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OPINION PAPER

Nature-Based Solutions as a Tool in the New Circular Economic Model for Climate Change Adaptation

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Abstract

While our modern global society enjoys the benefits of an economic growth that was never seen before, at the same time, it is facing the existential threat of climate change. We now realize that the linear economic model cannot sustain our life standards indefinitely. A new circular approach is already suggested that will adjust our priorities and re-orient future infrastructure investments. In this context, we look back to nature to find the solutions we need to increase the resiliency of our societies, to protect and restore the ecosystems, and to maintain the necessary economic growth without further undermining the planet's boundaries. Nature-based solutions serve exactly this ambitious and multi-factorial purpose due to their inherent ability not only to tackle climate change but also to provide a series of ecosystems services and social benefits. This opinion paper discusses the potential of nature-based solutions to stimulate a circular model of economic growth, their contribution to new circular strategies for climate change adaptation, the various benefits of such concepts, and the key actions needed to increase the awareness and attract more investments on nature-based approaches in the near future.

Keywords Green infrastructure · Nature-based solutions · Economic growth · Sustainable development · Climate change adaptation · Climate change mitigation · Greenhouse gas emissions · Ecosystem services

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The Global Environment Crisis

We are living in a world that is changing at a pace that the planet and the human history have never seen before. Many have already adopted a more direct term for this change referring to it as the environmental crisis or climate crisis. The Intergovernmental Panel on Climate Change (IPCC) reports that the global climate change will cause irreversible harm to humans, the built environment, and the biosphere [1]. The water cycle (global and regional) will be significantly affected and water variability is already increasing; some regions experience frequent extreme precipitation and flooding events and others suffer from extended droughts, while such extreme events may appear in the same region in a short time. Flooding and erosion incidents are further exacerbated by the destruction of the natural mangrove forests that protect the shoreline. An unprecedented loss, if we consider that mangrove forests can store more than 1000 tons of carbon per hectare [2], is a unique contribution to climate change mitigation. At the same time, biodiversity loss is proceeding so fast that some wild species could be lost forever, along with wild forests, grasslands, and other habitats that sustained them.

The reasons for this global situation are more or less known though the debate is still ongoing. The global development was and is still based on the linear economic model, in which raw natural resources are taken, transformed into products, and get disposed of. This development model led of course to some positive results. Within the last 30 years, the share of the population in developing regions living in extreme poverty (i.e., under $1.25 a day) was reduced to half and the prospects to end extreme poverty within the next 10–15 years have never been so promising [3]. This is achieved due to a consistently large mass of people leaving the extreme poverty level every year and a sufficient consumption growth to carry many of these individuals across the poverty threshold. It is thus important to have a "legal framework with the aim of transforming our common inhabitation of the planet from a system of exploitation to a system of stewardship of the Earth System through a process of self-organization to manage its use" [4].

On the other hand, this linear economic model (i.e., "take-make-use-waste") is considered responsible for the current climate crisis. The resource use index perfectly integrates the global outcome of this economic model; as Fig. 1 shows, we cannot continue this course as the rate we consume the planet's resources far exceeds the planetary boundaries.

The Era of Circular Economy

An alternative model has already been proposed, that of a circular economy, which is designed to minimize not only the resource input but also the waste and emission production. The Ellen MacArthur Foundation, a leading think tank on circular economy, defines it as an "industrial system that is regenerative and restorative by design, rethinks products and services to design out waste and negative impacts, and builds economic, social and natural capital". Circular economy aims at the maximum efficiency in the use of finite resources, the wider use of renewable resources, the recovery of materials and products at the end of their useful life, and the regeneration of natural systems [5]. Circular economy strategies hold the key to a resource-efficient, low-carbon, and inclusive future. Essentially, circular economy target is to improve the way we meet our current needs but through the use of less raw materials and natural resources and the reduction of the environmental impacts such as greenhouse gas emissions. The gap to cover through circular economy interventions and strategies is indeed huge: today, more than 80 billion tons of materials per year is extracted, but only 7% is reused or recycled [6, 7], while material management in the global economy accounts for an estimated two-thirds

