenge (AIC) defining the relative priority of intervention at the national scale. Finally, we conducted a hotspot analysis to identify areas where a spatial aggregation of contiguous high AIC values occurred, thus identifying portions of territory where particular attention should be paid by decision-makers. All the analyses were conducted at the national scale using a spatial resolution of 1 km^2. Furthermore, both AIC values and hotspot areas were compared to the administrative areas (i.e., CM, LC and NoFund) currently involved in funds allocation by the Decree on Climate (2019) to explore the agreement between challenges and political choices.

3.1. Selection of the environmental quality standards

Based on literature analysis of national and international regulatory frameworks, we identified relevant EQS for five factors (PM_{10}, NO_2, O_3, heatwave, flooding return period) representative of three environmental stressors (air pollution, thermal stress, hydraulic vulnerability) (Table 1). These factors were selected because i) they alter the population's mortality, ii) their mitigation represents key environmental challenges, iii) both at the European and national scale, strategies and policies were envisaged to face them and dataset are available to facilitate their large-scale multitemporal monitoring. We carried out a

Table 1
Environmental Quality Standard (EQS) selected for five factors related to three environmental stressors. NO_2, O_3, and PM_{10} for Air Pollution, Combined Hot days and Tropical night (CHT) for Thermal Stress and flood hazard for the Hydraulic Vulnerability.

Environmental Stressors	Factors and Environmental Quality Standards		
Air Pollution (Air Quality Directive, 2008/50/EC)	**NO_2** 40 μg/m^3 (year)	**O_3** 120 μg/m^3 (25days/year)	**PM_{10}** 50 μg/m^3 (35days/year)
Thermal Stress (Fischer and Schär, 2010)	**CHT Combined Hot days (T > 35 °C) and Tropical nights (T > 20 °C)** 4		
Hydraulic vulnerability (Trigila et al., 2018)	**Flood Hazard** return period < 200years		

collinearity test to exclude correlation among the five different variables that could affect the robustness of results (see table S1 in supplementary materials).

3.1.1. Air pollution

Europe's most harmful pollutants for human health (Lim et al., 2012) are PM_{10}, NO_2, and ground-level O_3, resulting in economic, medical costs, and productivity impacts (European Environment Agency, 2020). The EU, with the Air Quality Directive (2008)/50/EC), set pollutants concentrations standards for their member states. These standards are legally binding so, in case of their exceedances, countries must develop and implement air quality management plans to bring their concentrations below the standard values.

Accordingly, we focused the analysis on PM_{10}, NO_2, and O_3 and we derived EQS (Table 1) from the EU Air Quality Directive (2008)/50/EC) as follow: 1) particulate matter with a diameter of 10 μm or less (PM_{10}), with the threshold of 50 $\mu g/m^3$ for more than 35days/year; 2) nitrogen dioxide (NO_2), with the threshold of 40 μg annual average; 3) tropospheric ozone (O_3), with the threshold of 120 $\mu g/m^3$ for more than 26days/year. The dataset used is provided by the European Environment Agency, with a spatial resolution of 1 km^2 (Horálek et al., 2019).

3.1.2. Thermal stress

Human health vulnerability to temperature extremes depends on the definition of heatwaves (Brimicombe et al., 2021; Xu et al., 2016) as well as intrinsic person-specific and extrinsic characteristics such as age, health status, socio-economic circumstances and climate adaptation (Fernandez Milan and Creutzig, 2015). Recently, the Italian Ministry of Health developed "National Operational Plan to prevent effects on human health from heatwaves", including a mapping system with bulletins announcing heatwave risks in few municipalities (European Commission, 2021b). However, as opposed to air pollution, a common definition of heatwave and related threshold for monitoring this parameter were not explicitly identified. Thus, the identification of a unique EQS for heatwaves is hampered. Firstly, we decided to use the definition of heatwaves given by Fischer and Schär (2010), due to its focus on warm nights (besides hot days) and its emphasis on the correlation of spatial and temporal variance of heatwaves with mortality. Therefore, according to Fischer and Schär (2010), we intended heatwaves as the "Combined Hot days (TMAX > 35 °C) and Tropical nights (TMIN > 20 °C)", hereafter defined as CHT. Then, considering that climate change projections rely on intensification in terms of frequency and severity of heatwaves during the future, we set up a CHT of 4days/year of heatwaves as EQS. We used this threshold because it is considered as the minimum expected values of CHT in the projection period 2021-2050 for the Mediterranean area (Fischer and Schär, 2010). Hence, all the pixel showing CHT values above EQS are considered in exceedance.

We used the Dataset proposed by Moreno and Hasenauer (2016) to calculate CHT in Italy with 1 km^2 resolution. Considering the climatic variability, we performed the analysis of heatwaves over the 2005-2012 period. We calculated the sum of CHT during the summer period (June-August) for each one of these years. Consequently, following a precautionary approach, the highest CHT value in the time-series was selected for every 1 km^2 pixel. In this way, we obtained a map showing the worst case of CHT that occurred in the time-span.

3.1.3. Hydraulic vulnerability

The hydraulic vulnerability of a territory can be established if information on its exposure to floods is known (Scheuer et al., 2011). The EQS selected are thus based on the probability that a flooding event will occur in the future based on their estimated return period. Hence, we divided the national territory into i) areas for which a return period for floods has been estimated by ISPRA (Trigila et al., 2018) (i.e., areas with flood hazard), and ii) areas for which a return period has not been estimated and where no floods events are expected to occur in the future. In this work we considered the former areas as those in exceedance (e.g., risk for population). The dataset used is provided by ISPRA with 1 km^2 resolution (Trigila et al., 2018). According to this classification, return period for floods are divided into three classes: lower than 50 years, between 100 and 200 years, higher than 200 years. For this factor, the lower is the estimated return period for floods (e.g., lower than 50 year), the higher the exceedance.

3.2. Spatial aggregation of multiple stressors in an Aggregate Index of Challenge

Human wellbeing, especially in urban areas, is strongly affected by the cumulative effect of different environmental stressors (Su et al., 2009; Brousmiche et al., 2020). During planning activities aiming to mitigate the negative effects of such stressors, win-win solutions can be adopted to maximize the effectiveness of the interventions and public investment (Meerow, 2020). Accordingly, we applied a spatially-explicit multi-criteria analysis (MCA) approach (e.g., Corona et al., 2008; Nisar Ahamed et al., 2000; Zadeh, 1996) to aggregate these factors into a single Aggregate Index of Challenge (AIC). MCA is often used to solve controversial situations dealing with planning conflicts requiring the evaluation of multiple factors (Adem Esmail and Geneletti, 2018), thus playing a pivotal role in supporting decision-making processes (Lewis and Kelly, 2014). We performed MCA within a geographic information system (GIS) environment to produce a spatially-explicit AIC with a spatial resolution of 1 km^2 for the whole national territory. AIC provides valuable information on how the single factors simultaneously occur in each pixel, thus offering the possibility to better understand the relative priority of intervention.

We used the GIS-based MCA decision support module in IDRISI Selva (v.17.02, Clark Labs, Clark University, MA, USA) to standardize the values of the five single factors and to aggregate them into a unique AIC. We first standardized the scores of the five factors on a 0-1 scale. Values were standardized setting to 0 all factors' values lower than their EQS and standardizing the others according to the maximum value of the distribution observed at national scale for the single factor. Accordingly, the standardized value of each factor is equal to 0 for all pixels below EQS while it tends to 1 with the increasing of its exceedance regarding its EQS. This means that the higher is the single standardized value the more challenging is the situation for the exceedance of that factor. Five different maps of these standardized values were produced with a spatial resolution of 1 km^2, and they can be used to identify specific policies and interventions aiming to mitigate the single factor. The five single factors, and their maps, were then combined through a weighted linear combination (WLC) method (Corona et al., 2008). We assigned the same weight of 0.2 to each factor within WLC to balance their relative incidence in determining the final AIC values. This choice is shared with other authors (Cutter et al., 2010; Scheuer et al., 2011) when there is no relevant scientific reason for a factor having more weight than another (Brousmiche et al., 2020). Consequently, being composed by three factors (PM_{10}, NO_2, O_3), air pollution has a greater weight (0.6) than the other two stressors composed by one factor each. Similar to the standardized values of the single factors, AIC map represents the spatial distribution of the AIC ranging from 0 to 1. AIC equal to 0 means that none of the five factors exceed its relative EQS. The higher AIC the higher is the exceedance of the different factors for their relative EQS. Although the same AIC values can represent different combination of factors in exceedance, it provides the relative magnitude of the challenges to be addressed due to the co-occurrence of multiple factors.

3.3. The hotspots and coldspots analysis

We performed a Cluster and Outliers analysis to better understand the spatial variability of AIC. This analysis is usually used to have an analytical representation on how single values of indices are aggregated within a given territory (e.g., Di Febbraro et al., 2018). This allows to not limit the analysis to the value of the single pixel but to extend it to the spatial relations of the values among different pixels.

Particularly, we used the methodology applied by Anselin (1995) allowing us to spatially identify statistically significant hotspots, coldspots, and spatial outliers using the Anselin Local Moran's I statistic implemented in the "Cluster and Outlier Analysis" tool in the ESRI ArcGIS® software package. This tool indicates spatial similarity (spatial clustering) or dissimilarity (spatial outlier) by classifying each pixel based on its cluster/outlier type (COType). The hotspot is intended as an area characterized by high-density clusters of a specific indicator (i.e., AIC) and surrounded by low-density clusters of the same indicator, referable as a coldspot. The clustering algorithm classifies the single pixels of the national territory into i) statistically significant (0.05 level) clusters of high values (hotspot; HH), ii) statistically significant (0.05 level) clusters of low values (coldspot; LL), iii) outliers in which a high value is surrounded primarily by low values (HL), and iv) outliers in which a low value is surrounded primarily by high values (LH) (Sallustio et al., 2017). We used a threshold distance of 10 km to perform the Cluster and Outlier Analysis, which represents the radius of an area of 320 km^2 (i.e., the average extent of the 100 larger cities in Italy).

3.4. Comparison between aggregated factors and boundaries of current Italian policies

We evaluated the spatial agreement between the policy's boundaries of the Decree on Climate (2019) and the co-occurrence of factors through analyzing three indices within the three administrative domains to which this study refers (MC, LC, and NoFund), particularly: i) average AIC; ii) the relative incidence of hotspots; iii) average AIC per population (AICpop). AICpop is given by the product of the AIC and the population density within the pixel, hence it increases as these two parameters increase. The population density layer with 1 km^2 of spatial resolution used for population exposure estimates is retrieved Horálek et al. (2019). While average AIC and incidence of hotspots only refer to the state of the stressors within the administrative domain (i.e., relative magnitude), mean AICpop also includes the risk for human well-being, considering the number of people exposed to such stressors. The higher AICpop, the higher the inhabitants exposed to high values of AIC. Therefore, we explored the current rationale in allocating funds for the environmental and societal needs considered in this study.

4. Results

4.1. Environmental stressors against their environmental quality standards

Concerning the three factors related to air pollution, O_3 exceeds its EQS for about 89% of the national territory with a maximum value of 176.08 $\mu g/m^3$, PM_{10} for about 8% with a maximum value of 90.91 $\mu g/m^3$ while the annual NO_2 exceeds EQS for less than 1% with a maximum value of 54.39 $\mu g/m^3$. As shown by Fig. 2, the highest frequency of heatwave occurred in the time-span considered (2005-2012) ranges from 0 to 36 days. About 45% of the national surface exceeds the EQS of 4CHT/year. Regarding the hydraulic vulnerability, about 10% of the national territory is in exceedance, being the flood hazard expected in the future.

The maximum values for all the five factors are mainly distributed in Northern Italy, particularly in the Po' valley, and the main urban areas of Central and Southern Italy (Fig. 2), with the most vulnerable area for flooding concentrated in the southern part of the Po valley, along Apennines' riverbeds and close to coastlines. As regards the whole percentage of the national territory showing EQS exceedances (Fig. 3), 51% presents one of the five factors in EQS exceedance while 43% shows at least two factors simultaneously in EQS exceedances. Just 6% of the national surface shows no EQS exceedance for any of the five factors examined.

4.2. Aggregate index of challenge and its spatial aggregation

AIC ranges from 0 to 0.85 (Fig. 4), where 0 represents the areas with no environmental challenge and the index increases as the challenges increase due to the combination of the five factors. The national average value is 0.03, with approximately 6% (about 19,000 km^2) of the national territory showing AIC values of 0, and 68% (about 208,000 km^2) between 0 and 0.1. Analyzing the spatial aggregation of AIC, the hotspots cover 18% (about 54,000 km^2) of the national territory while the coldspots among 49% (about 150,000 km^2). 32% of the territory is instead represented by areas where AIC values do not aggregate in a spatially significant way and correspond with the transition zones between hotspots and coldspots as visible in Fig. 4. AICpop shows a trend very similar to AIC but it ranges between 0 and 15,262 and the distribution of values is more stretched throughout the territory due to the role of population density in giving more emphasis to densely populated urban areas.

The average AIC values for each administrative domain (Table 2) are 0.09 in NoFund, followed by 0.12 in MC and LC. The high values of coefficient of variation, ranging from 114% to 131%, show that AIC values are heterogeneous within the considered administrative boundaries. This variability should be considered during National policies implementation and funds allocation in order to better address the real needs of territories as well as enhance the effectiveness of the interventions. This high variability was also found - even more emphasized - in the average AICpop, where the general trend for which the index is higher passing from NoFund to MC domain was confirmed. This trend is particularly emphasized due to the contribution of the population density, much higher in MC and LC when compared to NoFund. The relative incidence of the hotspot to the total surface of the three domains increases from NoFund to MC and LC (17%, 21% and 24%, respectively).

We explored the high variability of the three indices with particular regard to MC, which is currently the administrative domain with the higher attention by urban sustainability policies in Italy. The cumulative effect of factors is widely heterogeneous within this administrative domain, as already suggested by the high CV% (Table 2) and confirmed by analyzing the three indices within each of the fourteen MC nationwide (Table 3). Indeed, mean AIC ranges from a minimum value of 0.029 in Cagliari to a maximum of 0.561 in Milan, followed by Bologna and Venice (0.250 and 0.211, respectively). A similar trend is observed for AICpop, with the cases of Naples and Rome (472 and 106, respectively) that, together with Milan and Venice (1202 and 121, respectively), show values remarkably higher due to their higher population densities. The different ranking of AICpop values compared to AIC for the fourteen MC, support the hypothesis to include population density as an important parameter to analyze funds allocation compared to beneficiaries of the policies. As for the three administrative domains previously analyzed, even in this case, the generally high values of CV% demonstrate the high heterogeneity within the analyzed MC, ranging from 13% to 157% for AIC and from 177% to 609% in AICpop. The relative hotspots incidence within the different MC is consistent with AIC values' distribution, with Milan completely falling within a hotspot area, followed by Venice and Bologna (69% and 56%, respectively). Furthermore, Table 3 shows as six of the fourteen MC do not have any hotspot area within their territory. This means that even having factors in EQS exceedances within their boundaries - as demonstrated by AIC values - the spatial aggregation does not result in a significant aggregation of such high values.

5. Discussion

5.1. Environmental stressors and possible synergies for their mitigation

Each of the five factors considered in this work shows a different magnitude of EQS exceedance, and just 6% of the national territory (19,000 km^2) has no EQS exceedance. Moreover, we identified a spatial

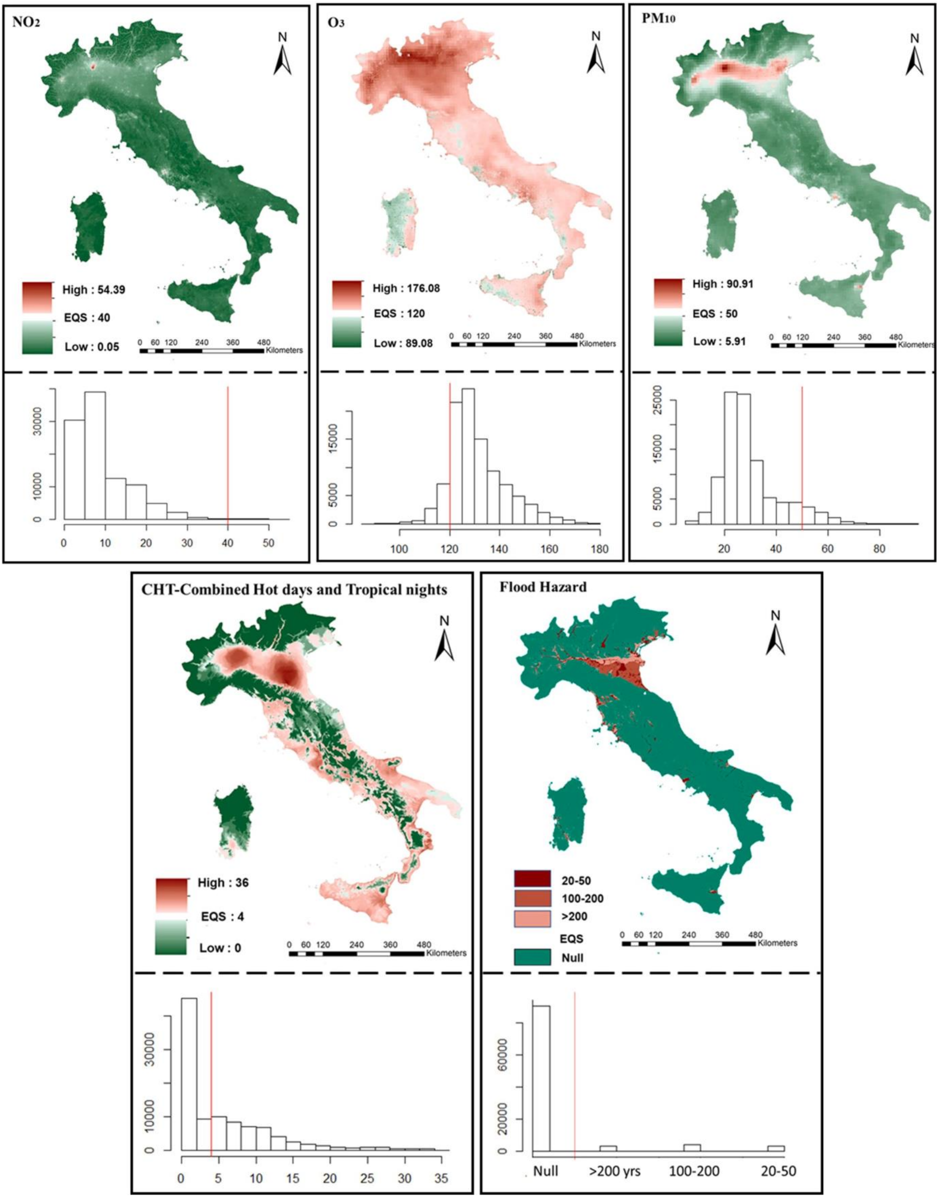

Fig. 2. Maps and histograms of the distribution of values (from minimum to maximum) for each of the five factors. The red line in the histograms represents the Environmental Quality Standard (EQS) selected for each factor. Starting from the top left, the three air pollution factors NO_2, O_3 and PM_{10}. On the bottom, from the left, the highest frequency of CHT-Combined Hot days and Tropical nights- occurred in the time span 2005‐2012 and Flood Hazard with the expected flooding return periods in Italy, "null" are the areas where no return period is estimated (i.e., no flood hazard).

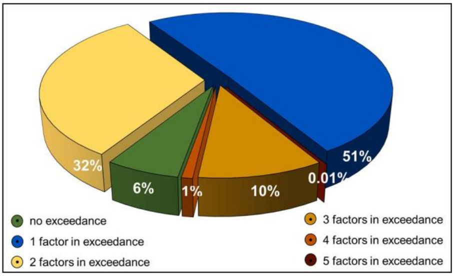

Fig. 3. Relative incidence (% of the total National surface) of the simultaneous exceedance of different factors.

overlap of these exceedance areas particularly in the Po' Valley and in correspondence with some urban areas of central and southern Italy.

Regarding air pollution, our results are consistent with data reported by EEA and SNPA. Accordingly, despite O_3 is the second harmful pollutant, Italy failed to comply with the long-term objective to reduce its concentration below the EQS set in EU directive 2008/50/CE (Nuvolone et al., 2018; SNPA, 2020), hence showing EQS exceedance for about 89% of the territory. Both at the European and national level, policies are already in place to reduce O_3 precursors, among which NO_2. In fact, the significant reduction recorded in Europe as well as in Italy in the last ten years (SNPA, 2020) led to the observed slight EQS exceedance of NO_2 (less than 1%). Nevertheless, no consistent decline has been observed in the O_3 concentration over Europe so far (European Environment Agency, 2020 and previous reports). Analogously, at the same time-span, PM_{10} decreased in 72% of the Italian air quality monitoring station (SNPA, 2020). However, the current exceedance (8%) is of concern since it is responsible for both long and short-term effects on mortality (Cohen et al., 2017; Lim et al., 2012; Pascal et al., 2013). As regards thermal stress, 45% of the national territory shows at least 4 days of heatwaves until a maximum of 36. Despite heatwaves strongly affects human health (D'Ippoliti et al., 2010; Hajat and Kosatky, 2010), national policies are still piecemeal. This issue is shared by other countries (e.g., UK; Brimicombe et al., 2021), and it is particularly worrying considering future projections of climate change and urban population growth (Pyrgou and Santamouris, 2018). Although heatwaves are usually tricky to be monitored at the national scale, adopting a globally recognized definition of the heatwave and the relative EQS would lead to i) avoid heat stress underestimation, (WMO and WHO, 2015) ii) improve or develop early warning system and mitigation actions especially in urban contexts (Antics et al., 2012; Xu et al., 2016). However, when passing to the local scale, the use of a common threshold for heatwaves is less appropriate considering that the demand for urban temperature regulation is strongly context and user-dependent (Baró et al., 2015; Hajat and Kosatky, 2010). 10% of the national territory is under hydraulic vulnerability and according to Trigila et al. (2018) about 9 million inhabitants live in these conditions, 2 million of which are classified as high risk. Data regarding flood hazard are already used for the identification of intervention priorities and the distribution of funds nationwide (Trigila et al., 2018).

