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Green and Blue Infrastructures and Nature-Based Solutions to Reduce Pollutant Emissions and Make Transitioning Urban Ecosystems More Climate Change-Adaptive

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Abstract: The growing impact of extreme weather phenomena in different areas of the globe and the empirical evidence of the economic, social and environmental damage caused by global warming, urgently, calls for appropriate responses. Urban areas are part of the planet where the greatest social costs of global warming will be paid, and so it seems very important to take on the issue of climate change adaptation in land use and urban planning. In several cities, new planning instruments and projects have been developed that highlight a profound cultural change and approach to urban planning that we have known for the last two centuries. The lack of adequate management measures concerning increasingly frequent disasters lead to environmental, economic (e.g., exposure to risks and costs associated with extreme weather events), and social impacts (e.g., health impacts related to air quality, heat islands, etc., with an increase in chronic ailments and various diseases). As recognised by Sustainable Development Goal 11 (SDG11), the United Nations (UN) New Urban Agenda and the World Forum on Urban Forests, green and blue infrastructures (GBIs) and nature-based solutions (NBSs) can reduce these impacts by promoting population health shaping as an adaptation strategy to climate change. GBIs and NBSs for the sustainability, resilience and well-being of urban communities are increasingly considered efficient strategies to mitigate climate change-dependent disasters, but they are not yet considered in a systematic way within urban planning. The paper aims to investigate the role of GBIs and NBSs in the resilience of cities and urban communities against the risks associated with the climate crisis. Furthermore, the paper suggests how GBI and NBS could be interwoven into visions, urban planning, and design to create resilient places for people and resilient community behaviours.

***Keywords*:** urban planning, climate change, urban resilience, green and blue infrastructures, nature-based solutions

1. Introduction

As a result of climate change, urban areas are increasingly experiencing negative and unpredictable effects, such as devastating weather events, the tropicalisation of rainfall, severe soil instability, scorching summers, lowering of water tables, changes in air quality, urban heat bubbles, reduction of water reserves, desertification processes, coastal erosion, etc. [1]. Urban planning has a role in preventing these effects at whatever scale is involved. Therefore, both at the level of urban design and integrated policies in urban plans, climate-conscious choices can be made. The stress and

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impacts resulting from climate change and rapid urbanisation require that adaptation become a priority in urban policies [2-4]. Several European urban experiences inspired by the concepts of degrowth, improved resource management to reduce the impacts of climate change at the local level, the diffusion of more sustainable lifestyles through the search for practical solutions that are shared as much as possible within communities, and the introduction of more efficient and environmentally effective management practices are models to follow to create resilient cities. Climate change mitigation strategies for energy-efficient cities are also a significant challenge for urban planning as a global discipline [5-7].

From the very beginning, the climate has been a major focus of sustainable urban development policies. The urban carbon dioxide (CO_2) emission reduction plans launched by the International Council for Local Environmental Initiatives (ICLEI) in 1991 and the 'Cities for Climate Protection Campaign' organised by the United Nations Environment Programme (UNEP) from 1993 onward marked the beginning of awareness raising on this issue. 150 cities were involved, 60 of them in Europe, and the first climate plans were drawn up in 13 cities that set themselves the target of a 25% reduction in CO_2 emissions to be achieved between 1990 and 2005. In 2000, the European Commission launched the first climate change programme, and in 2005 the second. In 2007, the Leipzig Charter on Sustainable European Cities and the following years the Green Paper on Territorial Cohesion marked further important steps in this direction. Among the international and European conferences organised by ICLEI are 'The Assembly of Mayors on Climate Change' (Amsterdam, 1993), 'How to Fight Global Warming at the Local Level?' organised in cooperation with the Organisation for Economic Co-operation and Development (OECD) and the European Commission [8], 'The Second Mayors' Summit on Climate Change' (Berlin, 1995), and the growing interest and involvement of municipalities in mitigation and adaptation to change that also led to the creation of international and regional climate-related partnerships and networks over the last two decades. Cities work together in these networks to share experiences and develop common goals. In addition to pioneering examples such as the ICLEI [9], Climate Alliance, Energy Cities, C40 Cities Climate Leadership, and Covenant of Mayors, this is happening concretely with the establishment in 2014 of the Mayors Adapt [8]. In Italy, the drafting of the 'Charter of the Commitments of the Cities and Territories of Italy for the Climate' and the 'Covenant of Mayors' for greater energy efficiency and mitigation of the effects of climate change, which engage municipalities on climate change and provide support for the implementation of adaptation actions at the local level and to which 300 Italian municipalities have adhered, represent very important steps in this direction.