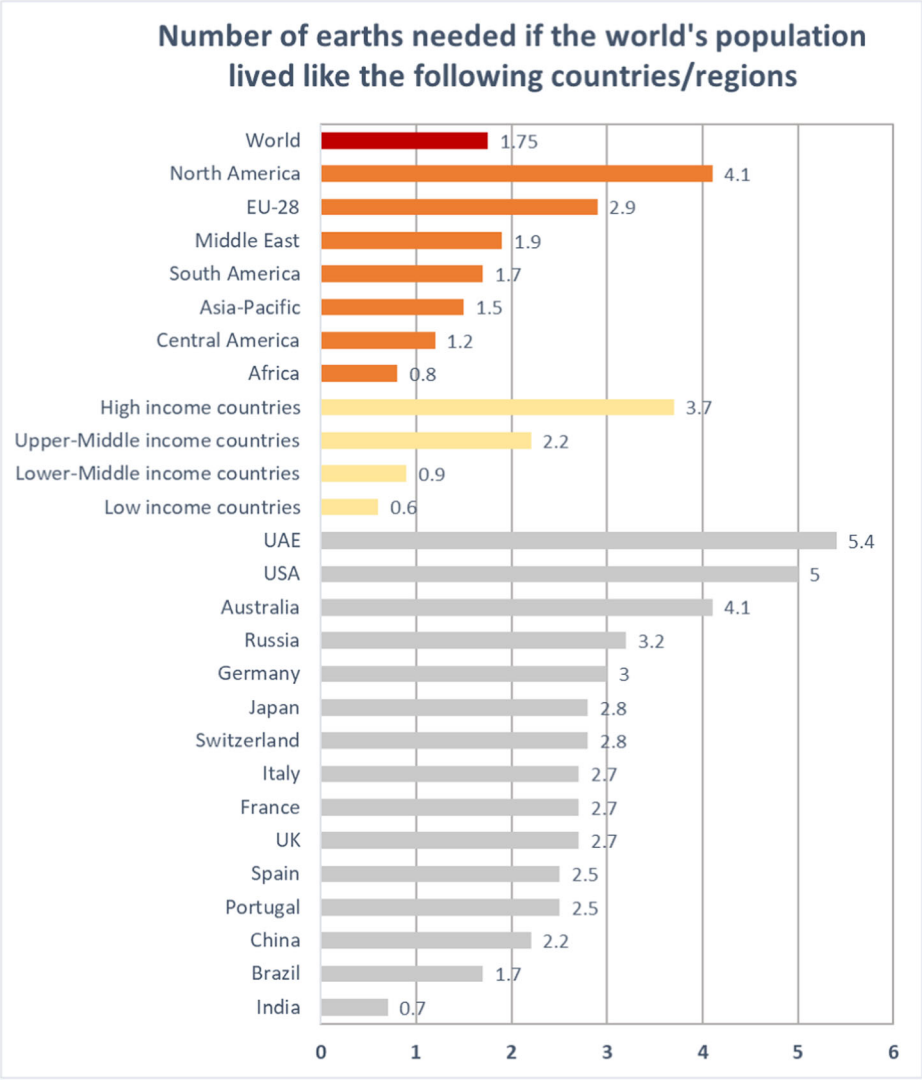

Fig. 1 How many Earths do we really need based on our current economic model. Source: Global Footprint Network National Footprint Accounts 2021 (https://www.overshootday.org/annual-report-2021)

of the global emissions [8]. Moreover, it is estimated that 3928 km^3 of freshwater is annually withdrawn, of which 56% is released back to the environment as largely untreated wastewater, thus resulting in considerable degradation of aquatic ecosystems and water resources [8]. Hence, circular economy has the potential to significantly contribute to climate change mitigation by improving material management, dematerialization, decarbonization, and systematic change with long-term prospects.

Moreover, the circular economy offers incredible potential; it is reported that circular economy strategies have the potential to reduce the global emissions by 39% [9], indicating the crucial role and the necessity of the circular transition to achieve the goal of the Paris Agreement. Another published report estimates that the circular economy could close

approximately half of the emission gap between current policies and the 1.5 °C target set by Paris Agreement [10]. Thus, it is clear that much bolder actions and stronger commitments are necessary to transform business models and market frameworks.

There seems to be a growing consensus regarding the necessity and the urgency for the transition to a circular economy in order to tackle climate change–related risks, but different stakeholders, business, government, and the civil society still need to better and more effectively coordinate their actions and work together in order to accelerate the necessary changes. However, the circularity index of the global economy dropped from 9.1% in 2018 to just 8.6% in 2020, indicating that the situation is practically stagnant if not even worse [9].

This means that we need to change not only the way we act but most importantly the way we think. The new circular approach calls for solutions that will contribute to the move towards constant climate adaptation, a decisive response to the major global environmental problem. And not only this. Even aggressive decarbonization of the major carbon-contributing sectors will not be enough to reach the targets of the Paris Agreement, since the greenhouse gas concentrations in the atmosphere are already at critical levels. This means that there is another challenge, but also an opportunity, for the industry and the business sectors to go beyond their limited scope and support carbon removal and storage actions such as the protection and restoration of natural land and water ecosystems. In simple words, emission reduction is only the one side of the coin, the other being the increase of the carbon absorption capacity by nature-based systems.