Detailed knowledge on the single factors (distribution, concentrations, exposed population) can play a crucial role to identify intervention priorities. Our findings highlight that about 43% of the national surface shows the coexistence of at least two factors in EQS exceedance. Although policies and directives are already in place to mitigate the single stressors, the interaction among different factors is still usually neglected. EEA (2020) reports that accumulation of risks related to high exposures to all three pollutants cannot be excluded. Their analysis evidence Italy as the second country in EU (after Turkey) showing the highest population exposed simultaneously to the tree standards exceeded (European Environment Agency, 2020). In this context, AIC represents an effective knowledge synthesis tool to inform decision-makers about the relative magnitude of challenges that a given

Table 2
The three administrative domains considered, Metropolitan Cities (MC), Large Cities (LC), and all the municipalities excluded from the funding of the Decree on Climate (NoFund). For each of them are presented, Area in km^2, population (millions of inhabitants), mean Aggregate Index of Challenge (AIC) and its coefficient of variation (%) in brackets, the relative percentage of hotspot and mean AICpop and its coefficient of variation (%) in brackets.

Administrative domains	Area km^2	Pop	AIC mean (CV%)	Hotspot %	AICpop mean (CV%)
MC	46,000	22 mln	0.12 (120%)	21%	102.437 (551%)
LC	22,700	26 mln	0.12 (114%)	24%	88.425 (432%)
NoFund	234,000	12 mln	0.09 (131%)	17%	20.258 (570%)

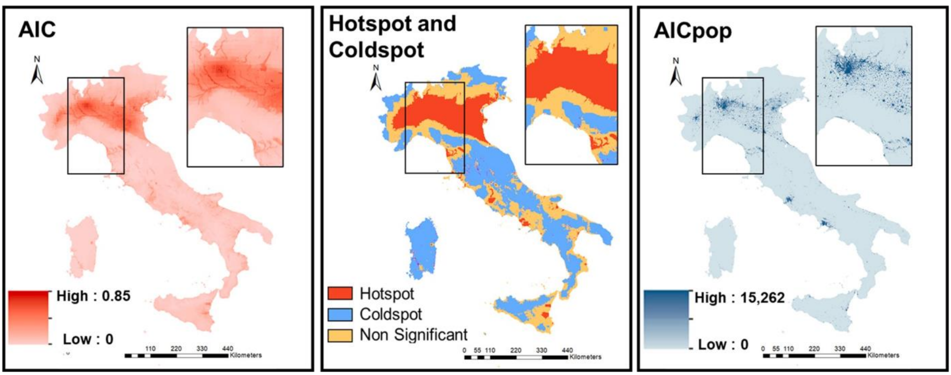

Fig. 4. Maps of the Aggregate Index of Challenge (AIC) (left), its spatial aggregation in hotspots and coldspots (middle) and AICpop (right), given by the product of the AIC and the population density for each pixel.

Table 3
The fourteen Italian Metropolitan Cities (MC) sorted according to their extension. For each of them is presented: Area in km^2, Total population (millions of inhabitants), mean Aggregate Index of Challenge (AIC) and its coefficient of variation (%) in brackets, the relative percentage of hotspot, and mean AICpop and its coefficient of variation (%) in brackets.

Metropolitan Cities	Area km^2	Total population	AIC Mean (CV%)	Hotspot %	AICpop Mean (CV %)
Naples	1177	3,072,996	0.135 (60%)	35%	472.17 (216%)
Cagliari	1246	430,372	0.029 (157%)	0%	8.02 (609%)
Milan	1576	3,261,873	0.561 (13%)	100%	1202.77 (177%)
Genoa	1832	837,427	0.064 (38%)	0%	18.13 (591%)
Venice	2469	852,351	0.211 (59%)	69%	121.22 (301%)
Reggio C.	3217	544,815	0.059 (57%)	0%	11.15 (548%)
Messina	3269	622,962	0.047 (63%)	0%	13.94 (577%)
Florence	3521	1,012,407	0.069 (73%)	4%	41.48 (525%)
Catania	3580	1,103,917	0.112 (76%)	18%	26.48 (438%)
Bologna	3694	1,017,196	0.250 (78%)	56%	95.76 (424%)
Bari	3853	1,248,489	0.046 (51%)	0%	11.39 (534%)
Palermo	5015	1,245,826	0.030 (64%)	0%	6.90 (561%)
Rome	5370	4,335,849	0.082 (79%)	14%	106.50 (392%)
Turin	6829	2,256,142	0.151 (91%)	36%	96.65 (562%)

portion of territory has (e.g., Adem Esmail and Geneletti, 2018) and thus need to address. AIC values did not give insight on the relative importance of each factor. However, providing a concise parameter of cumulative stressors, AIC values allow to establish a priority of intervention as well as to design multifunctional interventions across the Country. The selection of the right and specific intervention (i.e., NBS) is out of the scope of the present work and need to consider the specific factors to be mitigated – as well as their combination - and the institutional capacity and possibility to implement them (Croeser et al., 2021).

Moreover, using AICpop instead – or in addition to – AIC, allow to include population density in this evaluation, helping to i) consider the variation of risk exposure (Darrel Jenerette et al., 2011); ii) evaluate funds allocation concerning the potential number of beneficiaries involved in the interventions. Indeed, especially in urban contexts, the positive value of enhancing ES provision is strictly related to the number of their beneficiaries and not limited to their physical characteristics (Kremer et al., 2016). Population density is considered as an explanatory factor (Brousmiche et al., 2020) to investigate how environmental benefits and/or burdens affect human health (Flacke and Köckler, 2015). Similarly to our approach, exposure indices are used in environmental justice to inform decision-makers about the social inequity of cumulative hazards' exposure (Su et al., 2009).

Despite the urgencies evidenced by AIC values and even more by AICpop, several constraints might hamper the feasibility of targeted interventions (e.g., limited space in historic centers, dense fabrics, ownership, landscape or archeological restraints). In these cases, the possibility to enlarge the potential area of interventions is supported by the hotspot/coldspot approach proposed in this work. Indeed, the aggregation of high AIC values reveals a hotspot area of 54,000 km^2 (18% of the national territory), where diffuse interventions on the territorial matrix can enhance the overall environmental quality. This approach would allow to i) overcome practical, physical, legislative etc., issues that could emerge at a fine-scale of application, thus enhancing the feasibility of the interventions, and ii) evaluate a wider spectrum of interventions that can improve their cost-effectiveness.

5.2. Comparing the different administrative domains based on their EQS and policy implementation

As regards the administrative contexts examined, on one hand the average AIC values are very similar in the three contexts (MC, LC, NoFund), slightly higher in the two involved in the Decree on Climate (MC and LC). On the other hand, the AICpop values show how the population exposed to the EQS exceedances increases from NoFund, passing to LC, and finally to MC, due to the significantly largest population density in the last two. This result would seem to support the greater emphasis on MC in deserving interventions oriented to promote both sustainable transportation (i.e., mobility voucher) and urban forestry, although this domain covers only 15% of the national territory and hosts 37% of its population. At the same time, the extension to LC of the mobility voucher alone involves another 46% in terms of national population in front of only 7.5% more in terms of surface. This result opens to the possibility of considering LC as a valuable administrative domain to be included in future policy discourses promoting sustainability in urban contexts.

However, high CV% in both AIC and AICpop suggest that a unique policy applied uniformly to the whole administrative domain could hamper its effectiveness, due to the high heterogeneity that characterize urban landscapes as well as their environmental issues (Borgström et al., 2006). Moreover, the low value of CV% for AIC in Milan reflects the environmental stressors homogeneity through its territory, while the high value of CV% for AIC in Cagliari reflects the high heterogeneity of environmental stressors. This variability is even greater when looking at CV% values for AICpop, demonstrating that the variability within the administrative boundaries is not limited to the environmental stressors' exceedances, but it can be extended to population density as well. Our investigation on the variability within the MC domain reveals that four MC located in the Po valley show values in contrast with other six MC. Indeed, Milan shows high AIC values and hotspot incidence followed by Venice, Bologna, and Turin, while six MC (Cagliari, Genoa, Reggio Calabria, Messina, Bari, and Palermo) show very low AIC values and have no AIC hotspots in their territory (Table 3). These results also suggest that in absence of spatial aggregation of AIC values, more prompt and local-scale interventions are preferable as opposed to those that can be applied in territories with more diffuse environmental challenges (e.g., Po' valley).

Moreover, this variability highlights the need to assign different interventions' priority to municipalities belonging to the same administrative domain based on their relative magnitude of environmental challenges and specific factor to mitigate. The use of indices such as those proposed in this work is already experienced to prioritize and orient both investments (Porter, 2015) and urban resilience strategies (Monteiro et al., 2012) as well as to measure the effectiveness of policies and interventions across administrative contexts (e.g., Counties; Cutter et al., 2010).

The quite balanced incidence of hotspot areas among the three administrative domains (from 17% in NoFund to 24% in LC) suggests that the policies based on administrative boundaries do not necessarily match with the spatial distribution of factors' exceedance. Moreover, the widespread diffusion of high AIC values and hotspot incidence in the Po' Valley suggest the urgency for a diffuse intervention on the environmental matrix rather than scattered and fragmented interventions concentrated in some administrative domains or municipalities. This approach is also supported by Martuzzi et al. (2006), confirming that, given the high concentrations of pollutants in the cities through the Po' Valley, diffuse policies' actions at the regional level may be preferable to actions taken by the single municipalities to achieve EQS. Moreover, in the specific case of NBS implementations, it should be considered that their local capacity to supply ES and reach the EQS within the urban core (or where high critical exposure is recorded) could be limited (Kremer et al., 2016) because supply and demand dynamics do not always align with administrative boundaries (Larondelle et al., 2014). At this purpose, Baró et al. (2014) concluded their case-study in the municipality of Barcelona, arguing that to abate air pollution effectively, green infrastructure strategy requires planning on a broader scale, considering an integrated approach in their management as well.

6. Concluding remarks and future perspectives

This paper suggests a novel methodological approach for environmental policies and planning based on the use and combination of EQS for multiple environmental stressors. EQS are meaningful to society because they can express a common threshold to assess environmental and societal demands across different contexts and scales, hence allowing comparative analyses for human well-being enhancement (Baró et al., 2015). Italy, like many other countries, is implementing policies and investing significant funding for the improvement of sustainability and quality of life, especially in urban contexts. However, our work reveals an incomplete spatial agreement between current National policies for the reduction/mitigation of single/multiple stressors and their real spatial distribution. Our findings contribute to provide information for a better inclusion of environmental challenges into sectorial National policies.

In this work, we proposed a multicriteria analysis assigning the same emphasis (i.e., weights) to all factors. However, for practical applications, weights could be assigned and differentiated depending on impacts on morbidity and health, policy demands, priorities of decision-makers and tradeoffs with other planning issues, thus opening to further in-depth analysis at finer scale of implementation or depending on specific decision-making issues.

Our methodology can potentially be upscaled (e.g., EU scale) and it can provide insight for future research with particular regard to NBS implementation and the improvement of their performance and multifunctionality. Indeed, in both policy and science, NBS multifunctionality is often taken for granted and not well-planned (e.g., EU, Hansen et al., 2019, and New York City, Meerow, 2020). A novel approach considering synergies and tradeoffs among NBS is needed to enhance their benefits and multifunctionality (Babí Almenar et al., 2018; Bodnaruk et al., 2016; Meerow, 2020). According to our findings, this evaluation should start from the funds' allocation at national scale towards the implementation at the scale of the single local administrative units.

Finally, our results highlight that administrative boundaries are not sufficient to delimit a homogeneous area of analysis and intervention (Kremer et al., 2016). Indeed, extended portions of territory (e.g., Po' Valley) show aggregations of high AIC values and need to be treated as a single unit, due to all the connections and dependencies that exist between cities and their hinterlands (Larondelle et al., 2014). Therefore, an evidence-based approach, as opposed to interventions merely based on administrative boundaries, seems promising to enhance the cost-effectiveness of interventions as well as their return in terms of human health and wellbeing.

CRediT authorship contribution statement

Elena Di Pirro: Conceptualization, Methodology, Data curation, Formal analysis, Software, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Lorenzo Sallustio:** Conceptualization, Methodology, Software, Investigation, Validation, Visualization, Writing – original draft, Writing – review & editing. **Gregorio Sgrigna:** Methodology, Investigation, Validation, Visualization, Writing – review & editing. **Marco Marchetti:** Supervision, Writing – review & editing. **Bruno Lasserre:** Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envsci.2021.12.010.

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3. Location matters: enhancing co-benefits of Nature-Based Solutions

Containing the article: ***Facing Multiple Environmental Challenges through Maximizing the Co-Benefits of Nature-Based Solutions at a National Scale in Italy,*** **Di Pirro, E.; Sallustio, L.; Castellar, J.A.C.; Sgrigna, G.; Marchetti, M.; Lasserre, B. Forests 2022, 13, 548. https://doi.org/10.3390/f13040548**

This chapter highlights the need to consider the multiple challenges to tackle as a key criterion to improve the NBS co-benefits and cost-effectiveness. The approach proposed in this chapter provides a defined set of NBS that could be ranked based on their performance of Ecosystem Services supply and implemented across the territory according to multi-scale policy and planning objectives.

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Article

Facing Multiple Environmental Challenges through Maximizing the Co-Benefits of Nature-Based Solutions at a National Scale in Italy

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Abstract: The European Union is significantly investing in the Green Deal that introduces measures to guide Member States to face sustainability and health challenges, especially employing Nature-Based Solutions (NBS) in urban contexts. National governments need to develop appropriate strategies to coordinate local projects, face multiple challenges, and maximize NBS effectiveness. This paper aims to introduce a replicable methodology to integrate NBS into a multi-scale planning process to maximize their cost–benefits. Using Italy as a case study, we mapped three environmental challenges nationwide related to climate change and air pollution, identifying spatial groups of their co-occurrences. These groups serve as functional areas where 24 NBS were ranked for their ecosystem services supply and land cover. The results show eight different spatial groups, with 6% of the national territory showing no challenge, with 42% showing multiple challenges combined simultaneously. Seven NBS were high-performing in all groups: five implementable in permeable land covers (urban forests, infiltration basins, green corridors, large parks, heritage gardens), and two in impervious ones (intensive, semi-intensive green roofs). This work provides a strategic vision at the national scale to quantify and orient budget allocation, while on a municipal scale, the NBS ranking acts as a guideline for specific planning activities based on local issues.

Keywords: human health; human well-being; urban sustainability; green deal; urban forests; green roofs; multifunctionality

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1. Introduction

In the European Union (EU), air pollution and the extreme events related to climate change (e.g., heatwaves and floods) are exerting pressure both on human health and natural capital integrity [1], leading to millions of premature deaths and economic losses each year [2]. This is especially relevant in urban areas, where 73% of the European population lives, compared to 50% globally [3,4]. For this reason, the EU is significantly investing in the European Green Deal, which introduces legislative and non-legislative measures to legally bind and guide the Member States to face sustainability and health challenges. The EU fixed targets across different strategies (e.g., Forestry and Biodiversity Strategy to 2030), laws (e.g., European climate law), and action plans (e.g., zero pollution action plan) [5] that the Member States need to meet at the national level for improving the quality of ecosystems and human life [6]. For example, a recent study by Khomenko et al. [7] estimated that about 52,000 lives would be saved annually if 1000 European cities met World Health Organization (WHO) air-quality standards. Particular attention is paid to policies and planning at the local scale to reconfigure urban areas so that they consume fewer resources, generate less pollution (including greenhouse gases), and become more resilient and sustainable [4] while facing budgetary pressure [8].

As a consequence, there is a growing interest in valuing Ecosystem Services (ES) and including them in decision-making processes [1,9] as a lens to achieve environmental and societal goals [10]. Hence, the concept of Nature-Based Solutions (NBS) rises as an environmentally friendly alternative to favor the provision/maintenance of ES. NBS are defined as “solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience” [2]. NBS is an umbrella concept related to and integrated into other concepts, such as green and blue infrastructure, urban forestry, ecological engineering, disaster risk reduction, and ecosystem-based adaptation [11–14]. These concepts were introduced to address the challenges from distinct perspectives while the NBS strength is the integrated perspective for providing co-benefits and generating win–win solutions (i.e., multifunctionality) [13,15,16]. Moreover, implementing NBS can foster both human well-being and biodiversity cost-effectively while offering new job and innovation opportunities [17].

Therefore, both governmental and non-governmental organizations are offering huge funding globally [18,19] to enable the implementation of NBS [20,21]. The focus is predominantly on afforestation and reforestation programs [22], e.g., “3 billion trees” in the EU [23], the “trillion tree campaign” [24], and the “great green wall” [25]. Notwithstanding, McDonald et al. [26] highlight that funds for tree-planting and maintenance initiatives are often constrained or limited by planning silos. Indeed, governments generally receive several indications on NBS from the EU that are not easily translated into effective and practical urban greening programs. For this purpose, the Horizon 2020 program classified NBS as a priority area of investment to enhance the resilience in urban areas in the face of global changes [1] and establish Europe as a world leader of NBS [10,27]. Demonstration projects of NBS—and related concepts—are in place in several cities of the Member States to tackle different urban issues such as the mitigation of air pollution, temperature extremes, noise, drought, and flooding [27–30]. EU-funded projects on NBS work in task forces to improve knowledge, reduce duplication, and facilitate progress towards shared goals [31]. These projects are proving to be a catalyst for research-practice partnerships [18], increasing knowledge and awareness regarding NBS indicators, impacts, performance, and cost-effectiveness assessment, building repositories with different case studies (e.g., OPPLA, the online EU repository of NBS). All projects aim at strengthening NBS regional development and translating results from experts to stakeholders [6]. More details regarding the status of H2020 projects are available from Wild et al. [31].

However, projects are still often implemented as standalone experiments in urban areas, scattered and uncoordinated throughout various policy levels and sectors [32,33]. As hubs of population and socio-economic activity, urban areas represent concentrated opportunities for addressing issues of sustainability at the local scale [4,18]. Nevertheless, ameliorating the environmental conditions in a few cities can only partially contribute to delivering the national-level commitments that countries have with the EU and with United Nations [33]. Therefore, lessons learned from single case studies need to be coordinated across multiple political and geographical levels to enable the long-term respect of national targets and international commitments [34,35]. Despite the fact that NBS are implicitly or explicitly cited in different European legislative frameworks [6,36,37], the H2020 NATURVATION project underlined as a legal initiative or policy coordination at the EU level requiring Member States to systematically program and invest in NBS is still absent [32]. In addition, the review conducted by Mendonça et al. [20] reveals that the policy instruments to mainstream the NBS concept into policy are usually investigated just at the city level, thus neglecting the country or higher levels of implementation.

However, considering the huge funding opportunity for the member states envisaged by the EU Green Deal—and other key policy initiatives [37]—national governments need to develop appropriate strategies to coordinate local projects and face multiple and complex challenges throughout the territory [33] to maximize the NBS effectiveness [22,32] and involve all relevant stakeholders [9,38]. Although this strategic level is still missing in most of the member states [32], it is crucial, especially for countries located in vulnerable areas currently facing climate and pollution issues (e.g., Mediterranean region [39]). In these countries, a wide and national perspective could help to coordinate the implementation of NBS at lower levels for reaching multiple national targets related to different environmental policies, with the final scope to improve the state of ecosystems and human health as a whole. Accordingly, we selected Italy as a case study, since it is a representative member state both for the challenges related to pollution and climate change and for the national policies in place to improve urban sustainability.

This paper thus aims to introduce a replicable methodology to integrate and strengthen NBS into a multi-level planning process to maximize their cost–benefit from the large-scale policy and planning initiatives (e.g., national) to the local scale (e.g., municipal). Generally, the former is focused on ameliorating environmental sustainability through reaching fixed targets, while the second is oriented to directly reconfigure urban areas, improving the wellbeing of inhabitants. Although many authors have already dealt with methods and approaches for planning and designing multifunctional NBS [40,41], they are usually limited to the municipal scale. Therefore, to the best of our knowledge, this is the first framework conducted on a national scale. We started from the Environmental Quality Standards set by Di Pirro et al. [42] to map the spatial co-occurrence of the same environmental challenges (individual or multiple) nationwide (i.e., spatial groups). These spatial groups of challenges serve as functional areas where NBS providing multiple co-benefits can be identified to effectively mitigate peculiar multiple environmental stressors altering human health and well-being (i.e., air pollution, heatwaves, flood hazards). Consequently, different rankings of 24 NBS were built for each spatial group based on i) their capacity to supply ES, and hence their performance to address the challenges, and ii) the current land cover in which they can be implemented. Using the Environmental Quality Standards helped to establish a replicable, clear, and spatially explicit understanding of the challenges that the country needs to tackle. The here-proposed framework is able to support the strategical coordination of national funds allocation and to enhance the effectiveness of interventions at the local scale consistent with the national objectives.