Following the input of the European Union (EU) Climate Adaptation Strategy [10], many governments and organisations at the national and regional levels have already developed policy and legislative frameworks to support cities in implementing appropriate adaptation measures to current climate change. The EU Strategy calls on Member States to undertake cost-effective and rapid adaptation actions as these will be less costly than repairing the damage caused by climate change (estimates show that every euro spent on flood protection would save us six euros in damage). One of the objectives of the European Strategy is to promote the adoption by Member States of national, regional and local adaptation strategies and plans; this is being implemented with the recent development by European governments of National Climate Change Adaptation Strategies (NCCAS).

Although many climate adaptation measures have been gradually implemented at different scales in recent decades, some issues remain unresolved:

- Which successful examples to draw inspiration from to adapt urban dynamics to make cities less vulnerable to climate change and less likely to generate pollution and greenhouse gases?
- Which best practices should inspire the formulation of specific green and blue infrastructures (GBIs) and nature-based solutions (NBSs) actions to be considered in urban climate change adaptation plans and policies?

Leaving aside useless theorising, it is necessary to start by identifying the factors that determine the responsiveness of urban societies to global environmental risks, such as those related to climate change. The capacity to respond also depends on the perception of the risks and their social acceptability, elements that vary greatly depending on the stakeholders, the interests represented, and the territorial scale of reference. It is also necessary to formulate working tracks and proposals to contribute to the emergence of renewed adaptation and mitigation strategies aimed at increasing urban resilience. Local sustainable development policies that have succeeded in producing concrete effects are very rare. In the face of this situation, there is a clear need to rethink the settlement system adaptively to changing climatic conditions, implementing decision-making processes that go beyond the traditional objective of reducing the vulnerability levels of exposed elements, and instead aim to enhance the resilience characteristics of the built environment as a whole, in the interest of citizens and economic development.

2. Importance of GBI in cities

Accommodating about half of the world's population, more than 70% of greenhouse gas emissions are generated in cities. However, cities are also the places most vulnerable to the effects of climate change [2, 11]. To think that the urban impact of climate change, as far as issues of heavy rainfall or high temperatures are concerned, is attributable to climate change is wrong. However, the impact that these phenomena can have on cities adds to the vulnerabilities already present in cities, which become prone to heat islands as well as heat waves, which are continental phenomena, but because cities are mostly characterised by soils with very low permeability, rainfall has the greatest impacts. So, it is not all attributable to climate change, but climate change has amplified some important impacts of these events on urban areas. Cities are therefore particularly susceptible to increasing risks from climate change and the resulting extreme events, not only due to the increased exposure of population and assets but also due to the limited ability to combat the impacts of extreme events [12, 13]. Also, the presence of many mineral materials we find in cities has its albedo, i.e., the colours of the materials interact with solar radiation in a more or less positive way from the point of view of reflecting this radiation or vice versa for trapping heat. The same urban morphology can hinder the passage of air in the city, and thus a lot of hot air and also many pollutants can be trapped [14]. Land use that shapes the urban form, which is considered an effective approach for adaptation to climate impacts, is also crucial [15]. The presence or absence of vacant soils and the presence of urban vegetation is, in fact, always rather low, as is the presence of water bodies or watercourses, and the human activities that take place in cities generate heat through emissions from cooling systems, which have a great impact during the summer season. Green infrastructure, such as wetlands and green spaces, for example, plays a strongly positive role in flood adaptation [16]. Materials in the city also play an important role because they behave differently: a very dark-coloured material, such as asphalt or porphyry, raises the temperatures present, while the materials that remain cooler are the more natural ones, such as lawn or drainage paving, or light-coloured materials. But our historic cities are often characterised by very dark paving, and this aspect combined with the vertical variation, i.e., the elevations of buildings that are often characterised by a fairly dark colour and therefore with a low albedo and with a limited distance between buildings, exacerbates the problem. The height of the buildings is very important for the solar radiation that hits these walls, which is characterised by multiple reflections and ends up being trapped, keeping these materials warm as well, whereas the more we move towards a less dense city model, the more solar radiation can enter, but dissipation also takes place at night; therefore, there is a situation where heat can be dissipated and the city manages to cool down a little. Consequently, the intensification of heat waves due to global warming will be exacerbated in urban areas when combined with urban heat island (UHI) effects, causing dramatic negative public health effects [17, 18].