Implementing Green Infrastructure

In the battle to reach this target, green infrastructure has a critical role to play. Green infrastructure is defined by its capacity to provide a series of ecosystem services through a strategically planned network of high-quality green spaces that can further boost resilience [11]. Climate change and infrastructure development make disaster-prone areas more vulnerable to extreme weather events and natural disasters (e.g., floods, landslides, forest fires) that cause loss of life and result in billions of euros of damage. Green infrastructure solutions or also known as nature-based solutions (NBS) can, however, limit the impacts of such events on human society and the environment and support the wider vision of circular economy for increased resilience and effectively addressing the challenges posed by climate change. NBS can act as complementary interventions to the decarbonization of sectors' operations by neutralizing emissions that businesses and enterprises cannot eliminate due to technological barriers. In this sense, evidence-based outcomes already highlight that NBS can facilitate the transition to circular economy, not only through a more sustainable management of resources but also by providing additional benefits and ecosystem services.

Defining Nature-Based Solutions

The concept or, better, the philosophy of NBS is based on what is called biomimicry, i.e., the process where we learn from, inspire by, and copy nature. The fundamental requirement for NBS to work effectively is first to understand the natural environment and the natural processes in order to harness the power of ecosystems and the sophistication of nature as infrastructure to provide natural services to benefit society and the environment and to turn environmental, social, and economic challenges into innovation opportunities. In this view,

NBS are distinct concepts than nature-derived solutions, i.e., wind, wave, and solar energy derived from nature, which help fulfil our low carbon energy needs through production methods deriving from natural sources but are not directly based on functioning ecosystems. NBS use the features of complex natural system processes, e.g., the ability to store carbon and regulate water flow, in order to achieve the expected and desired outcomes. Therefore, NBS can also be a key factor for well-being, life quality, prosperity, biodiversity, green growth, social and economic sustainability, and of course environmental sustainability [12–14].

At the 2016 World Conservation Congress and members' assembly, the International Union for Conservation of Nature's (IUCN) members adopted a resolution (WCC-2016-Res-069-EN) that defined for the first time the use NBS as "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (available at https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_069_EN.pdf). A simple NBS example to better understand their concept is the construction of permeable pavements to reduce the flood risk or green roofs to improve the biodiversity and cooling/heating energy demand in cities.

NBS have been described as an effective framework to tackle and reverse global environmental issues such as biodiversity loss, ecological restoration, and natural resources degradation [15] on the basis of a set of best practice principles concerning climate change, disaster risk, water security, food security, human health, and socio-economic development.

Another definition is given by the European Commission as viewed from a social aspect of NBS implementation: "Nature-based solutions to societal challenges are solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions. Nature-based solutions must benefit biodiversity and support the delivery of a range of ecosystem services" [16].

Nature-Based Solutions as a New Tool for Economic Growth

A widely used argument discusses that there are already broad and well-established links between building infrastructure and economic development; hence, it is only reasonable to further enhance these existing links to deal with global environmental issues. However, before any decision is taken on the future investments for the installation of new or the upgrade of existing infrastructure, we should consider the following three main challenges:

A. Today, 55% of the world's population is living in cities, a figure which is projected to rise to 68% by 2050, according to the UN [17]. Although population growth rates vary by world region, in Europe, this figure is already reaching 72%. Projections show that ongoing urbanization combined with the continuous growth of the world's population could add another 2.5 billion people to urban areas by 2050, with almost 90% of this increase taking place in Asia and Africa. As the urban population grows, many countries will face challenges in meeting the needs for housing, transportation, energy systems, water supply, sanitation, and other infrastructure. This means that only a new sustainable urbanization strategy and a new framework of urban development would meet the 2030 Agenda for Sustainable Development [18–20].

B. Many countries, especially in the developed world, are already facing the gradual aging of existing infrastructure such as roads, energy grids, pipelines, and water and wastewater management [21]. Aging infrastructure needs continuous follow-up and maintenance, while deteriorating structures start failing as they approach the end of their lifecycle, causing accidents, injuries, fatalities, large property damages, etc. Moreover, as climate change is progressing, an additional pressure is put on existing infrastructure. In Europe and North America where many infrastructures were installed 40–60 years ago, there is an increasing need for repair, replacement, and management improvement to support the population growth and the continuous urbanization. This means that future investments in public infrastructure should be re-oriented towards sustainable and green solutions. This is also the case for cities in the developing world which are under even higher pressure for new infrastructure.
C. As climate change is progressing, its impact will become more and more apparent. Desertification, sea level rise, mean temperature increase, frequency, and intensity of extreme events will further increase the risk and the pressure on existing infrastructure [21].

