ASIAN INFRASTRUCTURE INVESTMENT BANK

ASIAN INFRASTRUCTURE FINANCE 2023

NATURE AS INFRASTRUCTURE

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CONTENTS

LIST OF TABLES, FIGURES AND BOXES

FIGURES PAGE

FIGURES **PAGE**

BOXES

ABBREVIATIONS

AB	Arellano-Bond
AIIB	Asian Infrastructure Investment Bank
BAP	Biodiversity Action Plan
BAU	business-as-usual
BHI	Biodiversity Habitat Index
BII	Biodiversity Intactness Index
BNG	Biodiversity Net Gain
CBA	cost-benefit analysis
CBD	Convention of Biological Diversity
CDSB	Climate Disclosure Standards Board
CGE	computable general equilibrium
COP15	15th Conference of Parties to the UN Convention on Biological Diversity
CWON	Changing Wealth of Nations
DFI	development finance institution
DID	difference-in-difference
DMO	debt management office
DNS	debt-for-nature swaps
DSA	debt sustainability analysis
EMDEs	emerging markets and developing economies
ENCORE	Exploring Natural Capital Opportunities, Risks and Exposure
EPI	Environment Performance Index
ESG	environmental, social and governance
ESIA	Environmental and Social Impact Assessment
ESVD	Ecosystem Services Valuation Database
GBF	Kunming-Montreal Global Biodiversity Framework
GBS	Global Biodiversity Score
GDP	gross domestic product
GEF	Global Environment Facility
GFCF	gross fixed capital formation
GHG	greenhouse gas
GQ	Golden Quadrilateral

IBA	Important Bird and Biodiversity Area
IFC	International Finance Corporation
IMF	International Monetary Fund
KPI	key performance indicator
LAI	leaf area index
LPI	Living Planet Index
MDB	multilateral development banks
NBI	nature-based infrastructure
NBS	nature-based solutions
NBSAPs	National Biodiversity Strategies and Action Plans
NCV	natural capital valuation
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
NGO	non-governmental organizations
NHDP	National Highways Development Project
NHM	Natural History Museum
PAI	Principal Adverse Impact
PPML	pseudo-Poisson maximum likelihood
RISE	Regulatory Indicators for Sustainable Energy
SBTN	Science Based Targets for Nature
SDG	Sustainable Development Goals
SFDR	Sustainable Finance Disclosure Regulation
TNFD	Task Force on Nature-related Financial Disclosures
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-WCMC	UN Environment Programme World Conservation Monitoring Centre
WEF	World Economic Forum
WWF	World Wildlife Fund

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FOREWORD

Nature is a form of infrastructure, and a very special form so far as humanity is concerned. While infrastructure is commonly understood as being a human construction, nature is the most essential form of infrastructure that can be imagined. Nature has the power to feed us, heal us and help us grow. We depend on nature, and the biodiversity it facilitates, for our food, energy, water, resources, medicine, employment and leisure. Humankind cannot exist without nature.

Our natural world is the most fundamental type of infrastructure that can be conceived. Indeed, human imagination could not have created the modern marvel of today's man-made infrastructure systems were it not for the immaculate conception of our living planet replete with a system of natural infrastructure designed through billions of years of evolutionary wisdom.

The history of infrastructure development is a history of overcoming the barriers to connection that frustrate the satisfaction of human needs and of reshaping our natural world according to human desire. From the Roman aqueducts that were among the earliest infrastructure for agricultural and urban life, through to China's Grand Canal which has connected China's North and South over the last 2,500 years with an endless flow of passengers and goods. Today, infrastructure laces between every corner of our planet, in what must appear like a rapidly multiplying organism when viewed by the untrained extraterrestrial eye.

Over the last two centuries, the infrastructure built by humankind has proliferated in scale and complexity. Railways, expressways, tunnels, bridges, seaports, airports, telecommunications towers, power plants and more – our modern infrastructure has catalyzed global trade and economic growth, which itself is underpinned by the invisible infrastructure of an international financial system that instantly channels financial resources for trade and investment. This marvelously complex system of infrastructure has enabled human living standards to improve across our world faster than in any other period of history.