2. Case Study

In the Mediterranean basin, climate change has exacerbated existing environmental challenges caused by the combination of increasing pollution, land use changes, and declining biodiversity [39]. Indeed, Italy is consistently experiencing the adverse effects of climate change, such as heatwaves, floods, and drought events, combined with the strong exposition of the three most harmful air pollutants in the EU [39,43–46]. In addition to these challenges, within the Italian territory, the sealed surface reaches one of the highest relative national coverages (7.1% [47]) among EU countries [48]. The scattered and fragmented urban mosaic [49] has smoothed the boundaries between urban and rural areas [50], exacerbating issues related to ecological connectivity, biodiversity, and ecosystem services loss [51–54]. Therefore, the Italian national government envisaged different urban sustainability strategies and policies and set ambitious tree-planting objectives, based on the premise that planning urban forests is a feasible response to current challenges and that they can enhance the resilience of cities and safeguard the population's health [55]. For example, the "Decree on Climate" [56] is a national policy adopted to tackle the climate emergency and achieve the objectives related to the EU Air Quality Directive [57]. Within the decree, the "Urban Forestry Program" (Azioni per la riforestazione-Art.4 [56]) allocates funds to implement urban and peri-urban forests and to reduce impervious surfaces (i.e., de-sealing actions), as key interventions to address urban challenges [58]. The National Strategy on Urban Greenspaces [59] guides the municipalities to the effective implementation of local-scale initiatives for strengthening ecological networks. The Urban Forestry Program allocates funds to just 14 metropolitan cities, while the National Strategy on Urban Greenspaces includes all the Italian municipalities in its analysis. However, Di Pirro et al. [42] reveal an incomplete spatial agreement between the current fund's allocation envisaged by the Urban Forestry Program and the real spatial distribution of the challenges to address. Sallustio et al. [60] highlight that the inclusion of all municipalities can ensure an equitable distribution of economic resources and provide guidelines that can be easily replicated and implemented at the municipal scale.

While the current policy mix provides a starting point to promote/maintain NBS, there is significant potential on the national level to uptake NBS into policy and optimize the rationale of budget allocation to design an optimized NBS network. Accordingly, we provide a wide strategic perspective that can support the allocation of funds currently envisaged by the EU Green Deal. We include the whole national territory in the identification, first of the challenges' distribution and then in the most effective and multifunctional NBS available for their mitigation.

3. Materials and Methods

This study was developed according to the three stages shown in Figure 1. Stage I: the identification and mapping of three environmental challenges in Italy (i.e., air quality, climate adaptation and mitigation, and water management), adopting the Environmental Quality Standards proposed by Di Pirro et al. [42]; Stage II: the overlay of the three challenges allows the identification of portions of territory threatened simultaneously by the same challenges (i.e., spatial groups); Stage III: a ranking of 24 NBS suitable to address the challenge(s) for each spatial group is proposed, based on the NBS performance assessment provided by Castellar et al. [30] and the land cover (Figure 1). All the analyses are conducted by a pixel-based approach.

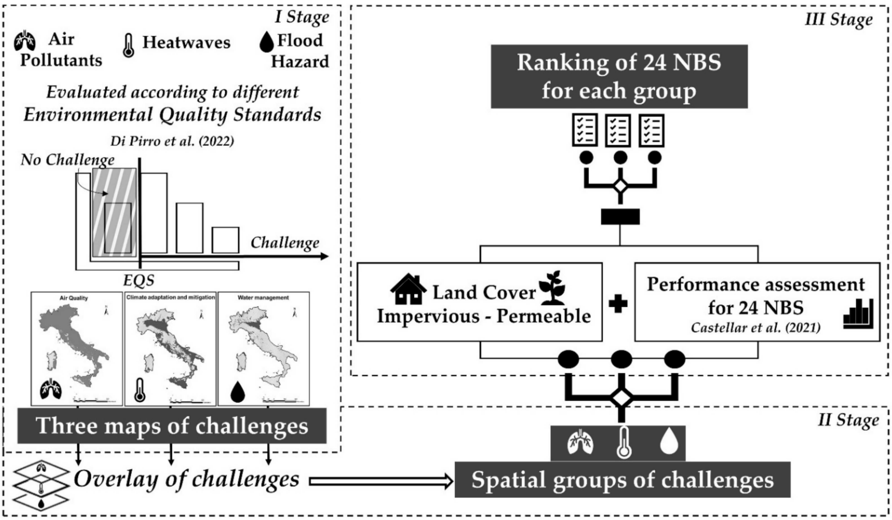

Figure 1. Workflow developed according to three main stages.

3.1. Environmental Challenges in Italy and Their Combination in Spatial Groups

According to Stage I (Figure 1), we considered three challenges, air quality, climate adaptation and mitigation, and water management (following Raymond et al. [15]), defined by the presence of three environmental stressors (air pollutants, frequency of heatwaves, flood hazard, respectively) altering human health when they exceed specific thresholds [61] (e.g., Environmental Quality Standards—EQS [62]). Consequently, to identify the portion of national territory threatened by these challenges, we adopted the methodological framework proposed by Di Pirro et al. [42], where different EQS were selected and used as common thresholds to assess environmental and societal demands. The EQS proposed by Di Pirro et al. [42] are defined according to (i) the European standards set in Air Quality Directive (2008/50/EC), (ii) the definition of heatwaves and projections of climate change given by [43], and (iii) the flood hazard estimated by ISPRA [63] (further details are reported in [42]).

To define portions of the Italian territory showing air quality challenge, we considered EQS for the three most harmful pollutants in the EU, namely PM_{10}, NO_2, and O_3 [57]. All the pixels showing at least one of the three pollutants in exceedance for the respective EQS are considered as portions of territory where air quality regulation is needed to address the challenge. As regards the challenge of climate adaptation and mitigation, we considered the EQS of 4 days/year of heatwaves [43]. Hence, all the pixels exceeding this EQS are considered as portions of territory where climate regulation is needed to address the challenge. Finally, for the water management challenge, we considered EQS based on the probability that a flooding event will occur, according to estimates of their return period [63]. Hence, all the pixels in flood hazard are considered as portions of territory where water regulation is needed to address the challenge. Thus, starting from the methodological framework proposed by Di Pirro et al. [42], we derived three maps with the spatial distribution of the three challenges, with a spatial resolution of 1 km, as shown in Figure 2.

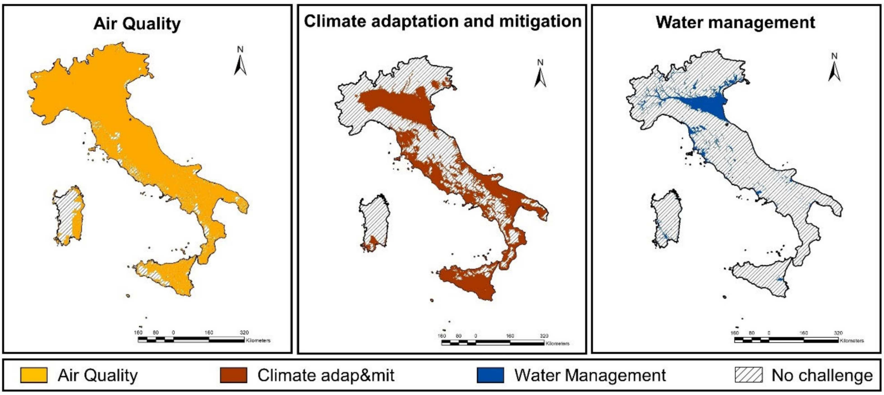

Figure 2. The three challenges considered: air quality, climate adaptation and mitigation, and water management. The areas with no challenge are represented by the striped pattern.

According to Stage II (Figure 1), the three maps of challenges were then combined in a GIS environment to investigate where, which, and how many challenges overlay in the same portion of the territory, thus needing to be addressed simultaneously. From this analysis, we obtained different homogenous groups, where interventions need to be differentiated to address the specific challenge(s). According to Stage III (Figure 1), for each group, we explored (i) the population density [64], to estimate the inhabitants exposed to single or multiple challenges as well as the potential beneficiaries of NBS; and (ii) the land cover, to define quantity and typology of space available for NBS implementation. We focused our analysis on two land covers (i.e., impervious and permeable) using the 2018 High-Resolution Layers, with a spatial resolution of 20 m [65]. The impervious surfaces were reclassified according to Congedo et al. [66], thus considering values of the Degree of

Imperviousness greater than 29%. The permanent water bodies (covering about 1.4% of the national territory) were neglected, since specific policies (e.g., water quality and security) and NBS might be implemented, out of the scope of this work.

3.2. Calculating the Nature Based Solutions Performance in Dealing with Challenges

Relying on the NBS capacity to provide multiple ES and mitigate environmental stressors, we assumed that NBS are the unique interventions to address the challenges in each group. In the literature, NBS encompasses a wide range of interventions and actions. Following the classification proposed by Eggermont et al. [67], NBS can be considered as conservation and restoration of ecosystems (i.e., Type 1), sustainable management for improving ES supply (i.e., Type 2), and the creation of new ecosystems (i.e., Type 3). For this work, we considered only the creation of new ecosystems, i.e., NBS Type 3 according to Eggermont et al. [67], focusing in particular on NBS spatial and technological units proposed by Castellar et al. [30]. New NBS thus need to be identified and differentiated according to their capacity to provide ES able to address the challenge(s) (i.e., performance). We adopted the performance assessment proposed by Castellar et al. [30], where for 32 NBS they calculated a performance score (PS), ranging from 0 to 1, representing the NBS capacity to provide ES able to address ten different challenges. We limited our analysis to 24 NBS and respective PS related to the three challenges under investigation in this study (i.e., air quality, climate adaptation and mitigation, and water management). Eight NBS were thus excluded since they are not terrestrial or not considered as Type 3 (i.e., new ecosystem). Therefore, when a single challenge characterizes the group, we reported the same PS of Castellar et al. [30]; when multiple challenges characterize the group, we averaged the PS for the respective challenges of the group. Accordingly, starting from the 24 NBS, we produced different rankings of PS as many as the groups of challenges, thus allowing us to select the best performing set of NBS to effectively address the environmental challenges.

3.3. Classification of Nature Based Solutions for Land Covers

The 24 NBS considered for this study are the following: community gardens, constructed wetlands, extensive green roofs, green corridors, green façades, green wall systems, heritage gardens, infiltration basins, intensive green roofs, large urban parks, planter green walls, pocket gardens/parks, private gardens, raingardens, semi-intensive green roofs, street trees, swales, urban forests, urban orchards, vegetated grid paves, vegetated pergolas, vertical mobile gardens, (wet) retention ponds, and shelters for biodiversity.

We classified NBS into two categories: implementable in impervious surfaces (I-NBS) and permeable surfaces (P-NBS). The classification is based on descriptions provided by Castellar et al. [30], considering both the NBS' structures and sizes. Accordingly, I-NBS are those implementable on buildings (i.e., green façades, green wall systems, vertical mobile gardens, planter green walls, vegetated pergolas, extensive green roofs, intensive green roofs, semi-intensive green roofs), and along streets and parking lots, close to buildings and houses (i.e., raingardens, swales, street trees, and vegetated grid paves, pocket gardens/parks, private gardens). Except for vegetated grid paves, where we consider the conversion from traditional car parks to green parking lots, we excluded the possibility of de-sealing actions (land cover changes from impervious to permeable), e.g., building's removal and conversion to a large urban park. On the other side, P-NBS are those that can be implemented on permeable land covers (green corridors, large urban parks, urban forests, heritage gardens, community gardens, urban orchards, infiltration basins, (wet) retention ponds, constructed wetlands). NBS similar to each other for the structure but not for the size (e.g., pocket gardens vs large parks) were distinguished by a 0.5 ha threshold [30]. Consistently with the HRL spatial resolution used to estimate land covers surfaces [65], we reduced this dimensional threshold to 400 m^2 (i.e., one pixel). In this way, pocket gardens were assigned to I-NBS while large parks were assigned to P-NBS.

Therefore, for each group, we can provide the quantity and typology of challenges to address, the incidence of permeable and impervious land covers, a ranking of P-NBS and I-NBS ranging from 0 to 1 based on their ability to address the specific challenges of the group.

4. Results

Eight different spatial groups resulted from the spatial combination of the three challenges; Figure 3 shows the map with their spatial distribution while the pie-chart shows the relative coverage of each spatial group. Only 6% of the national territory shows no challenge ("NoChal" group). Conversely, 7.9% of the territory shows all the three challenges combined simultaneously ("ALL" group). Three groups show the individual challenge covering 51.5% of the national territory: 47% air quality ("AIR" group), 4.3% climate adaptation and mitigation ("CLIM" group), and 0.2% water management flood hazard ("WAT" group). The remaining 35% of the territory is occupied by the last three groups, characterized by two challenges simultaneously. The challenge of air quality co-occurring with climate adaptation and mitigation covers 33% of the national territory ("AIR-CLIM" group), while its combination to water management spans over 1.2% of the national territory ("AIR-WAT" group). Finally, when the spatial combination is between climate adaptation and mitigation and water management, the group covers 0.3% of the country ("CLIM-WAT" group).

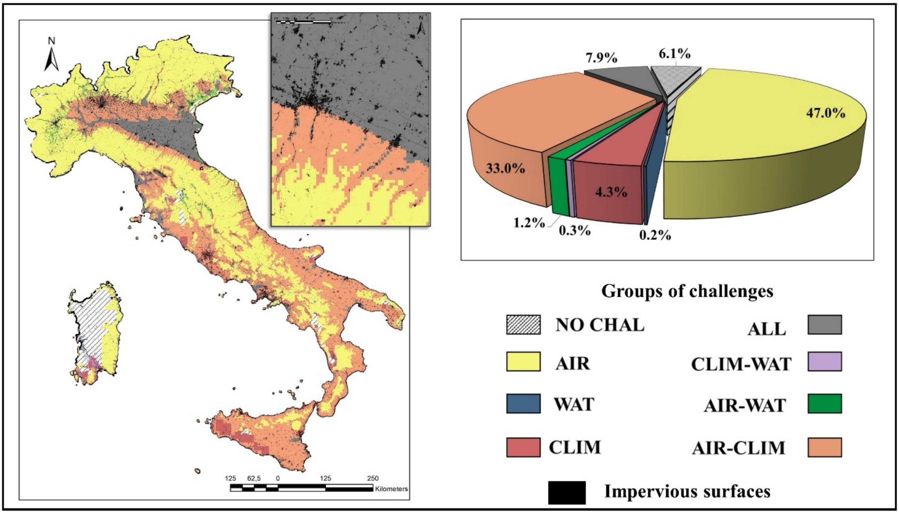

Figure 3. The eight spatial groups of challenges. The pie chart shows the relative coverage of each spatial group (% of the national territory). In black on the map is shown the spatial distribution of impervious surfaces throughout the national territory.

Built-up areas in Italy cover about 7.1% of the national territory [47], and their incidence is quite variable across the groups (Table 1 and Figure 3). The AIR and the NoChal groups are the only ones showing a relatively impervious surface lower than the national one (3% and 4%) as well as the lowest population density (91 and 150 inhab/km^2). On the contrary, CLIM and CLIM-WAT groups show the highest relative impervious surfaces (18% and 24% respectively) as well as the highest population density (1036 and 1086 inhab/km^2). AIR-WAT, ALL, WAT, and AIR-CLIM groups, respectively, show the following relative impervious surfaces, slightly higher than the national one: 13%, 11%, 9%, and 8%, with intermediate values of population density, 326, 257, 254, and 213 inhab/km^2.

Table 1. For each group, the area in km^2, coverage of permeable and impervious surface (km2), number of inhabitants, and population density (inhab/km2) within the groups are reported.

Groups	Area (km^2)	Permeable (km^2)	Impervious (km^2)	Population (n° inhab)	Pop Dens (inhab/km^2)
AIR	141,044	136,310	4734	12,974,163	91
CLIM	12,582	10,345	2237	13,468,447	1036
WAT	477	435	42	130,275	254
AIR-CLIM	97,769	89,603	8166	21,377,514	213
AIR-WAT	3352	2904	448	1,238,194	326
CLIM-WAT	1043	790	253	1,152,988	1086
ALL	22,875	20,446	2429	6,163,604	258
NoChal	18,393	17,639	754	2,802,590	150

All the 24 NBS show Performance Scores (PS) ranging from the minimum value of 0, only in the groups characterized by single challenges, to the maximum of 1, in each group. We divided PS into three classes, low PS (0–0.33), medium PS (0.33–0.66), high PS (0.66–1), to more facilitate the reading of the different performances.

The number of NBS with high PS (Table 2) is variable across the groups ranging from 16 in the WAT group to 11 in AIR-WAT. NBS with high PS can be implemented in both permeable (with a maximum of 9 P-NBS in the WAT group) and impervious land covers (with a maximum of 9 I-NBS in the CLIM group). P-NBS have similar PS and ranking among the different groups, while we registered more dissimilarity among the I-NBS both for PS values and ranking. This difference is particularly marked for I-NBS in AIR and WAT groups. Accordingly, their combination in the AIR-WAT group shows the least number of high PS (4 I-NBS), highlighting a lack of synergy between ES for simultaneously addressing the challenges of air quality and water management.

Vertical green (i.e., green façades, green wall systems, vegetated pergola, vertical mobile gardens) shows high PS for the mitigation of both air pollutants and heatwaves while low PS for the mitigation of flood hazard. We found the opposite PS trend for rain gardens, swales, and vegetated grid paves, which are particularly useful to mitigate flood hazards and so address the challenge of water management.

Seven NBS have high PS simultaneously in all groups: five P-NBS (i.e., infiltration basin, green corridors, urban forests, large urban park, heritage garden), and two I-NBS (i.e., intensive green roof, semi-intensive green roof). Hence, thanks to these co-benefits, these seven NBS can be potentially implemented throughout 94% of the Italian territory, thus ensuring good performances employing less than one-third of the available NBS. On the contrary, among P-NBS, urban orchards and planter green walls show the lowest PS in all groups, thus representing a sub-optimal solution for addressing the three environmental challenges considered here (Table 2).

Figure 4 shows a specific focus on the distribution of impervious land cover within the spatial groups. Among the 20,000 km^2 of built-up areas in Italy, 8100 km^2 are occupied by the AIR-CLIM group (42.8%), 4700 km^2 by the AIR group (24.8%), over 2200 km^2 by the ALL and CLIM groups (12.7 and 11.7%, respectively), about 750 km^2 by the NoChal group (4%), and less than 450 km^2 by the AIR-WAT, CLIM-WAT, and WAT groups. Therefore, combining these coverages with the NBS having high-PS in each spatial group, we obtained the overall area where both P-NBS and I-NBS could potentially be implemented to address multiple challenges. With specific regard to the I-NBS: intensive and semi-intensive green roof (18,309 km^2), street trees (17,819 km^2), green façade (17,566 km^2), green wall system and vertical mobile garden (15,137 km^2), private gardens (13,127 km^2), and extensive green roof (13,085 km^2) (Figure 4).

Table 2. Twenty-four Nature-Based Solutions (NBS) classified as implementable in impervious (I-NBS) and permeable (P-NSB) land covers. Performance Score (PS) ranges between 0 (low performance) and 1 (high performance) for each NBS in the 7 groups, namely: AIR, CLIM, WAT, AIR-WAT, AIR-CLIM, CLIM-WAT, ALL. The black triangles mark NBS with high-PS (PS > 0.66). The NoChal group is not included considering we assumed that no new NBS are needed.

Nature Based Solutions	Performance Score (PS)						
I-NBS	**AIR**	**CLIM**	**WAT**	**AIR-CLIM**	**AIR-WAT**	**CLIM-WAT**	**ALL**
Extensive green roofs	0.5	▲0.9	0.6	▲0.7	0.5	▲0.7	▲0.7
Green walls system	▲1.0	▲0.8	0.0	▲0.9	0.5	0.4	0.6
Green façades	▲1.0	▲1.0	0.2	▲1.0	0.6	0.6	▲0.7
Intensive green roofs	0.7	▲0.9	▲0.8	▲0.8	▲0.8	▲0.9	▲0.8
Planter green walls	0.5	0.5	0.0	0.5	0.3	0.3	0.3
Pocket gardens/parks	0.6	0.6	▲0.8	0.6	▲0.7	▲0.7	▲0.7
Private gardens	0.5	▲1.0	▲0.8	▲0.8	0.6	▲0.9	▲0.8
Raingardens	0.4	0.3	▲0.8	0.4	0.6	0.6	0.5
Semi-intensive green roofs	▲0.7	▲0.8	▲1.0	▲0.8	▲0.8	▲0.9	▲0.8
Street trees	▲0.8	▲0.9	0.4	▲0.8	0.6	▲0.7	▲0.7
Swales	0.6	0.2	▲0.9	0.4	▲0.7	0.5	0.6
Vegetated grid paves	0.2	0.5	▲0.8	0.3	0.5	0.6	0.5
Vegetated pergola	0.5	▲0.8	0.3	0.6	0.4	0.5	0.5
Vertical mobile garden	▲1.0	▲0.9	0.0	▲1.0	0.5	0.5	0.6
P-NBS							
(Wet)Retention Ponds	▲0.8	0.6	▲1.0	▲0.7	▲0.9	▲0.8	▲0.8
Community gardens	0.3	0.5	▲0.8	0.4	0.6	▲0.7	0.6
Constructed wetlands	0.0	0.3	▲1.0	0.1	0.5	0.6	0.4
Green Corridors	▲1.0	▲1.0	▲0.7	▲1.0	▲0.8	▲0.8	▲0.9
Heritage gardens	▲1.0	▲1.0	▲1.0	▲1.0	▲1.0	▲1.0	▲1.0
Infiltration basins	▲0.8	▲0.8	▲1.0	▲0.8	▲0.9	▲0.9	▲0.9
Large urban parks	▲1.0	▲1.0	▲0.9	▲1.0	▲1.0	▲1.0	▲1.0
Shelters for biodiversity	▲0.8	0.0	▲0.7	0.4	▲0.7	0.3	0.5
Urban forests	▲1.0	▲0.9	▲0.8	▲0.9	▲0.9	▲0.9	▲0.9
Urban orchards	0.3	0.2	0.5	0.3	0.4	0.3	0.3

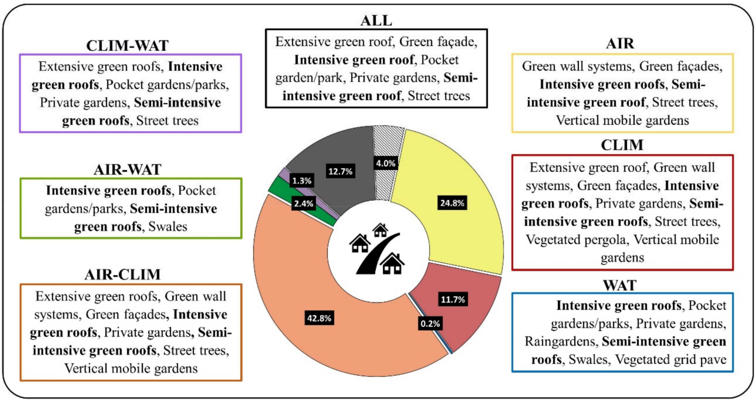

Figure 4. The pie chart shows the distribution of the spatial groups within the total impervious surface in Italy; the striped pattern represents the NoChal group. The I-NBS with high PS are reported in correspondence of each spatial group, with the I- NBS showing high PS simultaneously in all spatial groups marked in bold.