In urban areas, GBI and NBS can reduce these impacts by promoting population health modelling as an adaptation strategy to climate change. GBIs are defined as 'the network of natural and semi-natural areas and the network of water bodies, including rivers, canals, lakes and coastal areas that provide ecosystem services in and around cities' [19]. NBSs are defined as 'measures that use or mimic natural processes or utilise natural elements to address social challenges related to climate change' [20].

A combination of GBI and NBS can provide multiple benefits for urban resilience, including reducing flood risk, improving air and water quality, and enhancing biodiversity, as well as providing co-benefits for urban residents, such as increased access to green spaces and recreational opportunities [21].

Different types of NBS and GBI have been proposed or implemented in urban areas, such as green roofs, green walls, urban wetlands, and rainwater harvesting systems [22]. GBI and NBS are increasingly recognised as crucial components of urban ecosystems, particularly when cities face the twin crises of climate change and degradation of environmental quality.

In urban planning, discussions tend towards the immediate, biophysical or economic benefits of GBIs and NBSs, including flood and heat control [23, 24], air quality improvement [25], stormwater control and management [26, 27], carbon capture and climate change mitigation [28].

Several authors [29] argue that GBIs and NBSs can be a valuable approach to improving the resilience of cities to climate change, but that there is a lack of robust and consistent assessment of the effectiveness of NBSs and GBIs in urban areas, so further research is needed to fully understand their potential and develop effective implementation strategies. They also suggest that there is a need for further research on the social and economic aspects of NBS, such as the costs and benefits of implementation and potential barriers to adoption.

Finally, if properly integrated, GBI and NBS could be essential tools for environmental justice and equity in the urban environment, along with climate change mitigation, economic risk reduction and ecological protection. GBI and NBS, therefore, represent a concrete possibility for urban planners and policymakers who through their use, in addition to responding to looming environmental threats, could also respond to disparities that create socio-ecological vulnerability and inhibit resilience [30-32].

With a view to more resilient urban systems, NCCAS and the EU [33] suggest actions and technical solutions based on NBS and GBI, with an ecosystem approach aimed at encouraging and incentivising innovative interventions based on increasing GBI and NBS through the provision of ecosystem services it entails [34]. In addition to these, many other documents emphasise that a prior study for climate resilience, including a review of good practices already implemented in other contexts as well as an assessment of the vulnerability of urban settlement to future climate change, is indispensable for the identification of priority areas for action on climate adaptation and the formulation of adaptation strategies modelled on the actual needs of each place. A survey of the main good practices for climate change adaptation in cities cannot be separated from the integration of the concepts of resilience, ecosystem services, vulnerability to the effects of change and social cohesion.

On this last aspect, starting from the study of the literature on the subject, this article proposes a methodological pathway that provides answers to this need through the examination of some case studies, from which precise indications emerge on priority actions for intervention and the need to formulate general plans for GBI and NBS.

3. Materials and methods

The methodology with which the research was carried out aims to explore the topic of how GBI and NBS can bring benefits in the contexts in which they are applied to climate adaptation and to offer a cognitive approach based on case studies. The aim is to describe contextual situations and the application of these solutions. The descriptive-correlational empirical investigation is developed on two levels:

- First, the descriptive level aims to provide an accurate and faithful representation of what is happening;
- A further level, correlational, seeks to establish how what happens relates to certain dimensions (variables).

After reviewing the existing literature on the benefits of using GBI and NBS in more detail, we tried to find out how GBI and NBS operate by framing them within real-world contexts and situations; we also tried to describe the effects (visible and less visible) in real-world contexts of specific interventions and to study in terms of benefits how a specific intervention adopting GBI or/and NBS causes or does not cause the desired effects. In particular, sustainable energy supply policies, programmes, and urban plans incorporating GBI and NBS and concrete measures to reduce CO_2 emissions are highlighted, and their benefits in terms of economic savings are evaluated.