However, we now face a crisis of our own doing. Seventy-five percent of the planet's land surface is significantly altered. Over 85 percent of wetland areas have been lost. Around one million species already face extinction, many in the next few years, with the global rate of extinction at least tens to hundreds of times higher than the average over the last 10 million years (IPBES, 2019). Even the operation of critical human infrastructure is more frequently coming into tension with basic human needs as our climate changes and the symbiotic relationship between human and natural worlds fray. As climate change accelerates, human infrastructure's dependency on natural infrastructure will wither further in previously unexpected ways.

One such example is the Panama Canal. Considered a marvel of modern engineering at the time of construction, the Panama Canal was constructed as a lock-system that depended on natural flows of fresh water, instead of a sea-level option which asked less of nature over the long term but needed significantly more excavation and was thus more costly in the short term. In other words, it was a classic case of the infrastructure investment dilemma: short-term expediency versus long-term benefit.

Nowadays, the canal faces severe capacity restrictions following an extended drought in 2023. Every ship crossing requires a discharge of 52 million gallons of fresh water from Lake Gatun to fill canal locks and complete a crossing via this same lake, which also supplies drinking water to 50 percent of Panama's population. In an effort to preserve drinking water supply, canal operators reduced capacity from an average of 36 daily crossings down to 25 daily crossings in November, with an even more severe reduction to 18 daily crossings expected from February 2024 onwards. With three percent of global trade passing through the Panama Canal, such unprecedented restrictions have concerning implications for global trade and shipping costs, highlighting the fragile relationship between our planet's natural infrastructure and the human infrastructure built upon it.

We humans have yet to fully understand the subtle symbiosis between natural and human infrastructure. Over the last several hundred years, we have been indulgent in satisfying our insatiable appetite for nature's endowments with devastating consequences. We have been relentless in extracting from nature whatever we want; not just to meet our basic needs, but all too often to gratify our immense relish for luxury and material acquisition. In our pursuit of such vanity, we have been in the course of nibbling bare the very essence of nature as infrastructure which sustains our survival and offers humans the promise of long-term decent living conditions.

Nowadays, we are suffering from an increasing number of natural disasters that stem from our irresponsible behavior. Disasters that appear natural at face value – fires, floods, droughts, desertification, even earthquakes – are induced by human activity, and consequently, all other species are falling victim to the imprudent human way of life. Yet other species will not protest; they will not take to the streets. They simply disappear. Humans cannot survive alone on this planet. It is high time to stop this destructive process and reverse the course toward more sustainable behaviors. It is high time for us to come to terms with nature; we cannot keep asking for more.

This process of reconciliation must begin by understanding and recognizing the value that nature can offer us. Our ambition must be to turn the idea of nature as infrastructure from an abstract concept into an impactful asset class that commands increasing levels of investment and regulatory attention. Quite rightly, nature and biodiversity are thus growing areas of importance for AIIB.

Recent years have seen important global progress in halting and reversing the loss of nature and biodiversity. The Kunming-Montreal Global Biodiversity Framework agreed at the 15th Meeting of the Conference of Parties to the UN Convention on Biological Diversity (CBD COP15) has established an action roadmap with four overarching goals and 23 ambitious targets that must be completed by 2030. Rapid progress in the next few years is necessary to stop short of and pull back from looming tipping points of irreversible damage in natural assets and extinction risk for millions of precious species.

This year's Asian Infrastructure Finance (AIF) report provides a critical foundation for our thinking on biodiversity. While there are many rich insights contained within this year's AIF report, I would like to highlight three that stood out to me.

Firstly, AIIB's geographical scope of operations includes regions which are amongst the most exposed to our planetary biodiversity crisis. The Asia-Pacific, for example, has already lost 55 percent of its biodiversity, making this region particularly vulnerable to the effects of further loss (WWF, 2022). We at AIIB are therefore duty bound to make a meaningful difference.