5. Discussion

Our framework has implications for the future development of cross-scale strategies to reach multiple national targets through NBS. It highlights the need to consider the multiple challenges to tackle as a key criterion to improve the NBS co-benefits and cost-effectiveness. Current NBS (or related concept) planning frameworks usually tend to focus on a single ES supply or address a specific challenge [41,68] and with a specific focus on the municipality scale [69–71]. However, our results highlighted that about 42% of the national territory shows multiple challenges simultaneously, and 50% of the population is exposed to these critical conditions. In these spatial groups (AIR-CLIM, AIR-WAT, CLIM-WAT, and ALL), multiple targets need to be achieved, through implementing NBS with the best performance to provide multiple ES. Consequently, the widespread distribution of areas under multiple challenges underlines that (i) in the political agenda, actions for air quality improvement might be coupled with those of climate change mitigation and adaptation [15]; (ii) considering both multiple ES demand (i.e., challenges to address) and multiple ES supply (i.e., NBS performance) has a key role to maximize the cost-effectiveness of interventions and the optimal use of the available space [8]. Europe—and the Member States—need to effectively leverage investments in NBS provided by the Green Deal, developing strategies to generate gains for adaptation, mitigation, disaster risk reduction, biodiversity, and health [37]. Therefore, the definition of a national intervention priority based on the intensity of challenges and population exposed [42] combined with the NBS performance ranking provided by our framework could help in this path, optimizing investment allocation from the national to the local governments.

Of the 24 NBS assessed, all spatial groups show from 11 to 16 NBS with high PS, both on impervious and permeable land covers. Providing a defined set of NBS is crucial for decision-makers and planners given the variety of NBS available [72], with different nomenclature, as well as the numerous barriers that may arise in urban areas from the planning stage to the site-scale design and implementation. The 24 NBS we considered in this work were selected from Castellar et al. [30], where, through using different workshops and surveys, they evaluated their performance to meet ten challenges, including the supply of all categories of ES. In the present work, some NBS may show similarities or overlapping results, being limited to only regulation ES (i.e., mitigation of air pollutants, heatwaves, and flood hazards). This could stand as a limitation; however, we decided not to further manipulate the nomenclature, thus leaving the possibility to replicate our methodology by also including other ES (e.g., provisioning, cultural, supporting) and other challenges (e.g., social cohesion).

Furthermore, the surfaces we evaluated as potentially available for the implementation of high-performing NBS do not necessarily correspond with the real space availability. Due to the broad scale and the aim of the work, we did not consider, e.g., archaeological constraints, protected areas, limited space in historical centers, that could decrease the suitability and space availability for NBS implementation. Therefore, for the local-scale implementation of the NBS, an in-depth assessment is necessary to include many other biophysical, economic, and social variables. To conduct a more detailed analysis and support the local scale governance to overcome the over-mentioned barriers, other layers could be useful, e.g., implementation and maintenance costs, the urban form, endemic vegetation, the public opinion, and many others that would be out of the scope and scale of this study.

However, according to the aim of this work, the incidence of land covers (i.e., impervious and permeable) in each spatial group, combined with the population density, suggests (i) which combination of factors is most related to the built-up areas, (ii) which risks the population is mainly exposed to, (iii) where to localize the interventions, and (iv) the number of beneficiaries of the expected increase in ES supply. On the one hand, we found spatial groups showing both high incidences of impervious surfaces and high population density, where I-NBS might be preferred. On the other hand, we found spatial groups with a lower incidence of permeable surfaces and low population density, where widespread and large-scale P-NBS (e.g., large urban parks, urban forests) in the territorial matrix could be more adequate. For example, impervious surfaces in the CLIM-WAT group have a built-up area's incidence eight times higher than in the AIR group (24% vs. 3%) and a population density twelve times greater too. This result suggests that investing equal resources (e.g., budget) in the first group, I-NBS, would affect more beneficiaries in a smaller area, mitigating both heatwaves and flood hazards, hence addressing two challenges simultaneously. These findings are particularly helpful since limited available space can act as barriers to NBS implementation, especially in urban areas where land is a scarce and expensive resource [21]. Potentially, some I-NBS (i.e., vertical green), even if less performing than others in P-NBS, have the advantage to occupy space often unemployed [73] and consequently not contributing to exacerbating conflicts around open space (e.g., land use change) in densely built-up areas [74].

5.1. Nature Based Solutions Implementable in Impervious Land Cover

Our results show that intensive and semi-intensive green roofs can potentially be implemented on 18,300 km^2, showing high PS in all spatial groups and hence standing as the most versatile and effective NBS among all the I-NBS assessed in this work. Although intensive and semi-intensive green roofs were initially designed for water management [75], due to their more deeply planted vegetation [73], they are also proved to positively contribute to climate mitigation, air quality, and biodiversity.

In terms of coverage and performance, among I-NBS, street trees and private gardens have high PS in five spatial groups and can be implemented, respectively, across 17,800 km^2 and 13,100 km^2, usually close to buildings, houses, and streets. Street trees show the best performance for the mitigation of air pollutants (AIR) and heatwaves (CLIM), both individually and combined (AIR-CLIM). Furthermore, the species selection can help both to mitigate pollutants [76,77] and to provide shade by the crown coverage [78,79]. Otherwise, when heatwaves and flood hazards need to be simultaneously mitigated, private gardens are more effective than street trees, contributing both to water management through the broadest unsealed soils, and to enhance air circulation and cooling through plant transpiration and shading [80]. Similarly, vertical green solutions (i.e., green façades, vertical mobile gardens, and green wall systems), are mainly reliable to stock air pollutants [81] and heatwave mitigation [82,83]. These I-NBS perform better in AIR, CLIM, and AIR-CLIM groups, covering potentially 17,500 km^2 of impervious surface. On the other hand, extensive green roofs show high PS for heatwaves and flood hazards [84], hence represented within AIR-CLIM, CLIM-WAT, CLIM, and ALL groups, and covering 13,000 km^2 of impervious surface.

5.2. Nature Based Solutions Implementable in Permeable Land Cover

Unlike the built-up areas where NBS Type 3 are usually considered, before implementing P-NBS, it is first necessary to evaluate the current land uses to consider their conservation (Type 1) and management (Type 2) instead of the substitution with new ecosystems (Type 3). This is following what was observed by Sarabi et al. [21], i.e., the entity of interventions required in NBS increases when moving (closer) to the center of built-up contexts, and vice versa. Therefore, in the case of currently forested areas, the objective should focus on their preservation, restoration, or enhancement to maximize ES supply (Type 1 and Type 2 [67]). This is a relevant option, for example, in the case of the AIR group, mainly occupied by forested areas. This is in line with the trajectory identified by the EU Green Deal, where, along with the protection and management of existing forests, urban, peri-urban, and agricultural areas need to be integrated with additional trees (i.e., 3 billion trees [23]). Accordingly, the assessed P-NBS can be applied in marginal, abandoned, unproductive, peri-urban areas [85–87], since they are considered as new ecosystems (Type 3 [67]).

Despite the finding that five P-NBS have high PS in all spatial groups (green corridors, large urban parks, heritage gardens, infiltration basins, and urban forests), they are similar to each other for regulating ES supply and thus addressing the challenges we considered in this work. The choice to implement one P-NBS instead of others can be related to the supply of other ES categories (cultural, provisioning, and support) as well as to other policy and planning issues (e.g., people perceptions, recreation needs) and budgetary constraints. Particularly, large urban parks and heritage gardens refer to large green areas (>0.5 ha) with mixed land uses (i.e., forests, grasslands, ponds). The first ones are mainly oriented to provide a variety of recreational facilities, mainly addressing the social demands of the residents, while the second ones aim to preserve outstanding historical, cultural, aesthetic, or scientific value [30]. Moreover, co-benefits and multifunctionality (i.e., multiple ES supply) of the single NBS can be enhanced by adding some improvements, usually including tree planting. As an example, infiltration basins can be partially forested to fulfill other functions such as providing recreational spaces for inhabitants, increasing biodiversity and ecological connectivity [88]. Similarly, green corridors are usually renatured areas of derelict infrastructure (i.e., railway) or placed along rivers. They can be afforested where there is the need to enhance landscape connectivity and ecological restoration [70,89,90]. Furthermore, their social role can be emphasized by ameliorating the availability and accessibility of currently vacant and underused land in urban contexts [91]. Therefore, the five P-NBS considered here already include—or could include—individual trees and/or groups of trees, as they are considered to be the best natural elements to increase the spectrum of ES provided [26,79,85,92–94].

6. Conclusions

The environmental challenges addressed in this work can adversely affect human health and well-being, with associated mitigation costs. Accordingly, our work contains a novel framework that will help both the national government and the municipalities to identify NBS able to maximize the ES supply while addressing multiple challenges. Analogously to the already proposed "National Strategy on Urban Greenspaces" [59], this work can provide a strategic vision at the national scale, but it can be consulted and adopted by all municipalities as a common roadmap, also helpful in facing the recurring problematic of planning silos. Indeed, the relevance of our framework is not just focused on the NBS application at the local scale but also shows a great impact on a wider scale (e.g., national and regional).

On a national scale, the framework proposed here can reliably (i) identify the areas showing a simultaneous demand for the achievement of multiple national targets; (ii) spatially orient the new investment needed to mitigate the challenges (e.g., EU Green Deal); and (iii) support the NBS selection that provides more co-benefits, playing a crucial role in increasing budget allocations efficiency.

On a municipal scale, the NBS ranking can be used as a guideline for further specific planning and design activities based on local issues, barriers, and peculiarities, while remaining consistent with national targets.

Italy is currently allocating funds in the 14 metropolitan cities to implement urban forests. Our results confirm that urban forests are among the best performing NBS, and Di Pirro et al. [42] argue that reforestation programs could also be expanded to other municipalities with few additional resources (+7.5% of the national territory) but involving an extra 46% of the national population. Although trees and forests (especially urban ones) are considered by many authors as the best solution to address environmental challenges [79,85,92,93], our work also proposes a list of performing I-NBS (e.g., green roofs) that can be implemented on sealed surfaces. These can help mitigate environmental stressors by using impervious surfaces i) that are usually unemployed (e.g., gravel or bitumen roofs) and ii) that could even exacerbate the challenges due to their physical characteristics (e.g., thermal emittance, reduced infiltration capacity) [95]. This option can also contribute to mitigating the negative effects related to soil sealing, which is a remarkable issue in the EU [96,97], enhancing the values of interstitial and leftover spaces [87]. However, the technical feasibility and costs related to these I-NBS and their widespread implementation must be evaluated according to the specific local conditions [73]. Finally, at the local scale, additional co-benefits (i.e., energy savings, biodiversity increase, and social cohesion), as well as possible disservices (i.e., BVOC emissions, decrease in wind velocity, gentrification), should also be included for a more overarching assessment [94,98,99]. Planning and managing NBS can be approached holistically [40], considering diverse benefits concerning different spatial–temporal scales. The multi-scale approach can help in considering different stakeholders as well as social, economic, and biophysical characteristics that matter in the benefit provision and are thus better included in decision-making related to national, regional, city/site-scale spatial plans [100].

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4. Optimizing cost-effectiveness and equitable distribution of Nature-Based Solutions

Containing the article: ***Cost-Effectiveness of Nature-Based Solutions under Different Implementation Scenarios: A National Perspective for Italian Urban Areas.*** **Di Pirro, E.; Roebeling, P.; Sallustio, L.; Marchetti, M.; Lasserre, B. Land 2023, 12, 603. https://doi.org/10.3390/land12030603**

This chapter gives insights into the total investments required for large-scale implementations of NBS and to optimize their contribution toward achieving national objectives and international goals related to environmental health. Based on the framework proposed in this chapter, practitioners could make more informed choices for the provisioning of both large-scale and long-term ecosystem investments by promoting multilateral and multilevel partnerships.

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Cost-Effectiveness of Nature-Based Solutions under Different Implementation Scenarios: A National Perspective for Italian Urban Areas

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Abstract: Worldwide, national governments and private organizations are increasingly investing in Nature-Based Solutions (NBS) to foster both human well-being and biodiversity while achieving climate and environmental targets. Yet, investments in NBS remain uncoordinated among planning levels, their co-benefits underestimated, and their effectiveness undermined. This study aims to provide a spatially explicit approach to optimize the budget allocation for NBS implementation across Italian urban areas while maximizing their effectiveness in terms of environmental health. We explored three different NBS implementation scenarios oriented to (i) maximize the Ecosystem Services supply of NBS (Scenario BP), (ii) minimize costs of NBS (Scenario LC), and (iii) maximize Ecosystem Services supply of NBS at the lowest cost (Scenario CP). Once selected, we prioritized their allocation through the territory following an environmental risk index for population, and we explored the relationship between costs and effectiveness for the three scenarios. The implementation of Scenario BP costs EUR 777 billion while showing 31 billion of effectiveness. Scenario LC costs 70% less than scenario BP (EUR 206 billion) while losing 70% of its effectiveness. Scenario CP costs 60% less than Scenario BP (EUR 301 billion), offering just 20% less effectiveness. Our results show that employing the risk index for NBS allocation would allow for reducing the surface of interventions by saving 67% of the budget in the three scenarios with a negligible loss in terms of return for human health. The here-proposed approach can guide the national funds' allocation system, improving its cost-effectiveness and equitableness.

Keywords: bio-based economy; nature-positive economy; large-scale; environmental policies; urban challenges; risk index; co-benefits

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1. Introduction

Investing in nature is not only an ecological imperative, it is also a socio-economic one [1]. Nature provides essential services to human beings, simultaneously delivering several co-benefits [2]. Nature helps societies in the protection from natural hazards, i.e., landslides, floods, or extreme heat. The tragic natural disasters hitting the world in the last summers (e.g., heatwaves) [3,4] are stark reminders of how much this protection is crucial [5].

Natural capital stocks per capita have declined by nearly 40% between 1992 and 2014, and one million plant and animal species are facing extinction [6]. Consequently, half of the global GDP (about USD 44 trillion) is at immediate risk [1]. This is a severe threat to our present as well as future welfare, requiring a shift from an economy based on natural resources overexploitation and fossil fuels towards a regenerative bio-based and nature-positive economy [6–8]. A massive and rapid decarbonization (e.g., reaching climate neutrality by 2050) needs to be coupled with the restoration and sustainable management of natural carbon sinks and reservoirs [9].

Making investments with nature-positive outcomes can increase business opportunities to the scale of USD 10 trillion per year and generate, by 2030, about 395 million jobs [1]. Nature-Based Solutions (NBS) can be effective to lead this paradigm shift [10]. The European Commission defined NBS as "solutions inspired and supported by nature, designed to address societal challenges which are cost-effective, simultaneously provide environmental, social and economic benefits, and help build resilience" [11]. From investing in the conservation or restoration of degraded lands [12] to optimizing the performance of traditional infrastructures (e.g., roofs [13]), there is remarkable evidence proving that NBS play a critical role in meeting environmental and socio-economical needs [14,15]. Indeed, a large part of the NBS appeal is linked to their potential to simultaneously address multiple sustainable development goals and societal challenges [2,16,17], as well as generate job innovation [18,19]. The benefits provided by NBS are generally supplied over long time frames and multiple spatial scales, meaning that benefits accrue to society as a whole rather than solely to the single beneficiary or investor [1,20]. However, these multiscale benefits are still hardly captured in current economic models [21,22].

The European Commission invested and fostered research on NBS under the Horizon 2020 research and innovation program, aimed to improve knowledge regarding NBS [23,24]. Concurrently, a growing number of private businesses identified NBS as a strategic frame to meet the Paris climate goals, offsetting their greenhouse gas emissions [25]. In addition, the recovery strategies from the COVID-19 pandemic offered the chance to invest in bringing back nature to the core of our societies [26,27] and move out from a carbon-based economy (e.g., clean energy in EU) [6]. However, the opportunities to include NBS in the recovery strategy are seized with different budgetary efforts by countries [28]. Therefore, despite the strong economic case of national governments (e.g., [29]), the gap between the current and potential scale of investment in NBS urgently demands bridging [30]. Scaling NBS investments toward potential implies several challenges for national governments, including the predictability of benefits and costs and the need to maximize their effectiveness and equitableness [22].

Different economic evaluations have already been proposed in the literature to assess direct and indirect costs and benefits of the project or investment level [31–33]. The implementation costs for new NBS are generally associated with land acquisition, design, installation, maintenance/administration, employees' salaries, and opportunity costs associated with the loss of income that would have been obtained for alternative uses [34,35]. Obviously, all these costs can vary according to specific features, e.g., NBS lifecycle, location, etc. [33,36], with special regard to the transaction costs that are still hidden and variable, which hamper policy and planning [37]. Due to the different adopted techniques and methodologies, the evaluation and comparison of the benefits in monetary terms are also still tricky [12,38]. For this purpose, the cost–benefit analysis is usually employed to estimate the net present value over the project lifetime, valuing the stream of all benefits and net of the stream of all costs [39–41]. When social or environmental effects are impossible—or difficult—to monetize, the project performance can be evaluated with other criteria [42], such as cost-effectiveness, cost impact analysis, lifecycle cost analysis, and multicriteria decision analysis/making [21]. The main purpose of cost-effectiveness analysis is to identify the economically most efficient way to meet an objective, usually considering the cost of achieving one objective and the level of its achievement [39,43]. In the case of NBS implementation, cost-effectiveness studies can rely on environmental and social outcomes (effects) being quantified using a metric expressing these effects as a single number [43].

NBS cost-effectiveness is well investigated by scholars, helping to underpin investment decisions in both government and private sectors [22,23,30]. The literature includes, e.g., the development of frameworks for cost analysis through lifecycle costing [36,44], combining multiple outcomes in the effectiveness account [31,45], comparison between NBS and gray approaches [46], and analysis in contexts with limited space availability [47]. Yet, information regarding the cost-effectiveness of large-scale NBS implementation is still lacking. Especially, the possibility of supporting national governments in optimizing funds allocation through maximizing the return for people in terms of environmental health is almost unexplored. Indeed, previous studies often assess effectiveness as the Ecosystem Service(s) supply.

However, especially in urban contexts, the enhancement of Ecosystem Services supply is related to the amount of beneficiaries [38] and not only limited to their biophysical characteristics [48] (e.g., pollution mitigation). This is due to the fact that population density is considered as an explanatory factor [49] to assess how environmental benefits and/or burdens affect human health [50]. Furthermore, as the NBS provide co-benefits, the effectiveness could be higher if the interventions are planned to address multiple challenges simultaneously (e.g., removing pollutants and reducing flood hazards) [45,47]. Accordingly, this could also link NBS implementation and management to other sectors (e.g., linking financial streams for nature and health sector), opening the possibility to receive extra financial resources and fight planning silos [32], especially at the national scale. This approach could also help private investors to target specific areas and have confidence that their investments will help face actual challenges.

According to these gaps, this work aims to evaluate how to minimize the costs and maximize the effectiveness of different typologies of NBS in terms of (i) the number and intensity of environmental challenges to address and (ii) the degree of risk exposure for the population, under three different NBS implementation scenarios. Using Italian urban areas as a case study, we simulated the fine-scale (10 m resolution) NBS implementation in impervious and permeable non-forested land covers, according to a risk index for human health and well-being. We designed three different strategies of NBS selection, coupling their costs and their ability to address three environmental challenges threatening human health and well-being (i.e., air quality, climate adaptation and mitigation, and water management). A case study is provided to assess the potential scale of investments to reach the national environmental targets and improve human well-being through large-scale NBS implementation. The here-proposed approach can thus guide the national fund allocation system involving as many beneficiaries as possible while maximizing the return in terms of environmental health.