These basic challenges of the present and the near future cannot be addressed with the current conventional approach of simply expanding grey infrastructure using non-renewable materials (e.g., concrete, stone, asphalt) and increasing the impervious surface coverage in the urban environment. We now have evidence that such practices enhance the urban heat island effects, increase the flooding risk as they disturb the natural water cycle, and negatively affect human mental health and general welfare due to the lack of urban green spaces [22]. Hence, the selection of the proper infrastructure solutions to invest becomes today more and more crucial for both developed and developing countries. In fact, considering that developing countries and emerging markets were growing faster than the developed ones, at least up to the pre-pandemic era [23], the orientation of the future economic growth might be more relevant for the developing world. The global economic success and the associated long-term environmental impacts will impact the economic growth in the near future, which in turn will impact the types of infrastructure built and operated.

In addition, climate change is already challenging the sustainability of the current economic growth model. Infrastructures that add more carbon into the atmosphere will eventually undermine the growth of the economies, and poor decisions in water and land-use infrastructure will not meet the adaptation needs particularly important for the developing countries. At the same time, investment decisions for major infrastructures (i.e., which sectors will receive funding) that are currently being made will determine the ability of developing countries to achieve their growth targets and development aspirations while avoiding the catastrophic results of climate change [24]. Therefore, the new challenge ahead is to identify solutions that will enable funding and investment into infrastructure that supports sustainable growth, despite the misperception that this would be more costly upfront.

This is why upgrading and/or replacing existing infrastructure should follow the sustainability principles if the ultimate goal is to reach a sustainable society. Sustainable development requires that environment has a central role in the economic development and sets the wise extraction and use of natural resources as a prerequisite for economic growth and reduction of the environmental degradation [25]. There is a need to develop a wider framework for infrastructure that promotes a sustainable model of economic growth, the circular model. In this context, the adoption of green infrastructure and an integrated operation and management plan of urban infrastructures, urban water, and waste and urban green is viewed as a critical

tool for sustainable economic growth. NBS represent a crucial component in the new growth model of economies that can be applied not only in urban areas (where is probably more needed) but also in rural regions (Fig. 2). The concept of NBS can not only effectively address the climate change challenges but also increase the resilience of the ecosystems via circular economy strategies, i.e., reuse, reduce, recycle, remanufacture, and repurpose towards closing the loop of materials and energy flows and eliminating waste generation. NBS can work in a densely populated city where green areas can be built and/or created on top of the existing or new grey infrastructure, e.g., a park on top of a parking garage, or an urban garden on top of a school (Fig. 2).

Why We Need Nature-Based Solutions

NBS are developed as an alternative perspective due to the adverse environmental and social impacts associated with large-scale grey infrastructure. The European Commission identified four key areas for NBS implementation [27]: (i) supporting sustainable urbanization to stimulate economic growth and enhance human well-being, while making the urban area more attractive, (ii) restoring degraded ecosystems by improving their resilience and increasing the ecosystem services they offer, (iii) climate change adaptation and mitigation with focus on carbon storage, and (iv) improving risk management and resilience.

The starting principle of NBS is that the desired socio-economic development can be achieved in a different than the conventional way that is more sustainable and more equitable. The key here is decoupling the use of resources and the environmental impact from the economic activities by applying NBS methodologies and concepts and evaluate the circularity performance of different products, services, and systems. NBS can provide such alternative for new sustainable infrastructure in a cost-effective way while providing additional benefits and ecosystem services [28]. Such parameters are usually overlooked when implementing