Secondly, as an infrastructure investment bank, we must be open and honest about the risks of negatively impacting natural surroundings and species. We must look at nature through a new lens to explore how nature itself can deliver infrastructure services, build the case for integrating nature-based solutions into traditional infrastructure, and go beyond minimizing and mitigating impacts by enabling nature-positive investments.

Finally, nature matters to us in a special way because of our multilateral mission. Nature and biodiversity issues – like climate – traverse national boundaries. AIIB can lead from the front, bringing together our 109 Members to develop joint approaches for tackling these crises together.

As a multilateral development bank (MDB) with a growing portfolio of projects – standing at USD45 billion today – AIIB has a vital role to play. This includes collaborating closely with our MDB partners to implement the COP26 Joint Statement by the MDBs on Nature, People and Planet which commits us to: mainstreaming nature into our policies, analysis and investments; valuing nature so as to guide decision-making; supporting members with implementing nature-based solutions; and developing tools and methodologies for tracking nature-positive investments. It also means implementing relevant areas of the Global Biodiversity Framework, particularly those related to mainstreaming nature, managing and disclosing risks, and – perhaps most importantly – substantially increasing financial flows toward nature and biodiversity investments.

This year, AIIB published its first Climate Action Plan (CAP). In the CAP, we detailed our commitment to offering our clients tailored, holistic, local solutions by mitigating climate change, complementing adaptation efforts and maximizing co-benefits for nature and biodiversity. By viewing nature as infrastructure and integrating nature-based solutions into infrastructure design, we can enhance climate resilience and provide alternative solutions to withstand a range of climate change events, such as flooding, drought and urban overheating. Our Bank is committed to becoming a key driver of mitigation and adaptation finance in Asia by demonstrating our ambition to mobilize our capital, capacity and convening power to help our members in their efforts to address climate change.

Furthermore, next year, AIIB will develop its first Nature Action Plan which will detail how we plan to (i) integrate considerations for nature-based solutions into project identification, design and operations, (ii) establish partnerships to provide catalytic financing, and iii) enable opportunities for nature-positive investments to be scaled up across our portfolio and in our region.

AIIB's four thematic priorities provide a helpful framework for how we might mainstream biodiversity considerations in the future. For example, nature-based solutions are a form of green infrastructure which contribute to the fight against climate change while offering other environmental benefits such as biodiversity conservation. Nature can also provide technology-enabled solutions which enhance the efficiency of grey infrastructure projects, such as mountain forests which improve water capture and reduce soil erosion around hydropower plants. Regional cooperation lies at the heart of integrated river-basin management, mangrove rehabilitation that improves flood protection for riverine and coastal communities, and the installation of wildlife corridors to support migration routes for endangered mammals and bird species – such as along the East Asian-Australasian Flyway. Finally, the private sector must participate. A growing ecosystem of players are making substantive progress on nature-positive investments – development finance institutions, philanthropy, and the private sector – and MDBs must work together to coordinate these players into a common coalition for catalytic change.

AIIB is determined to be a pioneer in this essential arena. This year's Asian Infrastructure Finance report is therefore timely and will help to ensure AIIB's approach is data-driven and analytically robust. Just as biodiversity is stronger in symbiotic diversity, partnerships will be essential for humanity's effort to mainstream biodiversity protection and enhancement into our normal economic activity. As such, we hope this report is used as a resource by our Members, clients and development finance partners in our collective efforts to avoid the biodiversity tipping points ahead. While the challenges ahead are certainly daunting, the health of our planet and the prosperity of humanity depend on our success.

Jin Liqun
President and Chair of the Board of Directors
Asian Infrastructure Investment Bank

PREFACE

In last year's Asian Infrastructure Finance report, we highlighted the need to respect our planetary boundaries in the context of greenhouse gas emissions to ensure sustainable growth. While the many catastrophic events of the last twelve months have shown us that climate change remains the development challenge of the 21st century, a quieter, related–and potentially even more serious–crisis is playing out across our lands and seas. The rapid degradation of nature and declining biodiversity demand more attention from economists and policymakers. The continued erosion of natural capital undermines humanity's efforts to secure long-term economic prosperity for current and future generations. We need a new pair of glasses that allows us to see the planetary boundaries more clearly and identify opportunities to mobilize nature's own healing mechanisms and capacity to generate innovative responses.