The case study aims to describe the best practices developed and to understand the complex structure of relationships that identify and characterise the case itself in its unique and unrepeatable specificity, and only secondarily to use the empirical evidence gathered to shed light on the effectiveness of adopting GBI- and NBS-based solutions for climate change risk mitigation in cities.

To describe the case studies, taking into account the complexity of the concrete situation as much as possible, a holistic approach has been adopted, which aims to consider the case in its unique and unrepeatable complexity, i.e., as a system whose behaviour is determined by the behaviour of individual subsystems. In this sense, for example, the social effects on local actors, the inhabitants, and local political action are assessed.

The data collection techniques used in case studies are varied and are qualitative and quantitative in nature. Data analysis strategies favour longitudinal and ecological analyses of the data. The study was based on a cross-sectional literature review survey among sample cities. Secondary data was derived from relevant library data collected from published and unpublished books, journal articles, government documents, and websites. The literature reviewed focused on the reduction of pollutant emissions through the use of GBI and NBS for climate adaptation. The validity of the assertions produced by the case studies is confirmed by triangulation processes, i.e., data on the same factors in different times, contexts, and situations. When all the data collected lead to essentially the same conclusions, they are valid data and identify good practices to be adopted.

Finally, a research database based on multiple data sources is constructed, which allows the possibility of inter-subjective control of the research procedures. The database contains all the data and materials collected and the annotations, descriptions, and interpretations that are deemed relevant to shedding light on the problem in question (i.e., documents, observation reports, interviews, questionnaires, field notes, photographs, or audio-visual materials, etc.) and are appropriately annotated, organised in a form that is as comprehensible as possible, and structured in such a way that they can be easily consulted to assess the empirical evidence of the research.

The main objective of the research is to develop a framework that could be used by various local governments to find solutions in terms of addressing challenges incorporating climate resilience.

The nature of the aim, objectives, and research questions led to the choice of holistic multiple case studies as the most appropriate research strategy.

3.1 *Study areas*

This study focuses on the approaches to climate change mitigation and adaptation in cities that are very different in terms of size, socioeconomic context, and geography. The areas studied include several German and Scandinavian cities.

Regarding the choice of case studies in more detail, the cities considered were selected from those that have been on the road to climate sustainability for some time now (the 1990s) by putting GBI and NBS into practice, and thus it was possible to monitor the benefits of the solutions adopted over time through the relevant literature. In addition, the selected cities provide a fairly comprehensive and complete picture as they have different characteristics and sizes. For the selection of cities, preference was given to those that have developed plans to reduce CO_2 emissions.

The policies and interventions experimented with in cities with a view to sustainability, in line with international objectives, have favourably declined the use of GBIs and NBSs along four lines of action: climate policies, eco-building, ‘sustainable’ mobility, and planning, which is the most complex objective. Communities that systematically adopt all four of these registers are rare. The study areas that were selected have implemented specific initiatives in all four of these registers in their respective contexts.

Initiatives are more random in terms of opportunities and suffer from strong political fragmentation. Mitigation choices and measures are determined by the social, political and economic circumstances of each city and driven by the local emphasis on climate change issues rather than by the criterion of their potential effectiveness.

4. Results of the case study survey

Many cities, especially in Germany and Austria, have developed urban plans to reduce CO_2 emissions. Other cities, such as those of the Swedish Climate Cities Network, are more ambitious and have set themselves the goal of becoming ‘fossil-free cities’ through the use of biomass energy and energy decentralisation.

This section tends to present the benefits and advantages learned from examining case studies that have adopted GBI- and NBS-based solutions to reduce pollutant emissions as effective pilot actions that can be contemplated within urban climate change adaptation plans.

As climate change has a strong impact on the ecosystem and urban areas, any city or municipality is at risk of natural disasters (including more frequent and severe flooding, sea-level rise, storms, landslides, and water and food insecurity). Local governments must be prepared to meet the challenges through forward-looking and resilience-oriented spatial planning. Through the examination of the following case studies, the research offers insights into challenges and opportunities for addressing climate resilience measures, such as mainstreaming climate change adaptation.

The research evaluates and analyses the capacity of local governments in the various cities taken as case studies to incorporate climate resilience into the spatial planning process.

Since the research does not seek to observe the changes and development of a phenomenon over some time, from the point of view of the time horizon, but takes into account the benefits to date, it is consequently regarded as a cross-sectional study.