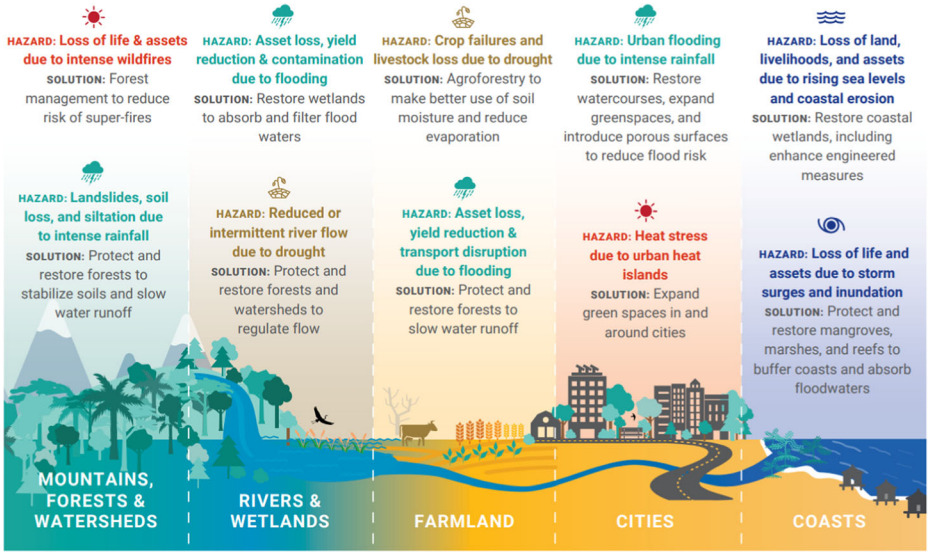

Fig. 2 How different nature-based solutions can work together across landscapes to build resilience (source: Global Commission on Adaptation, Adapt Now report [26])

traditional infrastructures and measuring infrastructure performance. NBS philosophy dictates that built infrastructure should be in balance with nature and its performance evaluation should also include efforts to minimize the adverse environmental impacts of these interventions. Such an approach could bring further positive results in diverse fields such as poverty reduction, water-food-energy security, biodiversity conservation, and climate resilience that are more equitable, efficient, and economically feasible. For example, it is reported that NBS can provide more than one-third (37%), equivalent to 11.3 billion emission tons per year, of the overall cost-effective climate solution required by 2030 to hold global warming below 2 °C [29].

As the current model of economic growth is under discussion, the first regional and transnational plans and strategies are adopted towards the transition to a circular economy (e.g., the European Circular Economy Action Plan, the establishment of eco-industrial parks in China). In these plans, NBS appear as ideal representatives of this new approach, as they not only contribute to the reduction of the carbon footprint, one of the main goals of a circular economy, but also enhance the resiliency against climate change impacts. NBS such as parks and wetlands further contribute to biodiversity and habitat creation and to a better health and well-being of the citizens living in the urban environment [12]. NBS interventions in the urban context can also improve the microclimate through shading, evaporative cooling, or wind shielding and reduce the urban heat island, thus improving the thermal comfort of people and the urban ecosystems, which further contributes to energy savings and to indirect CO_2 savings [30]. For example, it is estimated that the indirect carbon saving related to the shading and cooling effect can be more than 3 times higher than the direct carbon sequestration by the same tree [31]. Case studies have shown that such effects can be considerably high especially in hot and arid climates where the use of air conditioning is extensive; for example, a large constructed wetland treating an industrial effluent in the desert environment has been found to reduce the temperature by 10 °C at a radius of up to 1 km from its main body [32]. All these are important NBS services that significantly contribute to more resilient and circular cities but are not always considered in the decision-making process for infrastructure investment (Fig. 2).

Nature-Based Solutions as Climate Adaptation Strategy

NBS for climate change mitigation are seen primarily as measures (e.g., reforestation, forest conservation and management, agroforestry, cropland nutrient management, conservation agriculture, coastal wetland restoration, peatland conservation and restoration) that can either reduce CO_2 emissions or remove CO_2 from the atmosphere, which is why the capacity of NBS to sustain or enhance carbon storage and carbon sequestration is highly attractive within the circular economy context [16]. However, NBS can also contribute to climate mitigation through reducing energy demand. Increased thermal comfort from the scale of the single building to the neighborhood by NBS translates to reduced demand for heating and/or cooling and in turn saves energy. NBS can be used to create a conducive environment for active transport, i.e., walking and cycling routes that connect green spaces and create space for pedestrians and cyclists, thus limiting the use of cars and their associated emissions. NBS can also reduce the generation of embodied emissions in urban development and infrastructure provision by using alternative building materials than the non-renewable such as concrete and steel. An independent expert report by the European Commission analyzed several EU-funded projects that contribute to climate change mitigation through both storing and sequestering carbon and through reducing energy demand [16]. These exemplary case studies indicate the significant potential for addressing the challenge of climate change mitigation by using NBS concepts.

Of course, coupling infrastructure with nature brings a new development challenge to integrate ecosystem services and biodiversity in new plans, as also dictated by the circularity approach. In addition, an interdisciplinary knowledge and approach is now necessary to create new green infrastructure considering the multiple impacts and effects NBS can have on the environment, the economy, and the society. It should also be understood that despite the key role of NBS in climate change mitigation and adaptation, key target of a circular economy, they cannot completely substitute the use of fossil fuel and should be accompanied by urgent action to decarbonize our economies. However, the sense of urgency to scale up ecosystem-based approaches to address these pressing issues requires a wider understanding and adoption of NBS to exploit the services they provide towards not only mitigating the impacts of natural hazards and climate change but also contributing to sustainable livelihoods and therefore building resilience [26].