Until now, we have tried to take nature into account when building infrastructure, but we must go further and define nature itself as infrastructure. Nature has provided infrastructure for humans since the very beginning. The extensive river systems of China and India supported numerous constellations of kingdoms and states, and the Nile supplied Egyptian civilizations with infrastructure services over millennia. The river Indus played the same role in what is today Pakistan, and it was human interventions in the natural capacity of this majestic river to absorb the climate-induced heavy precipitation that caused much of the disastrous flooding in 2022. Viewing infrastructure in this way broadens our horizon and allows us to think in a more systemic way about how to find solutions.

Viewing nature as infrastructure is also about defining biodiversity and its varied features. When we seek to harness nature's capacity to provide essential services, we include under biodiversity not just the number of species, but their genetic diversity and diversity of functions. The diversity of ecosystems also has an intrinsic value as it contributes to the extraordinary richness of the global gene pool. Yet another characteristic of biodiversity is the complex evolutionary history of species – when they were separated on the "tree of life". It is only by deepening our understanding of the multifaceted notion of biodiversity that we will prize the true potential of nature and our impact on it.

The 2023 Asian Infrastructure Finance report addresses nature as our most critical infrastructure. We call attention to the many valuable and unpriced services nature provides. Drawing on a painstaking collection of data, we show the importance of more accurately valuing nature – at the macro level by internalizing the role of natural capital in growth and at the micro level by considering the effects of infrastructure on nature and the huge potential of nature-based solutions. As an infrastructure bank, we scrutinize our operations, evaluating how to make traditional grey infrastructure greener and presenting a leadership opportunity for the MDB community to go further by advancing the concept of nature as infrastructure. Finally, we point to how innovative financing instruments, such as sustainability-linked bonds and debt-for-nature swaps, can increase nature financing and help to resolve multiple concurrent crises facing debt-distressed countries in the emerging and developing world.

For AIIB, nature and biodiversity issues are particularly relevant, given our primary focus on infrastructure. Infrastructure is a vital part of development for our Members, but we know that it also has profound impacts on surrounding environments and inhabiting species. The world itself has already lost 60 percent of its species over the past 50 years [WWF (2018)]. Up to a further 42 percent of species in Southeast Asia could be lost by the turn of the century—and over half would be global extinctions, pointing to Asia's unique biodiversity [Sodhi et al. (2004)]. Furthermore, 99 of the top 100 cities facing the most significant environmental risks are in Asia [Verisk Maplecroft (2021)]. Our non-regional Members in Africa and Latin America also hold much natural capital that requires protection even as infrastructure is developed. It is our responsibility to become a leader in this space.

Economists have an important role to play in offering robust, data-driven insights into our natural world. Significant progress has been made in the last few years, with the World Bank's much needed Changing Wealth of Nations datasets, the ongoing deep research and capacity development by the UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC) and the landmark Dasgupta (2021) review. These paved the way for our report, which in turn contributes to the repository of knowledge with a focus on the nexus between nature, biodiversity, infrastructure and development. In our journey, we have been inspired by our peers. We have collaborated with numerous research institutions and development partners, and I would like to express my gratitude to all of them. More analysis will be needed—on the fungibility between climate and nature, mainstreaming nature across the value chain or enabling biodiversity credit markets, to name a few. Economists will need to help determine the scale of the problem and put forward and justify innovative solutions that can underpin policy dialogues.