The city of Vaxjo was the first in 1996 to vote unanimously in the city council on the first local policy programme to abandon fossil energy by 2050 to reduce the human impact on climate change. To date, half of the city's energy expenditure and consumption are based on renewable energy, including mobility, and it has officially reduced carbon monoxide emissions by 35%, aiming to become a zero-emission municipality.

The programme integrates various instruments such as the use of biomass for district heating and electricity generation, private dissemination of bio-mass appliances, low-consumption street lighting, low-consumption buildings, solar panels, bicycle lanes, wooden houses, ethanol cars, free parking spaces for non-polluting vehicles, a biomass-fuelled power plant with wood chips and waste wood from the many surrounding sawmills, etc. On the whole, urban CO_2 reduction plans have made it possible to introduce renewable energy in cities and improve the energy efficiency of buildings, but they have not fulfilled their promises, except for a few pilot communities. It is extremely difficult to reduce CO_2 emissions by 25% in ten years when energy consumption increases (air conditioning, house size, high mobility, etc.). Nevertheless, these plans had the merit of making local actors responsible for climate change and began to demarcate the registers of political action. While prospects are open in the field of habitat, emissions related to passenger and freight traffic are steadily increasing and represent the most sensitive field of political action [35].

Another field of action concerns eco-building, where the energy issue remains central. Indeed, the design and use of the built environment are key issues in mitigating climate change. Buildings account for 40% of final energy consumption in the EU [36]. Many metropolises have built low-carbon neighbourhoods that pursue energy autonomy for tens of thousands of inhabitants. The neighbourhoods built in Hanover, Malmo, and Stockholm show that it is possible to run a neighbourhood with renewable energy and draw very little fossil energy if micro-combined heat and power (CHP) plants are built [37]. The Kronsberg district in Hanover has shown that the reduction of CO_2 emissions in the residential and tertiary sectors depends more on energy decentralisation than on replacing one energy source with another. In addition to the fact that this district emits 75% less CO_2 than a conventional new district, Hanover has built 90 CHP microplants for its heat network and extended the Krosnsberg energy standards to new buildings [38]. These measures have social repercussions, as they reduce costs for the inhabitants. In addition, the Kronsberg district in Hanover has devised a rainwater collection system, reused for the sanitary sewers of schools and private homes, developed with a dense drainage system that includes, among other things, 11 km of ditches, through which water from streets, private gardens, and gutters is recovered. These neighbourhoods built in the second half of the 1990s are prototypes to be inspired by because the ecology of these neighbourhoods responds to global environmental concerns (climate, ecological footprint, and biodiversity) by seeking a quality of life based on a renewed relationship with nature and re-establishing relative density to curb urban sprawl. As in the case of the district of Västra Hamnen in the city of Malmö, where energy-saving housing saves one-third of the costs and devices to purify water with the help of plants represent the biggest challenge this city has faced in managing wastewater purification, in a country where the sludge produced in the purification process must meet strict quality standards to be used as fertiliser in agriculture [39]. In Stockholm's Hammarby Sjöstad district, water is the main source of energy. Biomass, biogas, solar panels, hydrogen, and a hydroelectric power plant provide the more than 8,000 flats with almost total coverage of their energy needs. Hammarby Sjöstad has a closed-loop recycling system in which the inhabitants "contribute" up to 50% of the energy needed simply by producing waste, while the remaining 50% comes from other clean sources: solar panels, water and wind power plants. All domestic wastewater in the neighbourhood is piped into huge underground cisterns where, through appropriate treatment, the wastewater forms biogas that is immediately reused in the kitchens of the buildings themselves, while the solid residues are subsequently collected and turned into fertiliser [40].

Other cities have conducted eco-neighbourhood experiments with less ambitious environmental goals but reaffirmed social mixes. Scandinavian metropolises, such as Stockholm, Malmo or Helsinki, have prioritised environmental and ecosystem performance, perhaps because ecological rehabilitation of the social habitat has become a parallel practice [41].