A recent study highlights that NBS represent the largest share of all potential solutions to climate change in more than three dozen tropical countries, while in more than 20 countries, NBS solutions would be enough to achieve carbon neutrality before 2030 [26, 33]. For example, it is estimated that 12 NBS across 79 tropical countries could cost-effectively mitigate more than 6.5 billion tons of CO_2 annually by 2030, i.e., more CO_2 emissions than the entire annual emissions of the USA, with the highest mitigation potential lying in Indonesia and Brazil, considering actions estimated to cost less than \$100/tCO_2. The biggest opportunities are avoided deforestation (2.8 billion tons CO_2 annually), reforestation (1.2 billion tons CO_2 annually), adding trees to agricultural lands (0.9 billion tons annually), avoiding degradation of peat soils (0.6 billion tons annually), and improving the management of natural forests (0.5 billion tons annually). These figures take into account only the climate change benefits of protecting and restoring ecosystems, before even considering the benefits for local people, biodiversity, habitat, livelihoods, health, water, and agriculture. Furthermore, Asia is identified as the region with the greatest potential for NBS, with 2.4 billion tons of CO_2 annually in 2030, followed by Latin America (2.3 billion tons) and Africa (1.9 billion tons) [34]. In addition, NBS represent more than 50% of the total national greenhouse gas emissions in 38 countries, making them the largest than all other mitigation options combined. This means that by increasing ecosystem-based carbon sinks, many countries such as Costa Rica, Kenya, or Liberia could become fully carbon neutral, or even net carbon negative, by 2030.

A recent report by the UN Environment Programme (UNEP) revealed that conserving 30% of land in strategic locations around the world could safeguard 500 gigatonnes of carbon stored in vegetation and soils, i.e., around half the world's vulnerable terrestrial carbon stocks, and reduce the extinction risk of nearly 9 out of 10 threatened terrestrial species [35]. This finding again highlights nature's key role in tackling the climate crisis, showing that conserving biodiversity and carbon stocks in priority areas is crucial to meet the ambitious goals for both nature and climate. This report also indicates the fundamental interconnections between the two crises, i.e., the climate change and biodiversity loss, and that more integrated approaches are needed to address them in our economic model. NBS actions that are based on inclusive decision-making are particularly important and necessary to effectively deal with these two global crises.

Nature-Based Solutions for Aquatic Ecosystems

Water is at the center of climate change impacts and also the key in making the change for all. This is the main message of the 2030 Agenda for Sustainable Development and the 17 Sustainable Development Goals (SDGs). SDG 6 goal is ensuring access to clean drinking

water and sanitation for all. Hence, NBS for improved water efficiency and protection and restoration of aquatic ecosystems are of particular importance.

For example, coastal wetlands protect communities from storm flooding and sea level rise. Well-managed forests can protect water supplies, reduce wildfire risk, and prevent landslides. Green space in the urban environment can reduce the heat stress and reduce the flooding intensity. Although a full accounting of this potential is still not available, it is estimated that wetland ecosystems cover approximately 8% of the planet's land surface [36, 37] providing ecosystem services, e.g., flood protection, fisheries habitat, and water purification, that are worth up to $15 trillion [38]. For example, offshore fisheries in mangrove areas provide fishermen with an average of 271 lb/h of fish (worth approximately $44 per hour), compared to an average of 40 lb (only $2-3 per hour in places without mangroves) [39].

NBS can change the way we manage our water resources, especially in the urban environment, supporting the transition to a sustainable sanitation in the new circular economy [40]. Stormwater management is a major issue in modern cities that contributes to combined sewer overflow, where municipal wastewater, urban runoff, and stormwater are collected in the same pipe that brings them to an end-of-the-pipe centralized wastewater treatment plant [41]. This often results in overloaded treatment plants and thus in flood incidents in urban areas or further re-contamination of surface water bodies and the respective damage of the receiving ecosystems [42]. Proper management of these volumes is also important to prevent damage to public infrastructure and private properties and to protect the community health and the ecosystems. NBS such as the green technology of constructed wetlands bring new alternatives in the field of decentralized urban water and wastewater management by providing effective sanitation and pollution load reduction while creating additional green spaces [25, 43–45].

Another example of effective NBS implementation is green roofs that cool the building due to the vegetation's presence, act as pollution filters, reduce the runoff that would otherwise end up in the city's sewers, and also provide an aesthetical upgrade of the surrounding environment [46], while increasing the property and community values. A characteristic example is also the so-called China's Sponge City Plan that promotes the use of soil and vegetation as part of the effective urban stormwater control strategy, rainwater harvest, water quality improvement, and ecological restoration [47]; the Shanghai government alone set a target of creating 400,000 m^2 of new green roofs.