Our report argues that we must go beyond a "safeguards" approach and reframe nature as our most critical infrastructure that needs to attract our investment and attention. Grey infrastructure using traditional materials and methods—roads, bridges, wind turbines, water-treatment plants—will remain central to our Members' development pathways and net-zero transitions. And they can also align with AIIB's thematic priorities, such as fostering greater connectivity. These projects must be appropriately designed and built, considering the mitigation hierarchy of impacts on nature (as with climate). But our report also details that we must—and can—do more. Turning infrastructure from grey to green by adding nature-positive components, such as green roofs, "living" walls and new habitats for species, is a first step. But our vision should move toward solutions which redefine nature as the infrastructure, in which forests, wetlands, reefs, mangroves and other landscapes deliver the infrastructure services if appropriately arranged.

To drive catalytic change, there will need to be further global cooperation on nature and biodiversity. Even if the political will to adopt a more nature-friendly development path and reverse biodiversity loss exists, significant financing gaps—estimated at USD598 billion to USD824 billion annually—must be closed [TNC, Paulson Institute, Cornell Atkinson (2020)]. The Kunming-Montreal Global Biodiversity Framework delivered substantial progress, which needs to be built on. MDBs have a real opportunity to tackle climate and nature issues together, unlock fresh financing from our balance sheets, deploy new lending instruments, use our convening powers to mobilize private finance and channel financing to where it is most needed, often the poorest countries. The future of our planet—and our co-inhabitants—will depend on our willingness and ability to work together to deliver meaningful impact.

Erik Berglof
Chief Economist
Asian Infrastructure Investment Bank

EXECUTIVE SUMMARY

Nature as infrastructure has the potential to be a transformative concept for development. It goes beyond nature-based solutions or mitigating the impact of human development on nature. Infrastructure is traditionally defined as the organizational structures and facilities that allow for the operation of society. It should now be clear that nature is an inseparable part of it. The degradation of nature and biodiversity over the past decades thus poses an existential risk as much as climate change. This must be reversed quickly, together with climate change.

A need to value nature. To begin, there is a need to understand the value of nature. At the macro level, there is a need to understand how the economic activity of countries and sectors depends on nature. At the micro level, there is a need to understand the intricacies of local ecosystems and the tremendous and often unpriced services they bring and factor these meaningfully into all development decisions. Internalizing the value of nature in macroeconomic and microeconomic decisions is the first step toward creating the necessary incentives to protect and enhance nature. This report discusses both the macroeconomic impact and project-level valuation tools.

Nature as infrastructure. Nature as infrastructure is a transformative approach. The report provides detailed examples of how trees, mangroves and wetlands can provide valuable services. Where nature can provide such infrastructure-like services, grey infrastructure should be carefully considered, and investments in nature's restoration should be the norm rather than the exception. As the report will emphasize, scientific knowledge of local environments, participation of local communities and governance are key to restoring and harnessing nature as infrastructure. There is also a need to find avenues to monetize nature's services to meet both nature and financial sustainability.

Building infrastructure greener. The report recognizes that grey infrastructure will always be necessary for development. Yet many forms of grey infrastructure, including those related to urbanization that Asia is experiencing, impact nature negatively. There is a need to design grey better, regulate and minimize impact on nature. There is also a seeming tradeoff between renewable energy infrastructure (which has a large ecological footprint) and nature. This can pose a significant net-zero transition risk if not well managed. Road infrastructure also fragments and damages ecosystems. Thus, it is necessary to design grey better, such as co-locating infrastructure on brown sites providing auxiliary infrastructure (e.g., wildlife highway crossings, green urban spaces, restoring nature as offsets, etc.) to mitigate the impact of grey infrastructure. Some examples are discussed in the report.

Finance, markets and other instruments. Building nature as infrastructure and as an asset class will require expanding various tools and financial instruments. At the micro level, this would require better pricing of nature's services (e.g., usage charges or permits, tax on damages, etc.) and adaptive local regulations. Micro-level policies can then support the development of other financial instruments and eventually markets (e.g., KPI-linked bonds, policy-based lending, debt-for-nature swaps, nature credit markets) to channel more financial flows to nature while taking in lessons of carbon markets and avoiding past pitfalls. There is a particular need to assist low-income economies, many of which will be adversely affected by nature's degradation, on the one hand, and have a large potential to benefit from their nature endowments on the other. MDBs can play a catalytic role at both the micro and macro aspects to mainstream nature into all development considerations.