2. Materials and Methods

Our case study is represented by Italian urban areas where we explored the relationship between costs and effectiveness of three different scenarios of NBS implementation, following a spatially explicit approach. NBS effectiveness is expressed as their capacity to (i) face multiple environmental challenges and (ii) reduce the degree of risk to which the population is exposed. The three proposed scenarios represent three different strategies for selecting the NBS to be implemented to face environmental challenges, while the priority of intervention is common among the three scenarios. Specifically, we hypothesized the following three strategies for selecting NBS to be implemented: (i) maximizing NBS biophysical performance to meet environmental challenges (without any budget constraints), (ii) minimizing costs (neglecting the different NBS capacities to address environmental challenges), and (iii) maximizing NBS biophysical performance at the lowest cost (combining the strategies proposed in the two previous scenarios). Once NBS were selected for each scenario, we adopted the same priority of implementation on the territory according to an aggregate index of risk exposure for the population to three environmental challenges (air quality, climate adaptation and mitigation, and water management). Accordingly, we prioritized the implementation of NBS in the pixels showing the higher population exposed to a higher intensity of challenges (i.e., high values of risk index). Lastly, we compared the three scenarios, investigating the relationship between different costs and the related effectiveness.

2.1. Study Area and Input Data

Italy, like many other countries of the Mediterranean basin, is facing the adverse effects of climate change, such as flood events, drought periods, and heatwaves, combined with high exposure of the three most harmful air pollutants in the European Union [51–54]. The intensity of these environmental challenges strongly varies throughout the national territory, as well as the number of inhabitants they affect. Furthermore, the national territory is characterized by a highly scattered and fragmented urban mosaic [55]. Accordingly, Italy is experiencing issues related to soil sealing (e.g., Ecosystem Services and biodiversity loss and habitat fragmentation [56]), with sealed surfaces reaching one of the highest relative national coverages among EU countries [57,58]. To tackle these challenges, the Italian national government envisaged different urban sustainability strategies and policies (e.g., promoting sustainable mobility and tree-planting initiatives), allocating money to specific administrative domains and municipalities [28,59]. Pursuing the aim of this work, we focused our analysis on the Italian urban areas according to the CORINE Land Cover map 2018 (CLC) [60]. CLC uses a Minimum Mapping Unit (MMU) of 25 hectares (ha) for areal phenomena and a minimum width of 100 m for linear phenomena. Particularly, we selected all the land uses included in class 1 of CLC, namely "Artificial surfaces", to define the boundaries of the Italian urban areas. Within these boundaries, we explored different layers of information: (i) the environmental challenges and their spatial co-occurrence [61], (ii) the population's exposure to the challenges (i.e., risk index [62]), (iii) the NBS Performance Score to address different groups of challenges (i.e., capacity to provide Ecosystem Service [61]), and (iv) the land cover where different typologies of NBS can be implemented, i.e., impervious and permeable non-forested [63] (Figure 1).

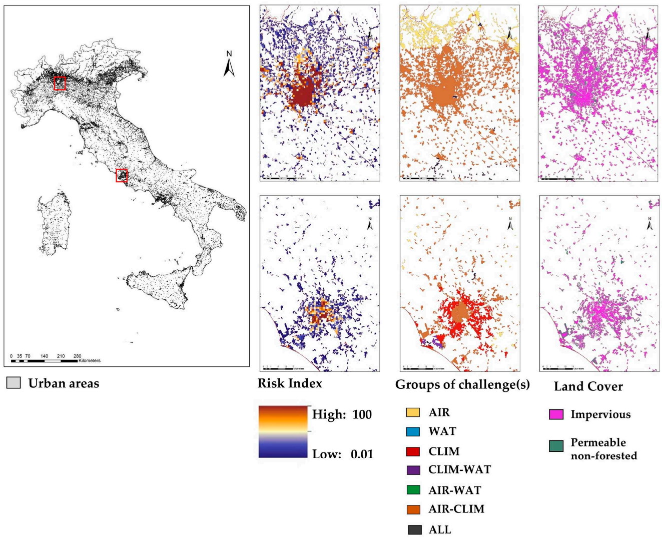

Figure 1. Datasets employed for the analysis within Italian urban areas, risk index (adapted from [62]), groups of challenge(s) (adapted from [61]), and land cover (adapted from [63]). The boundaries of Italian urban areas were defined according to Class "1- Artificial surfaces" of CORINE land cover.

From Di Pirro et al. [61], we derived the maps of three environmental challenges and their spatial co-occurrence. Specifically, the authors identified and mapped 7 groups of challenges: "AIR" group (i.e., air quality), "CLIM" group (i.e., climate adaptation and mitigation), "WAT" group (i.e., water management), "AIR-CLIM" group (i.e., air quality co-occurring with climate adaptation and mitigation), "AIR-WAT" group (i.e., air quality co-occurring water management), "CLIM-WAT" group (i.e., climate adaptation and mitigation co-occurring with water management), and "ALL" group (i.e., the three challenges simultaneously).

From Di Pirro et al. [62], we derived the aggregate risk index ranging from 0 to 100 that expresses the population exposure to these groups of environmental challenges with a spatial resolution of 1 km^2. The risk index was employed in this work to (i) guide the spatial allocation of the NBS for the three scenarios (i.e., priority of intervention) and (ii) estimate the effectiveness of interventions in each pixel.

From Di Pirro et al. [61], we derived the Performance Score (ranging from 0 to 1) of 24 NBS to address the different environmental challenge(s). Furthermore, for each of the 24 NBS, the authors provided information regarding the land cover where NBS can be implemented. The NBS that can be implemented in impervious land covers (I-NBS) are those fixed to buildings (i.e., extensive green roofs, green facades, green wall systems, intensive green roofs, planter green walls, semi-intensive green roofs, vegetated pergolas, and vertical mobile gardens), and along streets and parking lots, close to buildings and houses (i.e., pocket gardens/parks, private gardens, raingardens, swales, street trees, and vegetated grid paves). The NBS that can be implemented in permeable non-forested land covers (P-NBS) are community gardens, constructed wetlands, green corridors, heritage gardens, infiltration basins, large urban parks, urban forests, urban orchards, and (wet) retention ponds.

To refine the detection of impervious and permeable non-forested land, overcoming the MMU of CLC (i.e., 25 ha), we used the land cover map of ISPRA with a spatial resolution of 10 m [63]. Particularly, to identify the impervious surfaces within urban areas, we selected the class "abiotic artificial" (i.e., class 111), and to identify the permeable non-forested surfaces, we selected the class "herbaceous vegetation" (i.e., class 222). Forested areas were thus excluded from our analysis, as we did not consider the possibility to implement NBS in already forested areas.

According to the land covers, the spatial resolution of all the layers derived from the previous studies was changed to 10 m. Hence, we simulated the NBS implementation at a spatial scale of 100 m^2.

2.2. Assessing the Costs of Nature-Based Solutions

Investment and maintenance costs were assigned to 22 NBS out of the 24 identified by [61]. We could not find data regarding the implementation costs of "Planter green wall" and "Shelter for Biodiversity"; thus, they were excluded from our analysis. For each of the 22 NBS, we derived the investment costs (C_{Inv}; in EUR/m^2; see Appendix A) as an average of the investment costs reported in project reports from two H2020 projects and one LIFE project financed by the European Union [64–66]. Based on these same project reports, we derived that the annual maintenance costs ($C_{Main,t}$; in EUR/m^2/yr; see Appendix A) are, on average, about 2.5% of the investment costs. Although we are aware that an NBS can last over a long-time frame (e.g., 25 years for green roofs), and thus the investment costs could be averaged over those time frames, we decided to estimate the mean annual investment costs according to a policy cycle in the European Union (i.e., 7 years). Therefore, the Annual Costs (C_t) of implementation for each NBS (i) are given by:

$$C_{i,t} = \frac{C_{Inv,i}}{T} + C_{Main,i,t}$$

where T is the policy lifecycle. All costs are in Euro for the year 2019.

2.3. Scenario Building

Three alternative scenarios were designed to select the NBS to be implemented and relative budgets to be allocated in all Italian urban areas.

The first scenario aims to maximally address the environmental challenges by implementing the best-performing NBS for each of the seven groups of challenges, without any budget constraint. Therefore, for this Best Performance (BP) scenario, we selected, for each group of challenges, the I-NBS and P-NBS showing the highest Performance Score (i.e., Ecosystem Services supply) to address the specific challenges. In case two or more NBS showed the same Performance Score, the cheapest was selected.

The second scenario aims to minimize NBS costs (both investment and maintenance), neglecting the different NBS capacities to address the challenges. Hence, for this Least Cost (LC) scenario, the cheapest I-NBS and P-NBS were selected for each group of challenges.

The third scenario combines the first two scenarios to best address the different challenges at the least cost. Hence, for this Cost-Performance (CP) scenario, we selected, in each group of challenges, the I-NBS and P-NBS showing the lowest value resulting from the ratio between their costs and Performance Scores.

After the NBS were identified and selected according to (i) the scenario, (ii) the group of challenges, and (iii) the land cover (impervious and permeable non-forested), their allocation was simulated nationwide following a decreasing value of the risk index. Consequently, the higher is the risk index value, the higher the NBS implementation priority.

2.4. Calculating Costs and Effectiveness for Each Scenario

Applying the insights from previous studies (i.e., NBS Performance Score, groups of challenges to be addressed, and risk index and costs), we investigated the investment to implement NBS at a national scale, while exploring their return both for environment and society (effectiveness). For each of the three scenarios, we thus calculated the Total Annual Costs and Total Annual Performance that we obtain by implementing the selected NBS in Italian urban areas.

The Total Annual Costs (TC_t; in 2019 Euros) represent the annual investment and maintenance costs required to implement NBS in all available surfaces (impervious and permeable non-forested), dealing with at least one of the three challenges (i.e., risk index > 0). Hence, we calculated the Total Annual Costs (TC_t) as the product of the Annual Costs of the selected I-NBS and P-NBS for each scenario ($C_{t,i=I}$) and the suitable surfaces (S_i) over all pixels (p) in each group of challenges, as follows:

$$TC_t = \sum_{i,p} C_{t,i=I} \times S_{i.p}$$

where the minimum surface available is the single pixel (100 m^2).

The Total Annual Performance (TP_t) represents the biophysical performance provided by NBS to address all the challenges in the suitable surfaces, and it is calculated as the product of the Annual Performance Score per m^2 of the selected I-NBS and P-NBS for each scenario ($P_{t,i=I}$) and the suitable surfaces (S_i) over all pixels (p) in each group of challenges, as follows:

$$TP_t = \sum_{i,p} P_{t,i=I} \times S_{i.p}$$

where the minimum surface available is the single pixel (100 m^2). The value of the Annual Performance Score ($P_{t,i}$) ranges between 0 and 1 for all the NBS and, thus, the Total Annual Performance (TP_t) is always positive and greater than 1.

However, we did not limit our analysis to the NBS capacity to provide Ecosystem Services (i.e., Performance Score); rather, we included their potential effect on the population at risk.

The Total Annual Effectiveness (TE_t) is calculated as the product of the Annual Performance Score of the selected I-NBS and P-NBS for each scenario ($P_{t,i=I}$), the Annual Risk Index in each pixel ($R_{t,p}$), and the suitable surfaces (S_i) over all pixels (p) in each group of challenges, as follows:

$$TE_t = \sum_{i,p} P_{t,i=I} \times R_{t.p} \times S_{i.p}$$

where the minimum surface available is the single pixel (100 m^2). The value of the Annual Risk Index (R_t) ranges between 0.01 and 100, while the Annual Performance Score ($P_{t,i}$) in each pixel is always greater than 1. Hence, the Total Annual Effectiveness (TE_t) will be greater than the Total Annual Performance (TP_t) when the risk index is greater than 1. On the other hand, the Total Annual Performance will be greater than the Total Annual Effectiveness in all the pixels where the risk index drops below 1, as in those pixels, the Ecosystem Services supply by the NBS is high, while the number of beneficiaries at risk is low.

In other terms, while we can assume the Total Annual Performance as a measure of the potential Ecosystem Services supply (e.g., regardless of the beneficiaries of the intervention), the Total Annual Effectiveness, which includes the actual number of beneficiaries exposed to risk, represents a measure of the real benefits for people linked to the implementation of NBS.

We thus obtained, for the three scenarios (i.e., BP, LC, and CP), three different Total Annual Costs, Total Annual Performances, and Total Annual Effectivenesses. Considering the case of implementing NBS in all urban areas for the three scenarios, the value of the Total Annual Effectiveness is different only for the Total Annual Performance, as the Annual Risk Index stays the same.

Lastly, we calculated the Annual Cost-Effectiveness Ratio (CER_t; in 2019 Euros per unit) and its variation throughout the urban areas of the national territory and across scenarios. The Cost-Effectiveness Ratio determines the relation between the inputs in monetary terms and the outcomes in physical terms, and it is calculated as follows:

$$CER_t = TC_t/TE_t$$

Therefore, if we assume the same level of investment for the three scenarios, the lower the Cost-Effectiveness Ratio, the higher the return for society (i.e., Total Annual Effectiveness). Similarly, if we assume the same level of Total Annual Effectiveness for the three scenarios, the lower the Cost-Effectiveness Ratio, the lower the budget needed to achieve those benefits.

Finally, cost-effectiveness curves per scenario are derived by summing-up the single-pixel value effectiveness (Cumulative Effectiveness) and Annual Costs (Cumulative Costs), starting from those with the highest risk (i.e., 100) to those with the lowest risk (i.e., 0.01). Particularly, we explored the variation of the Cost-Effectiveness Ratio among scenarios above and below the risk index equal to 1.

3. Results

The results show that 12,694 km^2 out of 16,798 km^2 of Italian urban areas have a risk index higher than 0, overlaying with impervious and permeable non-forested land covers. Specifically, 8841 km^2 are imperviousness, while 3853 km^2 are permeable non-forested areas. The most recurrent group of challenges in urban areas is AIR-CLIM (47.1%), followed by AIR (27.4%), ALL (12.4%), CLIM (10.1), AIRWAT (1.6%), CLIMWAT (1.3%), and lastly, WAT (0.1%) (Figure 2).

3.1. Costs Assessment

Among the 22 considered NBS, 13 are I-NBS and 9 are P-NBS. The average cost of the I-NBS is 55 EUR/m^2/yr, ranging from the lowest cost of the raingardens (13.4 EUR/m^2/yr) to the highest cost of the vertical mobile gardens (142.7 EUR/m^2/yr). The average cost of P-NBS is 44.8 EUR/m^2/yr, ranging from the lowest cost of the urban orchards (22.7 EUR/m^2/yr) to the highest cost of constructed wetlands (125 EUR/m^2/yr). Please see Appendix A for extensive information regarding costs and performances of the 22 considered NBS.

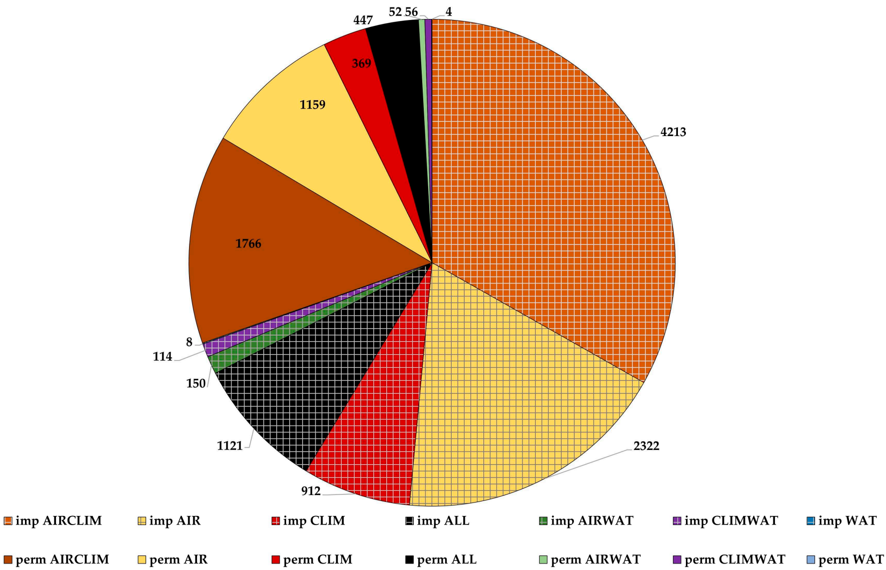

Figure 2. Absolute coverage (km^2) of groups of challenges and land covers (impervious and permeable non-forested) within Italian urban areas. The different colors represent the seven group of challenges (adapted from [61]). The different patterns, squared and full-color, represent impervious and permeable surfaces, respectively.

3.2. Nature-Based Solutions Selected for Each Scenario

According to the three strategies designed for the NBS selection in each scenario (Table 1), in the BP scenario, the selected I-NBS have Performance Scores ranging from 0.8 to 1 and costs ranging from 50.4 EUR/m^2/yr for private gardens to 78.9 EUR/m^2/yr for green facades. For the selected P-NBS in this scenario, the Performance Score is 1 in all the groups of challenges, and the costs range from 30.6 EUR/m^2/yr for the infiltration basins to 37.8 EUR/m^2/yr for the large urban parks. For the LC scenario, the selected I-NBS have Performance Scores ranging from 0.3 to 0.8 (i.e., raingardens) with a cost of 13.4 EUR/m^2/yr, while for P-NBS, the urban orchards were selected with a Performance Score ranging from 0.2 to 0.4 and a cost of 22.7 EUR/m^2/yr. For the CP scenario, the Performance Scores of the I-NBS range from 0.5 to 0.9, and the costs range from 13.4 EUR/m^2/yr for raingardens to 18.5 EUR/m^2/yr for extensive green roofs; for the P-NBS, the Performance Scores range from 0.9 to 1, and the costs range from 30.6 EUR/m^2/yr for the infiltration basins to 37.8 EUR/m^2/yr for the large urban parks.

3.3. Comparison among Scenarios

Firstly, we estimated the investment annually required to implement the NBS (both I-NBS and P-NBS) on the identified 12,694 km^2. Results show that, regarding the BP scenario, the estimated Total Annual Cost is about EUR 777 billion, with a Total Annual Effectiveness of 31 billion and a Total Annual Performance of about 12 billion. For the LC scenario, the estimated Total Annual Cost is about EUR 206 billion, with a Total Annual Effectiveness of 12 billion and a Total Annual Performance of about 5 billion. For the CP scenario, the Total Annual Cost is about EUR 301 billion, with a Total Annual Performance of 25 billion and Total Annual Performance of about 10 billion. Regarding the Cost-

Effectiveness Ratio, the BP scenario shows the highest value with 24.6, followed by LC and CP (16.3 and 11.9, respectively).

Table 1. Selected NBS for the three scenarios, Best Performance (BP), Least Cost (LC), and Cost per Performance (CP). The NBS are proposed according to the 7 group of challenges (i.e., AIR, CLIM, WAT, AIRCLIM, AIRWAT, CLIMWAT, and ALL) and the land cover (impervious and permeable non-forested). Particularly, the I-NBS are those implementable in impervious land covers, while the P-NBS those implementable in permeable land covers. For each NBS, the Performance Scores (PS per m^2) and cost (EUR/m^2/yr; in 2019 Euros) required for their implementation and maintenance are reported.

Scenarios	NBS, PS, Costs	AIR	CLIM	WAT	AIR-CLIM	AIR-WAT	CLIM-WAT	ALL
BP	I-NBS	Green facade	Private gardens	Semi-intensive green roof	Green façade	Intensive green roof	Intensive green roof	Private gardens
	PS per m^2	1	1	1	1	0.8	0.9	0.8
	Cost (EUR/m^2/yr)	78.9	50.4	52.0	78.9	52.0	52.0	50.4
	P-NBS	Large urban park	Large urban park	Infiltration basin	Large urban park	Large urban park	Large urban park	Large urban park
	PS per m^2	1	1	1	1	1	1	1
	Cost (EUR/m^2/yr)	37.8	37.8	30.6	37.8	37.8	37.8	37.8
LC	I-NBS	Raingardens	Raingardens	Raingardens	Raingardens	Raingardens	Raingardens	Raingardens
	PS per m^2	0.4	0.3	0.8	0.4	0.6	0.6	0.5
	Cost (EUR/m^2/yr)	13.4	13.4	13.4	13.4	13.4	13.4	13.4
	P-NBS	Urban orchards	Urban orchards	Urban orchards	Urban orchards	Urban orchards	Urban orchards	Urban orchards
	PS per m^2	0.3	0.2	0.5	0.3	0.4	0.3	0.3
	Cost (EUR/m^2/yr)	22.7	22.7	22.7	22.7	22.7	22.7	22.7
CP	I-NBS	Swales	Extensive green roof	Raingardens	Street trees	Swales	Raingardens	Raingardens
	PS per m^2	0.6	0.9	0.8	0.8	0.7	0.6	0.5
	Cost (EUR/m^2/yr)	15.1	18.5	13.4	21.0	15.1	13.4	13.4
	P-NBS	Large urban park	Large urban park	Infiltration basin	Large urban park	Infiltration basin	Infiltration basin	Infiltration basin
	PS per m^2	1	1	1	1	0.9	0.9	0.9
	Cost (EUR/m^2/yr)	37.8	37.8	30.6	37.8	30.6	30.6	30.6

Similarly, analyzing these indices and curves till the pixels corresponding to risk index equal to 1, we observe that, beyond this threshold, the tails of the curves of the three scenarios start to run almost parallel to the *y*-axis (i.e., Cumulative Costs) (Figure 3). Consequently, corresponding to this threshold, the analyzed indices are EUR 68 billion and 12 billion effectiveness in the LC scenario, EUR 98 billion and 24 billion effectiveness in the CP scenario, and EUR 270 billion and 30 billion effectiveness in the BP scenario.