How to Spread the Word About Nature-Based Solutions

Although the benefits of promoting NBS in the circular economy framework are well documented, as described above, there is still a gap between the fundamental understanding not only of the role of NBS as integral part of circular economy but also of the developing NBS concepts. By its definition, circular economy will change the way we use natural resources, promote the use of renewable resources, design out waste and negative impacts, and regenerate natural systems. NBS are a significant part of the toolbox to achieve these goals since their philosophy is exactly based on such principles. NBS that follow the circularity concept are viewed as enablers to the transition from linear to a circular society, as they bring new approaches and parameters such as biodiversity and ecosystem services that further support the goals of innovation for growth and job creation [48] and work towards sustainable growth and development. In a NBS-circular economy–based approach for growth and development, sustainability is based on the use of ecological materials and resources and on the

minimization of waste, emission, and energy leakage by slowing and closing energy, material, and water loops.

Despite this apparent ability of nature to provide multiple economic and climate resilience benefits, many countries are not fully utilizing NBS for adaptation, as indicated by the UN Environment Programme World Conservation Monitoring Centre [35]. Only 70 out of the 167 nationally determined contributions submitted under the Paris Agreement include NBS actions, the majority of which are in low-income countries [49]. Despite the many advantages offered by NBS for adaptation, their use is still relatively limited. Lack of awareness and/or understanding of NBS approaches, limited availability of knowledge and evidence, policy and governance challenges, limited access to funding for applying and scaling up NBS, and also technical challenges are the main barriers that hinder the wider implementation of NBS [49]. To overcome these, several steps have been proposed to promote circular nature-based adaptation actions [26, 49]:

1. Raise awareness on nature's value

Knowledge should be disseminated through collaboration and exchange of experience across different sectors to create awareness, facilitated by governments, civil society organizations, and the private sector. Governments, finance institutions, development and civil society organizations, corporate actors, research bodies, and other stakeholders should promote wider implementation of NBS for adaptation by monitoring, evaluating, and sharing experiences across sectors. The value of natural capital such as mangroves and other ecosystems and the benefits they provide should be better understood especially by policymakers. For example, it can be 2 to 5 times cheaper to restore coastal wetlands than to construct artificial barriers against sea wave erosion of the shores [50]. The median cost for mangrove restoration is about $0.01 per square foot, far less than the widely built grey infrastructure. The total net benefit of protecting mangroves globally is estimated at $1 trillion by 2030 [26]. Of course, specific assessments are needed for each region to identify the optimum opportunities and ways to utilize NBS for adaptation. The views and understanding of local people should also be taken into account in plans and relevant policies.

2. Integrate nature-based solutions into climate adaptation plans

As circular economy strategies are gradually adapted by many countries, reducing the greenhouse gas emissions is one of the key targets. NBS can play a vital role in reducing the carbon footprint, especially when used at a large scale, i.e., across ecosystems and cities, where they can be more effective. NBS concepts for adaptation are best implemented at wider scales to consider the interactions developed within and between ecosystems and the distribution of potential beneficiaries and impacts. Climate impact and vulnerability assessments should include analysis of impacts on ecosystems and the implications for people's vulnerability. For this, planning, decision-making, and action on adaptation should follow a system perspective and NBS should be part of such plans from the beginning. Such an example comes from Mexico, where the government designated protected water reserves in more than one-third of the country's river basins covering an area of 124 million acres and ensuring this way the water supply for 45 million people [26]. Similar approaches can be effectively applied in many regions. A study has shown that the conservation and restoration of upstream forests and water utilities in the world's 534 largest cities could better regulate water flows and save up to $890 million in treatment costs annually [51].

3. Encourage investment in nature-based solutions

As the new political priority of climate neutrality is already in place or in progress across the globe, circular economy and climate policies set the needs for the near future. Circular economy will require a technology push and significant investment in green technologies and climate change adaptation and mitigation plans. In this frame, for NBS to play their role in the new circular approach, financial institutions should develop new funding streams and models that can support long-term investment in NBS for adaptation, including private sector actors. Access to funding is one of the most common barriers to NBS implementation and climate adaptation actions. However, governments can attract such investments by modifying and re-orienting their policies, subsidies, and public investments and provide better incentives for private investors to finance adaptation projects, as indicated by UNEP-WCMC [49]. But again, another barrier here is the lack of awareness on the NBS use and capacities (see step 1 above). An example of such practices is Canada's public Disaster Mitigation and Adaptation Fund of $1.6 billion (available at https://www.infrastructure.gc.ca/dmaf-faac/index-eng.html) that is aimed at protecting communities from flood risks, wildfires, droughts, and other natural hazards by providing investments in both green (nature-based) and grey (built) infrastructure. This Fund recently implemented a $20 million project for the restoration of salt marsh and levee improvement along the Bay of Fundy in Nova Scotia, which will reduce coastal flooding that affect tens of thousands of people thousands of hectares of farmland [26].