While most German or Dutch neighbourhoods have understood sustainability as strongly integrated into a social mix, Dutch cities, for example, have generalised the integration of sustainable development into new construction as part of the Vierde Nota over de Ruimtelijke Ordening Extra (VINEX) lan, implementing the 4th Netherlands Development and Spatial Planning Report (1993-2005) and seeking a strong reduction in costs; this has reduced sustainability to a small number of parameters: outdoor rainwater management, soft mobility, energy efficiency, and biodiversity. In France and Italy, environmental quality and eco-conditionality in construction and redevelopment are gradually becoming established, but with very variable effects from one operation to another [42].

The final section addresses sustainable mobility and planning. In cities, a whole series of policies, such as parking regulation, increased public transport supply, promotion and planning of soft, non-motorised travel, and car-sharing, have been implemented to govern growth and stabilise car use, where the demand for motorised private mobility is increasing because urban life is structured at the scale of the urban region. The issue of transportation is often combined with that of urban planning. Hence, it is necessary to prevent, contain, and extinguish urban sprawl by intervening in the spatial structure of settlements. European experiences show that space is a resource that can be economised. Short-distance cities, urban densification and compaction, the mix of functions, polycentrism, green trams, support for peri-urban agriculture, biodiversity corridors: all these policies are applied here and there without globally reversing trends. An example of this is the Nancystrasse district in Karlsruhe, Germany, where the basic idea was to design a car-free urban district by adopting alternative mobility systems: train, tram, bus, car-sharing, taxi, bicycle and walking. The district, composed of buildings that use solar energy, has a biomass-fuelled cogeneration plant to cover its electricity needs. To save water, there are vacuum toilets in the houses. The little wastewater is purified in a phyto-purification plant. Or the city of Stockholm, where the first hydrogen cars and 160 ethanol buses were introduced [43, 44].

The experiences show that there is a need for increasingly strategic planning based on the sustainability, energy, and climate resilience of territories, with actions aimed at reducing the vulnerability of territorial systems and the population, while also assessing potential risks. But there is also, and above all, the need for urban governance based on attention to climate change, which is expressed through the management of services related to traffic and buildings, through sustainable energy supply policies (renewable energy, alternative fuels, low fossil energy consumption, etc.), through the use of social 'good practices' with communities, and in a vision of developing joint actions by local administrations with businesses, civil society actors, and inhabitants.

5. Conclusions

In the face of growing concerns about climate change, many cities have taken action, seeking to develop innovative policies and actions to respond to the problem, while others follow a more conventional approach. Cities have included a wide range of instruments in their urban and spatial planning for climate change mitigation and adaptation, ranging from climate policy making (in many urban sectors such as the built environment, transportation, water and waste management, energy use, green systems, waste management, etc.) to institutional capacity building (participation in the development of climate policies, new policies, and actions to address climate change, as well as participation in international and national climate alliances and networks, the launch of new departments within municipalities, etc., and climate-sensitive urban design). By these means, they can play a significant role in reducing greenhouse gas emissions [45, 46].

Some cities have achieved structural results by reducing CO_2 emissions by more than 20% in ten years, e.g., Heidelberg, Vaxjo, Malmo, Stockholm, etc., by building neighbourhoods where the energy supply falls entirely on renewable energies. These experiences respond to a strong local political will in contexts of advanced decentralisation, but most cities are only able to make partial progress because they lack the strength to make their policies coherent and suffer from a strong lack of capacity to work across the board. Achieving sustainability requires a very long learning process with never immediate results. These solutions offer a strategic scenario, potentially replicable in other contexts, to be tested and adapted in practice according to the technical and sociocultural issues that condition their acceptance by the community.

The methodological approach proposed in this paper aims to provide the basis for the formulation of urban plans that adopt GBIs and NBSs to enable significant adaptation to climate change. These practices, already adopted in many contexts as demonstrated in this paper, can be quantitatively evaluated in terms of their effects and benefits for each intervention and represent the breakthrough strategy to increase the resilience of the urban system.

A case study of good practices can thus be formulated from the case studies. However, the levels of action vary widely. The level of involvement and progress of cities differs across countries. Several factors underlie the different levels of involvement of municipalities [47-51], including local competencies and capacities in the areas of climate policy, availability of financial resources, framing of local issues and priorities, presence of scientific information on local climate conditions, willingness, and membership in climate-related networks and alliances.

Therefore, integrating climate resilience into land-use management requires a more radical rethinking of land-use control mechanisms, control policies, and action plans.

Conflict of interest

There is no conflict of interest in this study.

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