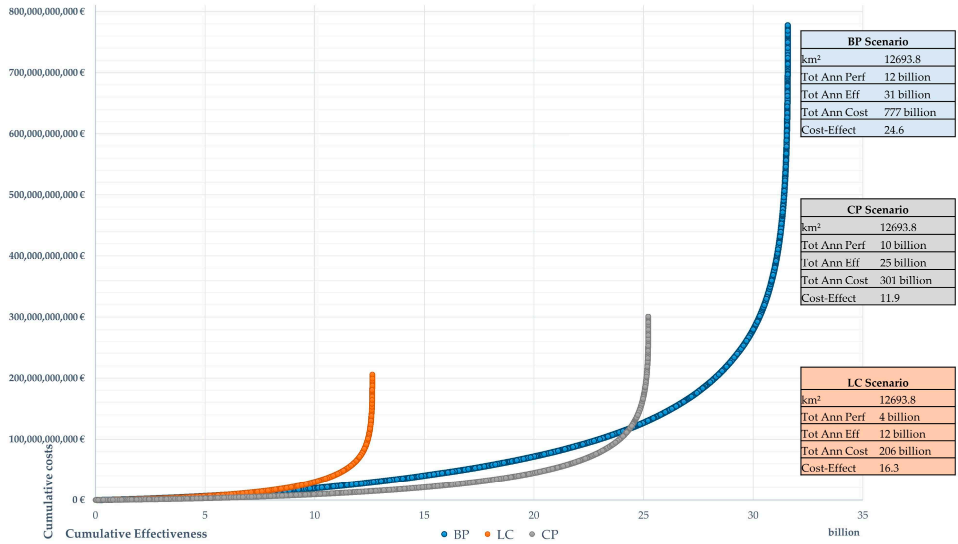

Figure 3. Trends of Cumulative Costs (*Y*-axis) as a function of Cumulative effectiveness (*X*-axis) for the three scenarios depicted: Best Performance (BP), Least Cost (LC), and Cost per Performance (CP). All the NBS, selected according to the scenarios, are allocated pixel by pixel following the decreasing values of the Risk Index. The three informative boxes, one for each scenario, show the surface covered by NBS implementation (km^2), Total Annual Performance, Total Annual Effectiveness, Total Annual Cost (2019 Euros), and Cost-Effectiveness Ratio.

4. Discussions

4.1. Characteristics of Urban Areas and Implication for Nature-Based Solutions Implementation

The characteristics of urban areas must be addressed in relation to the associated socio-economic challenges to ensure effective enhancements in urban Ecosystem Services provision by NBS planning and management [17,67]. Our analysis shows that 12,694 km^2 of urban areas in Italy are risky for the population's health: 70% in impervious surfaces and 30% in permeable non-forested surfaces (the forested surfaces were excluded from our analysis). Furthermore, 62% of these areas show multiple challenges simultaneously, particularly with the AIR-CLIM group (i.e., challenges of air quality and climate adaptation and mitigation occurring simultaneously), which occupies the greatest relative surface both on impervious and permeable non-forested land covers (Figure 2). These results are in line with the previous literature showing the relationship between sealed surfaces and the interaction of air pollutants and thermal discomfort [67–69]. From an urban planning perspective, these results offer the following insights: (i) the need to consider the multiple challenges to tackle as a key criterion to improve the NBS cost-effectiveness and (ii) NBS research and implementation need to strengthen their focus on impervious surfaces.

Currently, the financing commitments in urban areas are increasingly focused on tree-planting campaigns, mainly intended for climate adaptation and mitigation (e.g., 6.6 million trees in Italy [28] and 3 billion trees in Europe [70]), risking to trigger severe competition for land [71], a scarce and expensive resource especially in cities' core areas [72]. Our results show that impervious surfaces are the predominant land cover in Italian urban areas, around 70%, underlying the strategic role of I-NBS for increasing urban sustainability both on buildings and along the street (such as green roofs and vertical green technology [73], private gardens [17], and street trees [74,75]). Indeed, I-NBS, even if less-performing than P-NBS, are ideal to requalify often unemployed spaces [76] and, consequently, tone down conflicts around open spaces with fragmented ownership in densely urbanized areas [17,77]. However, due to intrinsic and structural characteristics of I-NBS (e.g., reduced amount of substrate in green roofs [78]), it is crucial to carefully consider their expensiveness and lower Ecosystem Services supply compared with P-NBS as the ratio between Cost/Performance Scores proposed in the CP scenario. If, on one hand, we considered a full-scale I-NBS implementation in all impervious surfaces regardless of their actual availability, on the other, we did not include the possibility of depaving actions. These measures are growing in the literature and in practice [64,79] as a valid alternative to re-establish the Ecosystem Services supply [80] undermined by soil sealing (e.g., carbon stock [81] and habitat degradation [82]). Moreover, these measures play a key role to reach the European goal of zero (net) land take. As the information regarding their costs is limited to specific case studies and not easily replicable in other contexts and scales, we did not include it in our analysis.

Despite impervious surfaces being the main land cover in urban areas, around 30% is covered by permeable non-forested surfaces. Recently, di Cristofaro et al. [83] underlined that this land cover decreased in Italian built-up areas during the last three decades, especially in densely populated areas. Their results support our findings and highlight the importance of maintaining and promoting these open areas through the implementation and management of new NBS, which can effectively address environmental challenges and restore degraded lands (e.g., brownfields [12,84,85]) at a lower average cost compared with I-NBS (Table 1). Furthermore, P-NBS can be employed in two other sectors with significant economic interests, biofuels production (e.g., growing perennial biomass crops [86]), and biomaterials constructions (e.g., building with timber, cork, and bamboo [87]). Both could substantially reduce the carbon footprint of our cities while creating durable carbon pools [8].

4.2. Variation in Costs and Effectiveness among Scenarios

According to our results, Scenario CP shows the best Cost-Effectiveness Ratio (11.9), followed by scenario LC (16.3), and lastly, Scenario BP (24.6).

Notwithstanding, the maximum Total Annual Effectiveness is found in the BP scenario (i.e., 31 billion), where the selected NBS show the maximum Total Annual Performance (i.e., the highest Ecosystem Services supply), involving all the population at risk in Italian urban areas. The maximum benefit (i.e., Total Annual Effectiveness) that can be expected by implementing NBS is crucial information for policymakers [88], as it allows to identify the BP scenario as the best option that should be adopted to pursue the main objective of addressing challenges and reducing the population at risk.

Reaching the maximum Total Annual Effectiveness also leads to the maximum investment, showing the highest Total Annual Cost among the three scenarios (i.e., EUR 777 billion), exceeding 61 EUR/m^2/yr, suggesting that the maximum return for the population could be reached but at the highest cost. On the other hand, selecting the cheapest NBS allows a mean investment of just 24 EUR/m^2/yr, with a Total Annual Cost of about 70% less than the BP scenario (EUR 206 billion), as well as losing 70% of its Total Annual Effectiveness. Although it is not surprising that the CP scenario is the most cost-effective, we quantitatively show that evaluating the ratio between cost and Ecosystem Services supply (i.e., cost/Performance Score), even in the NBS selection phase, can effectively help to save money, with a negligible decrease in terms of effectiveness. Indeed, the Total Annual Cost is 60% less than the BP scenario, while losing just 20% of Total Annual Effectiveness.

Therefore, the results obtained by scenario CP represent an optimal option for all the European Member States that need to effectively leverage investments in NBS provided by the Green Deal, developing strategies to generate gains for biodiversity, adaptation and mitigation, disaster risk reduction, and health [89].

We are aware that the results of all three scenarios show huge annual investments (EUR 777, EUR 206, and EUR 301 billion, respectively, for the BP, LC, and CP scenarios). This is due to the fact that we considered a full-scale implementation on all impervious and permeable non-forested land covers falling in Italian urban areas that do not necessarily correspond with the real space availability. Due to the large scale of this work, we did not consider archaeological constraints, limited space in city centers, nor social variables that should be included to support local-scale governance and NBS design [61].

However, these large investments might be considered more feasible if they do not limit NBS funding merely to the "environmental sphere" (e.g., environmental ministry and municipal forestry agency). Since NBS proved to be important to improving health [90,91], McDonald et al. [32] pointed out that the use of innovative finance and policy tools can enable public health funding to be linked to, e.g., tree-planting funding. Similarly to public health, funding for NBS could be linked to risk management and social policies [45], as well as the engineering sector and bio-based industry (as recently highlighted by the European Forest Institute [8,92,93]). Accordingly, the estimated Total Annual Costs for the three scenarios can represent a starting point to identify the investment gap to fill by (i) linking different levels of governance, (ii) streaming finance from different departments, and (iii) identifying and quantifying financial and other institutionalized incentives (e.g., PES [43]), with the final aim to fight the planning silos that often limit the correct management of resources and the definition of responsibilities among departments [22,27,32,94,95].

For this purpose, we adopted the descending order of the risk index to prioritize NBS implementation. Its employment confirmed how the effectiveness of the same intervention might be totally different in terms of human health improvement based on its location. This is particularly evident in the curves of Cumulative Effectiveness and Cumulative Costs, where we explored that the costs increase steadily along the curves, inversely to their effectiveness (Figure 3). Considering the effectiveness given by the product between the Performance Score and risk index values, the more the latter decreases, the more the effectiveness decreases. Indeed, the NBS implementation costs, as well as their potential Ecosystem Services supply, remain constant throughout the territory, while the return in terms of human health varies according to the amount of population exposed to a given level of environmental challenge (i.e., risk). Particularly, in the pixels where the risk index drops below 1, the Total Performance Score starts to be higher than the Total Effectiveness in all scenarios. Particularly, this threshold (i.e., risk index equals to 1) corresponds to EUR 68 billion and 12 billion effectiveness in scenario LC, to EUR 98 billion and 24 billion effectiveness in scenario CP, and to EUR 270 billion and 30 billion effectiveness in Scenario BP. The difference between the Total Annual Costs needed to cover the whole urban areas and this threshold (i.e., tails of the curves in Figure 3) highlights that EUR 138 billion, EUR 203 billion, and EUR 507 billion are additionally required to reach, respectively, the Total Annual Effectiveness of LC, CP, and BP (12 billion, 25 billion, and 31 billion, respectively). Thus, the tails of the curves represent the portions of territory where NBS are financially maintained, while potentially supplying Ecosystem Services, but their actual beneficiaries decline. Accordingly, in each scenario, investing about 33% of the respective Total Annual Costs needed to cover the whole urban areas would be enough to reach between 88% (BP scenario) and almost 100% (LC scenario) of the Total Annual Effectiveness. This evidence allowed us to identify the risk index equal to 1 as a helpful threshold to orient and optimize the budget allocation throughout the territory, maximizing the return in terms of benefits for the population. Therefore, the rationale "the higher the risk the higher the priority to implement NBS" would lead to improving the cost-effectiveness (i.e., maximizing the return for human beings), as well as the environmental justice (i.e., enhance well-being of most vulnerable groups [96]).

Our approach is also confirmed by the previous literature employing exposure indices in environmental justice to brief decisionmakers regarding the social inequity of cumulative hazards' exposure [97], to support and select urban planning alternatives reducing the risk for citizens [67], and to orient the allocation of the investment for disaster risk reduction [98]. Our findings also suggest that risk exposure to multiple challenges could be read as an Ecosystem Services demand from the population, representing a reliable parameter for urban planners to prioritize and locate multifunctional interventions. This approach is supported in the literature by other authors recognizing Ecosystem Services frameworks for their support in urban planning [99–102], to define priority areas for NBS implementation [103,104], and ensure their equitable distribution throughout the territory [17,105]. Yet, these frameworks are proposed at the municipal scale, conversely, we proposed a framework involving all urban areas in Italy (according to a land cover definition, i.e., CLC), improving the cartographic detail (10 m resolution). Our approach thus further allowed us to (i) detect the small patches of permeable spaces within urban areas, (ii) adopt a strategic vision of all urban areas and not consider municipalities as single and isolated units, and (iii) avoid the intrinsic limitation in employing administrative boundaries for Ecosystem Services assessment [82,106], NBS implementation (e.g., urban forests [107]), and environmental challenges mitigation [62].

5. Conclusions

In this work, we compared different NBS selection strategies and how their implementation in the Italian urban areas deals with two recurring issues for a national government: achieving environmental objectives (e.g., Italy has infringed EU law on air quality [54]) and saving money.

Our national-scale perspective gives decisionmakers and investors insights about the total investments required for large-scale implementations of NBS and to optimize their contribution toward achieving national objectives and international goals. This is in line with the need that recently emerged in the literature to upscale NBS [10,21,88], especially in national and European policy frameworks [108].

For a fine-scale application, our results show that relating information regarding Ecosystem Services and costs can be crucial to select the optimal set of NBS based on territorial conditions and threats (CP scenario). For a broader-scale application, our framework also proved that, contrary to NBS selection, their implementation throughout the territory should not be limed just to the potential Ecosystem Services supply but necessarily need the inclusion of their demand as well. Indeed, limiting the intervention surface to the portions of the territory with a risk index greater than 1 would allow saving 67% of the Total Annual Costs, with a negligible loss in terms of return for human health.

Even with optimizing the budget allocation, NBS implementation over all the risky areas would require significant investments, often a limiting factor for interventions. Thanks to their multifunctionality, we highlight that these large investments could be covered by co-financing actions following the needs of different stakeholders and policy areas (e.g., as similarly proposed in the "health in all policies" approach [109]).

In this work, we quantified effectiveness as a metric to improve citizens' environmental health. However, effectiveness could also synthesize other environmental and social outcomes (e.g., improve social cohesion, energy efficiency, etc.). We thus point out how the employment of an aggregated metric, able to quantify multiple outcomes, is a helpful approach to limit institutional fragmentation and, in turn, strengthen potential co-financing opportunities.

Moreover, we averaged the Total Costs for 7 years (an EU policy cycle), as annual calculations give policymakers insights into the impact of NBS implementation on their annual budget. However, we are aware that the short-term nature of decision making can hinder the longer-term planning and maintenance required to sustain NBS benefits, usually with a longer lifecycle. This is one of the main challenges for future financial and political systems, on which future research should be focused (e.g., transaction costs [30,37]). Based on the framework here-proposed, practitioners could make more informed choices for the provisioning of both large-scale and long-term ecosystem investments by promoting multilateral and multilevel partnerships. Our methodology can be potentially replicated across all Member States, as well as upscaled (e.g., EU) to ensure a more effective funds allocation and identification of new areas of research and innovation projects.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Nature Based Solutions	Performance Score (PS/m^2)							Inv Cost (EUR/m^2)	Ann Inv Costs (EUR/m^2)/7yr	Maint. Costs (EUR/m^2/yr) 2.5%	Costs (EUR/m^2/yr)
I-NBS	**AIR**	**CLIM**	**WAT**	**AIR-CLIM**	**AIR-WAT**	**CLIM-WAT**	**ALL**				
Street trees	0.8	0.9	0.4	0.8	0.6	0.7	0.7	125	17.9	3.1	21.0
Extensive green roof	0.5	0.9	0.6	0.7	0.5	0.7	0.7	110	15.7	2.8	18.5
Raingardens	0.4	0.3	0.8	0.4	0.6	0.6	0.5	80	11.4	2.0	13.4
Vegetated grid pave	0.2	0.5	0.8	0.3	0.5	0.6	0.5	115	16.4	2.9	19.3
Private gardens	0.5	1.0	0.8	0.8	0.6	0.9	0.8	300	42.9	7.5	50.4
Pocket garden/park	0.6	0.6	0.8	0.6	0.7	0.7	0.7	210	30.0	5.3	35.3
Semi-intensive green roof	0.7	0.8	1.0	0.8	0.8	0.9	0.8	310	44.3	7.8	52.0
Intensive green roof	0.7	0.9	0.8	0.8	0.8	0.9	0.8	310	44.3	7.8	52.0
Swales	0.6	0.2	0.9	0.4	0.7	0.5	0.6	90	12.9	2.3	15.1
Green faCade	1.0	1.0	0.2	1.0	0.6	0.6	0.7	470	67.1	11.8	78.9
Vegetated pergola	0.5	0.8	0.3	0.6	0.4	0.5	0.5	600	85.7	15.0	100.7
Green wall system	1.0	0.8	0.0	0.9	0.5	0.4	0.6	700	100.0	17.5	117.5
Vertical mobile garden	1.0	0.9	0.0	1.0	0.5	0.5	0.6	850	121.4	21.3	142.7
P-NBS											
(Wet) Retention Pond	0.8	0.6	1.0	0.7	0.9	0.8	0.8	193	27.5	4.8	32.3
Infiltration basin	0.8	0.8	1.0	0.8	0.9	0.9	0.9	183	26.1	4.6	30.6
Green Corridors	1.0	1.0	0.7	1.0	0.8	0.8	0.9	230	32.9	5.8	38.6
Large urban park	1.0	1.0	0.9	1.0	1.0	1.0	1.0	225	32.1	5.6	37.8
Community garden	0.3	0.5	0.8	0.4	0.6	0.7	0.6	160	22.9	4.0	26.9
Heritage garden	1.0	1.0	1.0	1.0	1.0	1.0	1.0	300	42.9	7.5	50.4
Urban forest	1.0	0.9	0.8	0.9	0.9	0.9	0.9	225	32.1	5.6	37.8
Urban orchards	0.3	0.2	0.5	0.3	0.4	0.3	0.3	135	19.3	3.4	22.7
Constructed wetlands	0.0	0.3	1.0	0.1	0.5	0.6	0.4	750	107.1	18.8	125.9

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5. Seized and missed opportunities to finance Nature-Based Solutions

Containing the article*: The Embeddedness of Nature-Based Solutions in the Recovery and Resilience Plans as Multifunctional Approaches to Foster the Climate Transition: The Cases of Italy and Portugal,* Di Pirro, E.; Mendes, R.; Fidélis, T.; Sallustio, L.; Roebeling, P.; Marchetti, M.; Lasserre, B. Land 2022, 11, 1254. https://doi.org/10.3390/land11081254.

This chapter investigates the narrative of the National Recovery and Resilience Plan and the investments dedicated to NBS. The approach proposed in this chapter provides a critical reflection on the missed opportunities to use nature to address multiple global challenges by building new ecosystems, new enterprises, and new jobs aiming to promote a more bio-based, nature-positive, and sustainable economy.

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Article

The Embeddedness of Nature-Based Solutions in the Recovery and Resilience Plans as Multifunctional Approaches to Foster the Climate Transition: The Cases of Italy and Portugal

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Abstract: European countries recently prepared recovery and resilience plans (RRPs) to recover from the pandemic crisis and reach climate neutrality. Nature-Based Solutions (NBS) are recognized as crucial drivers to fostering climate transition while addressing other challenges. Accordingly, RRPs offer the opportunity to promote the adoption of NBS. This article assesses the NBS embeddedness in the policy discourse of Italian and Portuguese RRPs and how they are considered to meet climate–and related environmental–targets. We conducted a discourse analysis based on two steps, (*i*) a quantitative analysis to classify different nature-related terms into four categories—biophysical elements, general environmental concepts, threats and challenges, and NBS—and estimate their frequency in the text; (*ii*) a qualitative analysis to understand the relationship between the categories of challenges and NBS as well as the dedicated investments. The results show that NBS are barely mentioned, with a frequency in the texts for the NBS category of 0.04% and 0.01%, respectively, in Italian and Portuguese RRPs. Narratives are mainly built around general concepts such as resilience and sustainability with nature scarcely considered as an ex novo solution to meet challenges. Notwithstanding, Italy invests 330 M in the implementation of urban forests, while in Portugal, no specific NBS interventions have been considered so far. To date, both countries are primarily orienting the climate transition toward reducing emissions instead of combining these measures with multifunctional NBS to address environmental and socio-economic challenges.

Keywords: discourse analysis; environmental policies; green deal; NextGenerationEU; bio-based economy; climate change; urban forests

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1. Introduction

The European Union is addressing the recovery from the pandemic crisis by investing in a stimulus package worth EUR 2.018 trillion at current prices. It consists of a combination of the EU's long-term budget for 2021 to 2027 and the NextGenerationEU [1]. The latter is a temporary instrument to stimulate the recovery with scope and ambition without precedent, including investments and reforms to accelerate the ecological and digital transition, support education, and achieve greater gender, territorial and generational equality. To access NGEU funds, each member state had to prepare a national recovery and resilience plan (RRP) for the period 2021–2026, according to the criteria established by Article 18 of Regulation no. 2021/241/EU. One-third of the overall EU budget aims to finance the European Green Deal, under which Europe aims to become the first climate-neutral continent by 2050, producing no more greenhouse gases than the ecosystems can naturally absorb. To reach this target, all the member states pledged to reduce net greenhouse gas emissions by at least 55% in 2030 as compared to their 1990 levels. Further ambitious environmental goals were set for all member states, such as zero soil sealing by 2050 [2] and a vast tree planting campaign (i.e., 3 billion trees by 2030; [3]). Achieving these goals relies on the transformation of all sectors of the EU's economy, requiring a paradigm shift for a transition to a circular, nature-positive, carbon-neutral, bio-based and equitable economy [4–7]. Therefore, the focus should not be only on the transformation of energy and transport systems, but also on measures across the economy to harness the potential of nature to contribute to both mitigating climate change and enhancing our resilience to its impacts [8]. As one of the main environmental challenges, climate change is already affecting Europe's ecosystems and human health, and it is expected to pose further threats to the ecosystem and socio-economic system shortly [9–11]. The RRP is thus an opportunity for all the member states to include and invest in a nature-based recovery, addressing the effects of climate change via adaptation and mitigation measures [4]. The latest IPCC report states that all scenarios that limit climate change to 1.5 °C rely on decreasing emissions, decarbonizing the economy as well as adopting land-use change mitigation strategies [12,13]. Accordingly, coupling the decrease in emission sources with the increase in carbon sinks through terrestrial ecosystems is one of the most reliable strategies to fight climate change [9,14,15]. Particularly, all nature-based approaches have emerged as a key instrument to face different challenges across sectors of society and business, also offering multiple cost-effective benefits to ecosystems and human wellbeing [12,16]. However, adopting a nature-based economic perspective means the explicit recognition of nature as both providing inputs and generating outputs for our economy [4,17]. Although it could be still difficult to assess the monetary value and the economic benefits of the outputs [18,19], it is recognized worldwide that there is a need to overcome the "business-as-usual" model based on resource exploitation, biodiversity loss, and carbon emission growth through investing in nature and fostering the transition to sustainable development [6,20].