4. Integrate the nature-based approach in financial conditions

Procurement, financing conditions, industry standards, and other policies should be improved to ensure that NBS are included and evaluated among the various adaptation solutions and their benefits are assessed for all options under consideration. The key is to link the current challenges with the available solutions and the existing expertise. However, only a slow shift is visible towards NBS integration, although few global financial institutions such as the World Bank and the Asian Development Bank (ADB) are increasingly including the nature-based approach in their financing conditions.

Experience has shown that the implementation of integrated NBS requires working on three main aspects, namely, science, policy, and practice [33]. Science is needed to document evidence to influence policymaking and to inform evidence-based field interventions. Moreover, to ensure community mobilization, citizen's participation, and adoption of NBS intervention, local communities should be kept involved through capacity building and engaging in project design, implementation, and monitoring.

NBS currently have considerable political traction focusing on their role as ecosystems that act as carbon sinks. However, there is a large and growing body of evidence that protected, restored, or well-managed natural or semi-natural ecosystems are essential to help people and economies adjust to and manage the negative impacts of climate change. To help increase the impact of science on the design and implementation of NBS for climate change adaptation, more and up-to-date evidence-based information needs to be supplied to the policymakers. A strengthened evidence base is a key factor to build the resilience of communities to the global warming and better communicate that the benefits provided by nature should be protected and harnessed. This is the necessity for new models, methodologies, and technologies that are currently developed considering the circular approach and evidence-based information that would prove the concept and upscaled examples and case studies to demonstrate the scalability

of the solution to strengthen and maximize the expected impacts. However, there is an identified imbalance in the geographic distribution of evidence; most studies are concentrated in the Global North, although it is the communities in the Global South that are more vulnerable to climate change impacts and could potentially gain most from the multiple NBS benefits [52]. Moreover, there is a lack of robust, site-specific investigations of the effectiveness of interventions compared to other alternatives that consider broader social and ecological outcomes [52].

The necessity and urgency to tackle climate change and the significance of NBS in doing so are also highlighted by a recent initiative by major international companies (such as Amazon, Coca Cola, Henkel, Mercedes-Benz, Microsoft, Siemens, among others) called "The Climate Pledge." The signatories call for a stronger commitment by companies to reach the net-zero carbon goal by 2040, 10 years earlier than the target-date set by Paris Agreement (2050). The group recognized the role of NBS in the decarbonization of business operations and formed a vision on the way forward based on four main principles for NBS: (1) cut emissions through increased carbon capture by NBS; (2) conserve and protect existing ecosystems such as soils, forests, grasslands, wetlands, and aquatic ecosystems; (3) be socially responsible and engage local communities; and (4) be ecologically responsible and protect biodiversity. It is noteworthy that such initiatives come from the international business sector since such companies have the power to spread the message and also set the example for the global business sectors. For example, Amazon already is the largest corporate purchaser of renewable energy, aiming at covering their operations with 100% renewables by 2025, 5 years ahead of its initial 2030 target, while the company also purchased 100,000 electric vehicles and has a vision to make 50% of shipments of net-zero carbon by 2030.

Conclusion

Nature-based solutions are facilitators towards the transition to circular economy, supporting a more sustainable management of the built environment. NBS have a broad spectrum of application in the built environment, and besides that, they can be implemented to complement the existent grey infrastructures. As it is highlighted in this study, they are considered a significant tool in a new circular economic model for climate change adaptation. They can actively contribute to the reduction of the carbon footprint by absorbing and storing CO_2 from the atmosphere. Considering their multiple benefits that go beyond climate adaptation, NBS can further establish ecosystems in the urban environment, forests, and coastal wetlands that support the economy and the society and provide fuel, food, livelihoods, critical habitat for biodiversity, health, jobs, education, and recreation benefits, and sustain cultural traditions. To stimulate greater commitment and attention to the undervalued role of nature in climate adaptation, it is necessary to better and more effectively highlight successful NBS implementation projects. The circular economy approach and targets create the necessary framework and favorable conditions to attract more investments for NBS scaling up and to further exploit the inherent potential of nature for climate adaptation and protect those most likely to be affected by climate change.

Data Availability Available upon request to the corresponding author.

Code Availability Not applicable.

Declarations

Conflict of Interest The authors declare no conflict of interest.

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