In recent years, several nature-based approaches have become a key topic of contemporary research on sustainable development of urban and rural areas [21] such as ecological restoration, ecological engineering, green and blue infrastructure, ecosystem services, urban forestry, ecosystem-based management and adaptation, and eco-disaster risk reduction [22–24]. Since 2015 [25], the concept of Nature-Based Solutions (NBS) enclosed each of them under its 'umbrella' including all the approaches, with different terminology, that work with and enhance nature to help address multiple challenges [26]. Several studies have indeed shown how NBS are very efficient in facing extreme events related to climate change, by adaptation and mitigation actions (e.g., reducing flood risk, and storing CO_2) [10,27,28], contemporarily able to preserve human health [27,28], psychosocial well-being [29,30], improve air quality [31–33], and increase landscape connectivity [34,35].

Thanks to their capacity and multifunctionality, NBS are gaining momentum in the emerging policy discourse, and multiple initiatives raised to mainstream the NBS, encouraging their development for more sustainable and just communities [36]. Therefore, NBS are expected to further shape the policy narrative in global environmental decision-making [37]. Accordingly, at a global policy level, 66% of all signatories to the Paris Agreement included NBS for climate change mitigation and adaptation in their nationally determined contributions [38,39]. Furthermore, the EU claims to be a world leader in NBS through supporting numerous projects in the Research and Innovation Agenda [23,25]. These projects are proving to be a catalyst for research–practice partnerships [40], gathering insights regarding NBS performance, impacts assessments, and cost-effectiveness [8,41]. Consequently, NBS are tested in front-runner cities, demonstration sites, and urban living labs, and the EU is using their outcomes to upscale these initiatives to a broader public [10,23] and to facilitate their operationalization from experts to decision makers and stakeholders [42]. However, the contexts of urban living labs, as well as frontrunner cities and regions, are designed to provide flexible governance conditions, supportive decision makers, and policy instruments [43], hence scarcely representing the complicated real-life contexts of practice [39]. Furthermore, working with limited and scattered case studies, and often only at the local and municipal level, increases the difficulties to spread the gained knowledge to other contexts and scales, rising the issues related to planning silos [44,45]. This overlaps with the fact that the policy instruments for NBS implementation are mainly restricted to the municipal level (i.e., focusing on urban planning [46]) and not to the landscape, country or higher levels [47]. So far, the processes to mainstream and institutionalize NBS into national policy are still not clear, and this concept, with its huge potential, is suffering multiple incorporation difficulties as already observed for other environmental concepts (e.g., ecosystem services) [45].

Given the planned investments to reach global and European targets (e.g., RRP) as well as the high NBS capacity to help in this path, there is still a need to enhance knowledge regarding the NBS inclusion at national and regional policy levels [16,48]. It is necessary to urgently strengthen policy frameworks at the national level [49] to enhance NBS multifunctionality in favor of climate mitigation and adaptation, biodiversity conservation and human well-being as a whole [12,44,48,50]. Therefore, as economic instruments are usually recognized as enablers for a successful NBS uptake [51], taking benefit from the investments related to the recovery from the pandemic crisis is probably the once-in-a-lifetime opportunity to systematically introduce NBS in the member states policy framework.

In this work, we explored if member states have seized this opportunity by analyzing how the role of nature is embedded in the narrative of RRP documents, and how NBS are framed as an investment to foster the climate transition. Narrative and discourse analysis have been applied to other environmental policies, processes, or plans [52] to assess the embeddedness of particular topics since different narrative approaches can influence decision making and knowledge production [37]. Particularly, we focused on two case studies, Italy and Portugal. Both countries are heavily impacted by climate change and are studied by several projects focusing on NBS and related approaches (e.g., H2020, LIFE). Firstly, we conducted a discourse analysis based on two stages. A quantitative analysis to collect different nature-related words included in both the RRPs, classifying them into four different categories of terms. After that, we conducted a qualitative analysis to understand the way NBS are included in the text and how they are translated into actions, interventions as well as investments. Finally, we presented a comparative analysis between the two member states, highlighting the current state, pros, cons, possible ways forward, and future challenges.

2. Background

Description of the Recovery and Resilience Plans in Italy and Portugal

The recovery and resilience plans (RRPs) aim to mitigate the economic and social impact of the coronavirus pandemic and to enhance EU sustainability, resilience, as well as its ability to face climatic and digital transitions' challenges. The EU regulation sets six major areas of intervention (pillars) on which all RRPs have to focus: green transition; digital transformation; economic cohesion, productivity, and competitiveness; social and territorial cohesion; health, economic, social, and institutional resilience; and policies for the next generation. The green transition pillar derives directly from the Green Deal and thus shares the dual goal of achieving a reduction in greenhouse gas emissions of 55% compared to the 1990 scenario by 2030 and, in turn, to achieve climate neutrality by 2050. The regulation of the NGEU stipulates that (*i*) at least 37% of planned investment and reform should support climate goals, and (*ii*) all the investments and reforms must respect the principle of "do no significant harm" to the environment [1].

The RRP is, in each member state, a reform plan mainly based on fostering economic growth and increasing job opportunities. The guidelines for the development of RRP identify under the name of "Components" the areas where aggregate investments and the respective reforms to reach specific objectives. In accordance, the investment lines need to be matched to a reform strategy aimed at improving the regulatory and legal conditions of the context and to steadily increase the country's equity, efficiency, and competitiveness. Each Component reflects reforms and investment priorities in the area of intervention to address specific challenges by building a coherent package of complementary measures.

The expected economic growth in terms of gross domestic product is similar between the two countries analyzed. Both countries start with a growth in the gross domestic product of 1.5%, expected to lift to 2.5% in Italy and to 2.4% in Portugal, by 2026, employing economic resources about 12 times higher in Italy than Portugal. The expected economic growth is up to 240,000 and 50,000 new jobs, respectively.

The Italian RRP is organized into 16 Components, in turn comprising 63 reforms and 163 investments, financing a total of EUR 191.5 billion. The Components and the respective reforms and investments are grouped into six missions: digitalization (40.3 billion) ecological transition (59.5 billion), sustainable mobility (25.4 billion), research and education (30.9 billion), social cohesion and inclusion (19.9 billion), and health (15.6 billion). The ecological transition takes the highest percentage of the total funding program with respect to the other missions [53].

The Portuguese RRP is organized into 20 Components that, in turn, comprise 37 reforms and 83 investments, financing a total of EUR 16.6 billion. The Components and the respective reforms and investments are grouped in three structuring dimensions: resilience (11.1 billion), climate transition (3 billion), and digital transition (2.5 billion). Both the transitions—climate and digital—represent 33% of the total funding program, while the remaining resources are dedicated to the resilience dimension, which encompasses the aspect of social vulnerabilities, economic and territorial resilience [54].

3. Materials and Methods

The methodology used in this work is based on a discourse analysis [52] conducted in both the original RRPs. In our understanding of discourse analysis, discourses are defined as "socio-cultural meaning structures identified through general characteristics of text, speech or the symbolic aspect of actions" [52]. Narratives are instead adopted by different stakeholders (e.g., policymakers, NGOs, and research institutes) to frame and legitimize their work associated with or adapted to a certain discourse [55]. In our work, we divided the discourse analysis into two different steps, quantitative and qualitative. Firstly, we conducted a content analysis of the RRPs considering different nature-related terms and we grouped them into four categories, Biophysical elements (I), General environmental concepts (II), Threats and challenges (III), and NBS (IV). Grouping the terms into categories was instrumental, as nature can be framed in the narrative of policies according to different aspects and functions, which is reinforced by the growing use of discourse analysis to study environmental challenges in policy topics [52]. As visible in Table 1, in category I, we considered the most common biophysical elements (e.g., tree). In category II, we considered the concepts that are usually included in the policy narratives (e.g., the environment in a broader meaning) but not associated with physical elements or established solutions. Particularly, some of the concepts that have become hegemonic in the policy discourse (e.g., resilience and sustainability) by functioning as a linguistic political mechanism, despite their frequent decoupling from objectives, indicators, and outcomes in policy achievement, from environmental conservation to social equity [56]. In category III, we considered threats and environmental challenges (e.g., climate change, biodiversity loss) that can be potentially addressed by NBS or related approaches (e.g., green infrastructure, urban forests), as already proposed in the literature [57]. Lastly, in category IV, we considered approaches and methods that conceptualize nature as a solution to face multiple challenges (e.g., urban forestry); thus, we considered them under the umbrella of NBS. In accordance with this classification, quantitative analysis is performed as an instrumental step to help understand the overall term frequency patterns shown in both documents and then employed to orientate the qualitative step by focusing on the relationship between specific groups of terms. Accordingly, in the qualitative step, we aim to investigate if nature is framed as a solution to meet the socio-economic and environmental challenges mentioned in the text and if traditional approaches (e.g., brown infrastructure [58], grey interventions [59]) are envisaged to address the challenges. In line with the aim of this work, we thus focused the qualitative analysis only on the last two categories, i.e., threats and challenges, and NBS. Through a coding process, we investigated the relationship between terms included in the threats and challenges category with terms included in the NBS category, selected in the quantitative step. To perform both the steps of the analysis, we used the Atlas.Ti (version 8.3), a software used in social science research that assists in both the qualitative and quantitative steps of the research (for a detailed review of the software, please see [60]).

Table 1. Coded terms and associated words, aggregated into four categories, "biophysical elements"—category I, "general environmental concepts" related to environment and ecological transition (hereafter "general environmental concepts")—category II, "threats and challenges" potentially addressed by NBS (hereafter "threats and challenges")—category III, and "different ecosystem-based approaches" (hereafter "NBS")—category IV. The use of the "*" at the end of the word accounted for both the plural and all the related words.

	Terms
Category I Biophysical elements	Tree* Air Territor* | Land Water | Wetland* | Irrigation* Soil Ecosystem* Biodiversity | Habitat* | Specie* Riparia* Forest* Agroecologic* Sea | Marin* | Coastal
Category II General environmental concepts	Natural Capital Circular Economy Green* Climate Transition | Green transition Ecological Transition Unsustainab* Resilie* Sustain* Resist* Natur* Ecologi*
Category III Threats and challenges	Climate change* Land take | Soil sealing | Urbaniz* Pollut* Biodiversity loss | Ecosystem fragmentation | Habitat fragmentation Hydrological risk | Landslide risk | Floods Drought Heat Island | Thermic stress | Heat wave Desertifi* Energy efficiency
Category IV Nature-based solutions	Ecological Network* | Ecological Connect* Natural Park* | National Park* | Protected/Natural area* | Marine area* Nature/Ecosystems/Biodiversity/Landscape conservation Ecological/Natural/Environmental restoration Ecosystem based approach* Ecosystem service* Renatur* Nature based solution* Blue Infrastructure* Green/Ecological Corridor* | Green Infrastructure Natural engineering solution* | Bioclimatic architecture solution* Permeab* Urban Forest* Forestation* | Reforestation | Afforestation | Forestry Green area* | Green space* | Garden*

3.1. Quantitative Step

First, we conducted a preliminary analysis of both RRPs in the original languages (i.e., Italian and Portuguese) to identify and collect all nature-related terms enclosed in the documents (please see Table S1 in the Supplementary Materials; the terms are selected in both original languages). In addition, through a grey literature review, we identified challenges and threats related to climate change that can be addressed by NBS [41] and collected them along the texts. In total, we found 46 different nature-related terms and grouped them into four categories able to explain the different roles and relationships with nature, namely "biophysical elements", "general environmental concepts" related to environment and ecological transition (hereafter "general environmental concepts"), "threats and challenges" potentially addressed by NBS (hereafter "threats and challenges"), and "different ecosystem-based approaches" (hereafter "NBS"). Specifically, Table 1 shows the 46 entries derived from the content analysis and classified according to the four categories. When necessary, for some terms, we also considered other associated words, i.e., both plural and singular (expressed in the table with the *) as well as the synonymous or close meanings, e.g., Heat Island* | Thermal stress | Heatwave* (Table 1). All the words identified (i.e., singular, plural, synonymous) were associated and coded as a single term (i.e., each of the 46 entries in Table 1) through the Autocoding tool included in the software Atlas.Ti (version 8.3) [60]. The search was conducted using the same principles of searching as in the scientific databases; the use of the "*" at the end of the search accounted for all the related words, e.g., "ecologi*" accounted for "ecological", "ecologically", etc. Hence, all the words selected for each entry of the table were counted as references and assigned to the respective term. In this way, we built a database with the number of references per term shown throughout the document. During the Autocoding process, we excluded the words that were not related to the meaning in the search, e.g., when the word "nature" is presented as "the nature of the problem", the word "nature" was excluded from the counting as it is not relevant with the meaning of our interest. The number of references for each term was then (*i*) summed up under each category to analyze the relative percentage of the category out of the total words of the document and (*ii*) analyzed as the relative percentage out of the total references counted in the document. These metrics allow us to discuss and compare the different RRPs in both absolute and relative terms.

3.2. Qualitative Step

In the qualitative step, we focused our attention on the terms included in the category of threats and challenges (III) and NBS (IV) identified in the quantitative step. We considered NBS, according to Eggermont et al. [61], as follows: Type 1 NBS, no or minimal intervention in ecosystems for maintaining ecosystem services supply (e.g., protected areas and conservation measures); Type 2, management approaches for improving the ecosystem services supply compared to what would be obtained with a more conventional intervention (e.g., multifunctional agricultural and forests management); and Type 3, creating new ecosystems (e.g., green roofs). For each of the terms included in the threats and challenges category, we thus investigated when they are addressed by NBS (i.e., Type 1, 2, 3) or by a traditional or grey approach (i.e., absence of NBS). We used an open coding approach to assess how the categories of threats and challenges (III) and NBS (IV) were framed in the policy discourse and then used an axial coding approach to relate the two categories and understand if and how NBS are being considered to address the challenges (for the different coding approaches please see [62]). Exploring the relationship between the terms in these two categories we proposed a critical reflection, inspired by critical discourse analysis and eco-linguistic, regarding the capacity of the government to seize the opportunity to include NBS to foster the climate transition and meet the challenges presented in the two policy documents (for further applications of critical discourse analysis in environmental and policy discourse see [63,64]).

4. Results

4.1. Quantitative Analysis

Of the 46 terms analyzed in both the RRPs, in the Italian RRP, we found 1410 references out of 111,178 total words of the whole document (1.27%), while in the Portuguese RRP, we found 1505 references out of the 127,171 words of the whole document (1.18%). All the categories show a frequency below 1% in both documents, with a similar pattern in both countries (Figure 1). Italy shows a higher relative frequency than Portugal in categories II, III, and IV (i.e., general environmental concepts, threats and challenges, and NBS, respectively) while only in category I (i.e., biophysical elements) was this ratio is reversed. The most frequent category is general environmental concepts (II), with, respectively, 0.67% and 0.58%, in Italy and Portugal, followed by the biophysical elements with, respectively, 0.45% and 0.49%, the threats and challenges with, respectively, 0.11% and 0.10%, and lastly, the NBS with values lower than, respectively, 0.04% and 0.01%.

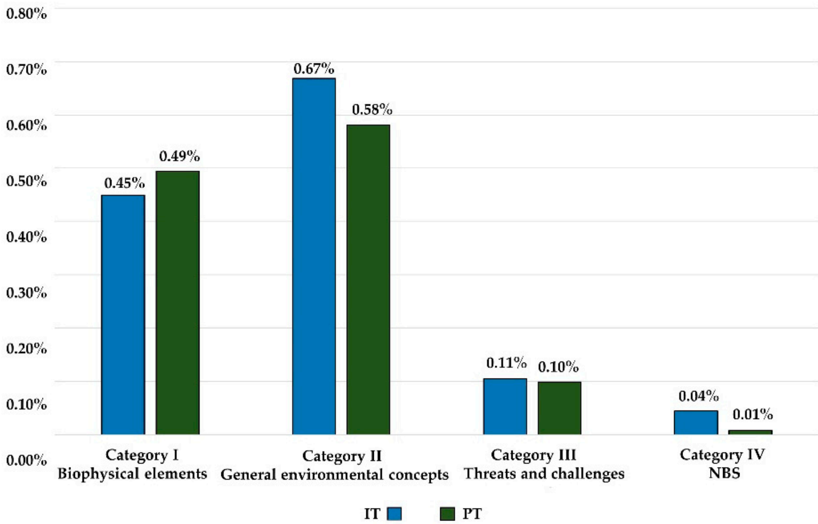

Figure 1. Frequency (%) of each category in the text of both resilience and recovery plans presented as the percentage of terms by the total amount of words in each document.

In Italy, the 46 coded terms show 1410 references throughout the document, with clear differences in their frequency among the four considered categories (Figure 2). Particularly, in category I (total 500 references), all the terms show at least one reference in the text. For ease of reading and exposure, we present the results referring to the first word for each entry (Table 1). The two most used terms are territory (i.e., 236 references) and water (i.e., 131), followed by biodiversity (i.e., 43) and ecosystem* (i.e., 34). In category II (total 733 references), the most frequent term is resilience (i.e., 337), followed by sustainability (i.e., 154) and green (i.e., 93), and ecology (i.e., 52). Climate transition, unsustainability, and resistance are terms completely absent in the Italian RRP. In category III (tot 117 references), all the terms show at least one reference, and the most frequent is energy efficiency (i.e., 46), followed by pollution (i.e., 25) and climate change (i.e., 23). In category IV, (total 50 references), the most frequent terms are gardens and green areas (i.e., 14), protected areas (i.e., 10), followed by restoration, nature conservation, renaturalization, reforestation, urban forest and ecosystem services. References to nature-based solutions, green infrastructure, blue infrastructure, naturalistic engineering, and permeability are absent.

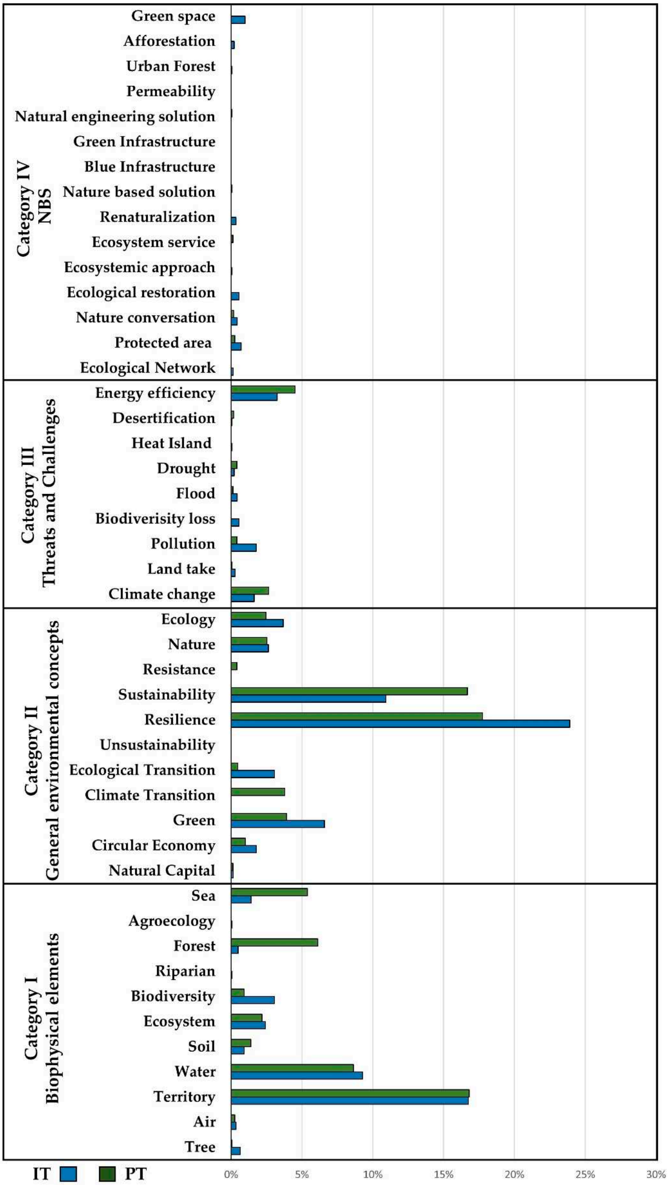

Figure 2. Relative frequency (%) of terms in the text of both national resilience and recovery plans, presented as the percentage of terms by the total amount of coded terms. We reported only the first word of the coded terms, for the complete list please refer to Table 1.

In Portugal, the 46 coded terms show 1505 references throughout the document, with a similar relative distribution frequency in four categories compared to the Italian results. In this country, particularly, in category I (total 629 references), territory and water are confirmed as the two most frequent terms (253 and 130, respectively), followed by forest (i.e., 92) and sea (i.e., 81), while riparian and agro-ecology are absent. In category II (total 739 references), resilience and sustainability are confirmed as the two most frequent of the category (267 and 251, respectively), followed by green and climate transition (59 and 57, respectively). Analogously to the Italian RRP, the concept of unsustainability is absent. Category III (total 126 references) is composed mainly of energy efficiency and climate change (68 and 40, respectively), while the other terms coded as challenges appear in the text less than six times, with habitat fragmentation and heatwaves absent. Considering category IV (total 11 references), the terms protected areas, natural conservation, ecosystem service, NBS, and ecological engineering appear less than five times.

4.2. Qualitative Analysis: The Role of Nature in the Narratives and Investments Envisaged to Meet the Challenges

Following the quantitative analyses, and considering the previous results, we explored across the documents how the threats and challenges presented in both plans (117 references for Italy and 126 for Portugal) were envisaged to be addressed and the respective mitigation role of the NBS mentioned (50 references for Italy and 11 for Portugal). We found that the inclusion of nature takes different meanings and roles in the policy narrative (e.g., nature as a resource, as hazard, etc.) and in the investments to tackle the challenges. Particularly, both plans included conservation and protection approaches (NBS Type 1) as well as management action (NBS Type 2) to face threats and challenges, while only the Italian plan includes and invests in NBS Type 3 (i.e., building new ecosystems). However, we found that the policy responses to the threats and challenges considered in the work are still mainly oriented toward conventional approaches or grey infrastructures (i.e., the absence of specific references to NBS in the texts). This is also confirmed by the fact that the investments to foster the ecological and climate transitions (Mission 2 in Italy and Dimension 2 in Portugal) are largely dedicated to mitigation measures (i.e., decreasing the emissions of industries and transports, decarbonization strategies), while poor emphasis is paid to adaptation measures in both policy narratives. Indeed, in the area of climate reforms and investments, Italy's major challenges include strengthening the energy efficiency of buildings (about EUR 15 billion), improving the management of waste and water resources (about EUR 12 billion), as well sustainable mobility (about EUR 35 billion). Similarly, Portugal's challenges include strengthening the energy efficiency of buildings (EUR 610 million) and sustainable mobility (EUR 967 million), as well as diversifying energy sources, hydrogen and decarbonization of the industries (EUR 1 billion summing up the two investments).

Accordingly, energy efficiency stands in both plans as the most referenced challenge to be addressed to foster the ecological and climate transition and fight climate change. Italy planned to increase the energy efficiency of buildings and facilities, particularly on farms and agricultural enterprises (Mission 2 Component 1; investment 2.2; hereafter, all the Italian investments are reported in the following short form, M2C1; i2.2), school and judicial buildings, as well as private buildings (M2C3; i1.1, i1.2, i2.1), reaching a potential surface of intervention of about 40 million m^2, and investing in total about EUR 15.3 billion. There is no mention to NBS or related approaches, despite the document proposed specifically structural works (e.g., thermal insulation, solar or photovoltaic panels). Similarly, Portugal also proponed structural interventions aimed at reducing emissions and energy expenditure with an overall investment of EUR 610 million (Component 13; hereafter, all the Portuguese investments are reported in the following short form, C13), explicitly referring to the possibility of NBS inclusion such as green roofs or, more generally, bioclimatic architectural solutions without envisaging any investment.

Among the other challenges here considered, large investments were dedicated to water management. In both RRPs, they are articulated to both face flood vulnerability (referenced six and two times, Italy and Portugal, respectively) and water scarcity, i.e., drought (three and six times, respectively). Nature takes the double meaning of hazard and biophysical resource to be preserved, being scarcely considered as a solution to actively address water management in an explicit manner. In the Italian document, the conservation, monitoring, and requalification of the territory are framed as possible strategies to mitigate the flood and hydrogeological vulnerability, providing investment up to EUR 2.5 billion (M2C4; i2.1). On the other hand, water scarcity is mainly addressed through investments in new grey infrastructure and traditional interventions, investing in Italy EUR 2 billion (M2C4; 4.1) and in Portugal EUR 390 million (C9).

Similarly, also in the investments dedicated to the sea and coastal areas, nature is conceptualized as a resource to be preserved and restored, but the narrative of the two RRPs shows different objectives. On one hand, the Italian plan recognizes the importance of the challenges related to sea-level rise as a cause of marine and biodiversity loss. Therefore, the protection and sustainable management of marine natural capital and restoration of coastal areas are mentioned in two different investments with a total of EUR 670 million (M2C4; i3.5 with EUR 400 million plus M3C2; i1.1 with EUR 270 million). On the other hand, in the Portuguese plan, the sea and coastal areas are mainly framed as an economic asset, and the narrative is embedded in terms such as "sea economy" or "sea potentialities", thus dedicating most of the investment to enhancing the sea and coastal-related economy (C10—EUR 252 million).

Both countries identified the integrated management of croplands and forests as crucial to preserve cultural and natural heritage and enhance job opportunities, but even in this case, the narrative of the documents is oriented to emphasize different objectives and aspects between countries. In the Italian RRP, the investment is oriented to foster the sustainable use of environmental resources (e.g., timber production), encourage "slow tourism" [65], and the energy autonomy of mountain and rural communities (Green Communities project, M2C1; i3.2 with EUR 140 million). Particularly, in Italy, these territories are referred as "inner areas" [66], and they are already subject to specific national policies and investments aiming to reduce the socio-economic gap with cities through enhancing a more sustainable and bio-based economy [67,68]. In the Portuguese RRP, an entire Component and related investments (C8—EUR 615 million) are dedicated to forests. However, the investment objective is mainly oriented to forests' management to increase the resistance and resilience to wildfire, framed as the main threat to Portuguese forests. Accordingly, the investments and reforms are mainly focused on the importance of the risk prevention for the population and biodiversity. Furthermore, the document refers to silviculture actions as a way to enlarge the portion of managed areas, increasing productivity and economic opportunities. Nonetheless, the Portuguese document explicitly recognizes the role of forest management to improve the potential of forests as a carbon sink, emphasizing their mitigation potential, also including the conservation and enhancement of biodiversity and natural capital to ensure the ecosystem services supply.

Analogously, the protection and enhancement of natural and cultural capital are identified in the Italian plan as an opportunity to foster culture and tourism without increasing threats related to land take and urbanization. In this regard, an intervention is planned to restore and requalify 5000 Italian historical parks and gardens in urban and peri-urban contexts (14 references) (M1C3; i2.3 with EUR 300 million allocated). The narrative related to this investment thus recognizes not only the cultural and social value of gardens, but also their importance in increasing ecosystem services supply can, in turn, improve human health and well-being.

The narrative of the Italian document builds an even more specific and explicit language, recognizing the value of restoring vulnerable ecosystems (e.g., riparian) and strengthening the ecological connectivity with new ecosystems to mitigate pollution, reducing hydrogeological risk, and fighting habitat fragmentation, pollution, and degradation. The investment of EUR 360 million (M2C4; i3.3) thus includes the ecological restoration of one of the most degraded, fragmented, and polluted areas in Italy (i.e., Po 'valley), providing for widespread renaturation interventions along all the ecological corridor (i.e., 1500 ha). Similarly, the investment related to the enhancement of urban green areas (M2C4; i3.1) provides EUR 330 million for urban forestry interventions, specifically planting 6.6 million new trees in the 14 Italian metropolitan cities for mitigating pollution in densely inhabited areas.

As opposed to the Italian RRP, in the Portuguese one, we could not find any measures clearly referring to the construction of new ecosystems (i.e., Type 3). Therefore, any measure is comparable to the renaturation or to the implementation of urban forests, as envisaged in the Italian RRP. Except for the unique reference to the possible NBS implementation to promote energy efficiency in residential areas (i.e., green roofs), the inclusion of nature in urban contexts is absent from the Portuguese RRP. The absence of terms encountered in the quantitative step, e.g., green spaces, green and blue infrastructures, confirms that nature is conceptualized in the Portuguese policy narrative mainly as elements belonging to the rural areas and not framed as a solution to tackle the urban challenges. Accordingly, urbanization, habitat fragmentation, and heat islands, challenges usually related to urban contexts, are absent in the Portuguese RRP. Furthermore, the threat of pollution is scarcely mentioned (six references), focusing only on a reduction in sources of pollutants. Besides the unique reference to prevent pollution in the sea, we could not find any other relation between nature and pollution nor investments that use nature as a way to deal with pollution issues.

5. Discussion

The RRP aims to promote a robust recovery of the economies achieving climate neutrality by 2050 and reducing greenhouse gas emissions by 55% compared to the 1990 scenario by 2030. The regulation of the NextGenerationEU required at least 37% of planned investment and reform to reach climate goals. Hepburn et al. [69] analyzed 300 global rescue and recovery policies from COVID-19 highlighting that the packages seeking synergies between economic and climate goals have better prospects for increasing national wealth, by enhancing productive, social, physical, and natural capital [69]. Following this logic, the former statement suggests that all EU member states might be considered on the right track, regarding both the expected economic growth and climate goals the EU set.

The environmental threats considered in this paper are all directly or indirectly correlated with the challenges of climate change and could be faced with NBS. We thus excluded other challenges that may be addressed in the literature by NBS, such as public health and social cohesion [28,70,71], as they cannot be limitedly associated with the causes and effects of climate change. As a consequence of our analysis, which focused on both policy discourse and allocated investments, we can state that NBS do not represent the main policy narrative in RRPs to respond to the environmental threats and challenges associated with climate change. Indeed, both plans identified the improvement of energy efficiency and renewable energy, and the decarbonization of industry and transport as the most relevant levers for reaching the climate goals, mainly financing interventions for reducing greenhouse gas emissions. However, even if measures to limit the temperature increase to 1.5 °C will be successful, some impacts will continue to increase due to climate system feedback and inertia (e.g., sea-level rise) [13,38]. According to Hepburn et al. [69], "natural capital investments for ecosystem resilience and regeneration including restoration of carbon-rich habitats and climate-friendly agriculture" stands as one of five policies with the highest potential on both economic multiplier and climate impact metrics. Notwithstanding, the NBS implementation to foster climate adaptation remains a neglected measure in both documents as well as their use to foster mitigation is scarcely mentioned and funded, even though NBS proved highly efficient for both measures [25,72] in the context of different initiatives and projects [42]. Italy and Portugal currently stand among the countries showing more literature related to NBS [45]. Although this research effort, the scientific outcomes have probably struggled to be translated into the policy narrative of the RRP, especially in Portugal. However, within RRP framework, the Italian Government has funded two new research Centers specifically aiming to increase sustainability in urban contexts—even establishing and upscaling NBS—namely the Sustainable Mobility Center and the National Biodiversity Future Center, with a total amount of about EUR 640 million [73]. This confirms the awareness of policymakers on the pivotal role of research in this sector.

5.1. Comparative Analysis of the Discourses

Both member states analyzed in this work show in their discourses a strong focus on ecological transition and green revolution (Italy) and climate transition (Portugal), with a dedicated section in the RRP (Mission 2 and Dimension 2, respectively). In the Italian RRP, the term climatic transition is excluded from the discourse. In the Portuguese RRP, three concepts of transitions appear related to environmental issues, namely climate transition, ecological transition, and green transition, which often appear linked, thus hindering the possibility to assert different meanings to each. As already shown in the literature, a variety of approaches to conceptualize transition appear in policy that often overlap, while being also distinct and divergent in their approaches and scopes [74]. We thus highlight how the absence of a clear definition of these concepts increases their mixed-use, and ambiguous meaning, complicating the policy discourse and the attribution of specific targets to foster the transition. Furthermore, these two missions alone do not reach the 37% of budget required by the EU for climate objectives (31% for Italy, 18% for Portugal). In both plans, other contributions are diffused and spread in other missions and dimensions to accomplish the climate targets, further increasing the confusion about terms, objectives and investments. Nevertheless, in the Italian document, Mission 2 (M2—ecological transition and green revolution) covers the largest portion of investments (59.5 billion euros out of 191.5 billion invested in the plan) which considers decarbonization, and nature protection and management as complementary aspects for fostering the ecologic transition and the green revolution. Portugal, on the other hand, adopts a different strategy differentiating the management of the territory into the resilience dimension (C8 and C9—Forests and Hydric management) from the dimension dedicated to climate transition (D2), which steers the investments exclusively to the reduction in greenhouse gases emissions, the increase in renewable energy sources, and the reduction in primary energy use. This division is probably due to the conceptualization of forest management mainly oriented to fight wildfires and, similarly, water management to fight water scarcity, thus neglecting the inclusion of NBS in fostering climate transition.

The lack of clarity and specific targets can be also confirmed by the results of the quantitative analysis. The narrative of both documents is framed around the terms included in general environmental concepts, showing the highest frequency (0.67%, 0.58%, in Italy and Portugal, respectively) with respect to the other categories, biophysical elements (0.45%, 0.49%), threats and challenges (0.11%, 0.10%), and lastly, NBS (0.04%, 0.01%). In addition to the concepts of climate and ecological transitions previously mentioned, among the general environmental concepts coded we found the terms with the highest relative frequency out of the coded terms, i.e., resilience, sustainability and green. These terms display their functions as a linguistic and ideological political mechanism often disconnected from specific objectives and outcomes. As illustrated by Tahvilzadeh et al. [56], "Sustainability discourse did not make any effective climate or environmental protection policies possible, nor did it have clout enough to combat rampant social inequalities". Analogously, the narrative of "green" can raise some contradictory interpretations [75]. In the PRRs, most of the references to the term "green" are not related to NBS, such as green infrastructure, green space or green area, but instead are referred to as an eco-friendly behavior or approach, e.g., "green economy", "green transition" "green communities" or "green islands". Given the heterogeneity and multiple interpretations, all these narratives, on the one hand, can serve multiple discourses (e.g., sustainable development and de-growth; [55]), but on the other hand, can overshadow ecological safeguarding and social equity concerns [56].

As shown in Figure 2, the terms classified in the NBS category are the least referenced in the text. Among these, both countries show higher references for NBS Type 1 and 2, i.e., nature conservation and management as well as different typologies of parks and protected areas. In Italy, these actions are mentioned within different investments across the document, recognizing the value of nature as a resource to be protected or restored (further details in the results section). Portugal dedicates a Component to increasing the management of forests and in turn the resilience to wildfires. Despite biodiversity conservation and enhancement of natural capital are considered as an objective of this component, no mention to the maintenance of native forest is made. The absence of this reference can be significant given that the Portuguese's forests ecosystems are strongly threatened by alien species, e.g., eucalyptus [76], and appropriate silvicultural measures applied to native forest can help in improving their resistance to alien species invasions [77]. Furthermore, forests are mainly conceptualized in the document as an element of the rural areas, thus neglecting the urban dimension.

Considering NBS Type 3, Portugal fails in the allocation of specific investments and interventions, listing only green roofs and NBS among the possible approaches to improve the energy efficiency of buildings. Although there is no reference in the text regarding nature-based solutions, green and blue infrastructures, and ecologic engineering, Italy foresees two important forestry interventions such as the plantation of 6.6 million trees in the 14 metropolitan cities and the ecological restoration of riparian ecosystems of the Po' valley. In the Italian history up to the mid-1970s, numerous reforestation interventions in mountainous and rural areas have already been experimented, with laws, funding, and large-scale implementations aimed to regulate runoff, preventing soil erosion and landslides (for further information see [78]). The two investments envisaged in RRP together are close to EUR 700 million, representing one of the largest structural investments ever allocated in terms of NBS implementation in Italy in recent decades. However, we highlight that, despite the huge investment in absolute terms, this represents in relative terms approximately 0.36% of the total investments envisaged in the Italian RRP (EUR 191.5 billion), and that an extra budget dedicated to other Italian cities could have helped to mitigate other environmental challenges and extend their effects to critical areas out of the major cities [49]. The different approach to urban forests between the two countries might be explained by the differences in research interest between Mediterranean countries found and described by Krajter Ostoić et al. [79]. Accordingly, Italy stands as the leading scientific force in the thematic of urban forests implementation, especially for the air pollution mitigation [79]. In addition, Italy already experimented the inclusion of urban forests in the political context (i.e., Decree on Climate, 2019) allocating EUR 30 million for their implementation [49,80].

5.2. Missed and Potential Opportunities to Include Nature-Based Solutions

In both documents, we identified a series of investments that explicitly mention the value of nature as a resource to be preserved or restored, but do not yet include NBS. We believe that in these investments there may be room for possible implementations of NBS, referring to the currently available scientific literature. Among these, we certainly include water management (both flood and water scarcity) [19,59,81,82], soil restoration and water quality improvement [83,84], industrial land regeneration [2,85], wastewater management [86], coastal protection [87], biomass crops for sustainable biofuel production [88], and energy efficiency [89,90].

Under the Green Deal, the EU already invited all member states to reach specific environmental targets across different action plans (e.g., circular economy and zero pollution), strategies (e.g., Forestry and Biodiversity Strategy to 2030) and laws (e.g., European climate law), to improve the quality of ecosystems and human life in the next decade [2]. Considering the link between the Green Deal and the RRP, we found that these environmental targets were not fully included in the investments and reforms in the analyzed documents. It could be argued that the RRP is not the proper document to include considerations and actions related to the protection, management and/or implementation of nature, given that RRPs are reform plans primarily providing investments to recover and increase the economic growth of the member states. However, the term 'nature-positive economy' has recently emerged in the context of sustainable business and finance [55], and the vital role of NBS in this economic shift has been presented in a recent EU report [4]. The latter profiles "some of the economic activities where nature-based enterprises are engaged in the delivery of NBS—generating new jobs, innovations, skills, and wider economic impacts, achieved through a nature-based approach respecting the needs of the environment and communities". As a consequence, we argue that the RRP could have been the ideal arena to bring NBS and nature-based enterprises [91] systematically and methodically into policy and reform, not binding them only to a strategic level or constraining them into an "eco-friendly" narrative.

6. Conclusions

This article assessed the embeddedness of NBS in the recovery and resilience plans of Italy and Portugal. In the narrative of both plans, we observed the dominance of generic concepts such as resilience, sustainability and green, supported by different typologies of "transitions" to reach the climate goals set out in the Green Deal. Ecological, green and climate transitions are used within the individual document and among the documents as synonymous. Furthermore, we observed that the category of NBS and related approaches is the least frequent in both plans, and we found indicative the total lack of specific terms such as, nature-based solutions, green and blue infrastructures that are instead well-established in literature as well as in EU reports and financing initiatives. This happens although the recent EU effort to become a leader in NBS, investing in practical projects and research, providing for assessments and evaluation of NBS as well as involvement of stakeholders. Despite the several existent best practices, their outcomes are still scarcely considered and included in both RRPs.

The central aim of the documents is reducing emissions stated as mitigation measures, while adaptation measures are not central in the RRP. Italy shows two large investments, planting 6.6 million trees in the 14 metropolitan cities and the restoration of riparian ecosystems in the Po' Valley. These two investments, besides helping to fight climate change, will help in the path to reach other two important EU goals, the pledge to plant 3 billion trees by 2030, and the zero net land take by 2050. The case of Portugal is instead emblematic because it does not consider any of the other EU goals and continues to mostly limit the role of nature to its "use value" (e.g., sea economy), instead of working with it or imitating it to tackle the national challenges, according to the NBS definition [25] and in line with a "people and nature" perspective [92].

We are aware that the selection of terms and the division into categories might be considered dubious regarding its robustness, due to the lack of a rigorous approach in their definition and classification. However, we tried to reduce possible software limitations and researchers' bias for the counting and coding of terms, (*i*) working in the original language texts, (*ii*) incorporating a wide number of terms, and (*iii*) promoting complete transparency to readers by reporting (Table S1) the selection of terms in the original languages and not limiting them to their translation in Table 1.

With the results of this article, we aimed to provide a critical reflection on the missed opportunities to use nature to address multiple global challenges, not only from a protection and conservation perspective but also by directly promoting the use of NBS through the construction of new ecosystems, new enterprises and new jobs and, in turn, the promotion of a more bio-based and sustainable economy. Accordingly, we identified multiple investments in both plans that use vague language in explaining the approach planned to address some of the threats and challenges considered (e.g., restoring contaminated sites in Italy and fighting water scarcity in Portugal). In these cases, we are confident that the future research centers and open calls will face the challenges in a more specific and unambiguous way, drawing on the scientific literature to implement NBS and develop a more nature-positive path. This is of utmost importance as the RRPs aim to be the main source of reforms and funding opportunities for the next decades, thus potentially playing a crucial role in positively contributing to a transformative society and economy towards real sustainability.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land11081254/s1, Table S1: Coded terms and associated words in the original languages.

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6. Conclusions

The relevance of the framework proposed in this research thesis is not limited to the NBS application at the local scale, as already proposed in the literature, rather shows a significant impact on a wider scale (e.g., national and regional), where it helps to tackle the recurring problem of planning silos. Therefore, the developed evidence-based approach seems promising for enhancing the cost-effectiveness of funds allocation as well as their return in terms of human health and wellbeing.

On a national scale, the framework proposed here can reliably i) identify the areas showing a simultaneous demand for the achievement of multiple national targets; ii) spatially orient the new investment and interventions needed to address the environmental challenges; iii) support the NBS selection that provides more co-benefits, playing a crucial role in enhancing budget allocations efficiency; iv) identify new financing opportunities in national plans to embed nature-based approaches and economy better.

On a municipal scale, the set of NBS assessed can be used as a guideline for further specific planning and design activities based on local issues, barriers, and peculiarities, while remaining consistent with national targets.

In conclusion, the proposed multi-scale approach can help in considering different stakeholders as well as social, economic, and biophysical characteristics playing a crucial role in the benefit provision and thus claiming a better inclusion in decision-making contexts related to national, regional, city/site-scale spatial plans.

As a future perspective, this research lays the groundwork for further in-depth analysis regarding, i) the economic evaluation of NBS benefits; ii) synergies and trade-offs assessment among multiple implemented NBS; iii) NBS scenarios building and evaluation of their contribution to the ecological connectivity and biodiversity.

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