CHAPTER 1
OVERVIEW

1.1 Objective and Background of the Report

Nature has proven its resilience, rebuilding from uncountable cataclysmic events. As human activity pushes Earth's present ecosystem toward tipping points, another cataclysm may happen. Biodiversity is declining faster than ever in human history. There has been a 60 percent loss in the populations of mammals, birds, fish, reptiles and amphibians in the last four decades [Dasgupta (2021)]. Agricultural expansion, a doubling of urban areas since 1992 and an unprecedented expansion of infrastructure, has come mostly at the expense of largely old-growth tropical forests, wetlands and grasslands, threatening the diversity of ecosystems [see IPBES (2019); IISD (n.a.)]. While nature will no doubt survive and rebuild from such an ecosystem collapse, the same cannot be said of human life. Restoring and sustaining nature is now a pressing task.

The urgency is clear in the Kunming-Montreal Global Biodiversity Framework (GBF), resulting from a collaborative effort led by the Conference of the Parties at the Convention on Biological Diversity. Building on the predecessor Strategic Plan for Biodiversity 2011-2020, the GBF establishes four long-term goals for 2050 and 23 action-oriented targets for 2030 to change society's relationship with biodiversity and achieve a vision of living in harmony with nature by 2050.

Traditionally, large infrastructure projects are seen as negative for ecosystems. Yet infrastructure can be made better to conserve and work with nature. Builders and policymakers can integrate biodiversity conservation into infrastructure development alongside nature-based solutions (NBS) and natural infrastructure. This Asian Infrastructure Finance Report recognizes nature as an essential part of infrastructure. With data and analysis, AIIB hopes to motivate positive action with all stakeholders toward the twin challenges of restoring nature and mitigating climate change.

1.2 Global Economy: Nature's Contributions

Nature is the entirety of physical world with an emphasis on the diverse lifeforms and ecosystems. Within nature lies biodiversity, defined as the variability among living organisms from all sources, including, among other things, terrestrial, marine, and other aquatic ecosystems and their ecological complexes. This diversity includes variation within species, between species and within ecosystems.[1] The Task Force on Nature-related Financial

[1] See Convention for Biological Diversity (https://www.cbd.int/convention/articles/?a=cbd-02).

Disclosures (TNFD) framework categorizes nature into land, freshwater and atmosphere.[2] Each has unique structures delivering essential services that benefit businesses and societies. Broadly, nature contributes through:

- **Provisioning services:** Nature provides resources such as wood, water, fertile soils and natural rubber, which are crucial for industries. Various living species like plants, animals, and microorganisms contribute to food chains and ecological balance.
- **Regulatory services:** Regulatory services refer to the natural processes sustaining the livable environment. Living species such as birds, insects, aquatic organisms and trees play essential roles in these processes, providing benefits like pollination, water filtration and carbon sequestration. Wetlands protect coastal communities.
- **Cultural services:** Through their aesthetic and recreational value, natural landscapes enhance property values in sectors like real estate while fostering a connection between people and their environment.

The global economy depends entirely on nature, encompassing everything from the food we eat to the minerals that anchor our technology. Unfortunately, many economic practices fail to acknowledge nature's true value and exploit it unsustainably. This generates mounting costs—greenhouse gases, degraded lands and a polluted ocean—estimated to be 13 percent of the gross domestic product (GDP) in 2009 [Trucost (2013)]. Similarly, the global food system, worth around USD8 trillion, generates sizeable negative externalities [UN Food Systems Summit Scientific Group (2021)]. If these negative externalities were accounted for, the global economy would be technically insolvent [Dasgupta (2021)]. According to the Dasgupta Review, at the current rate of exploitation, we would need 1.6 planets to sustain its impact on nature. This grave situation is further worsened because the loss of nature directly contributes to climate change.

Identifying potential risks associated with losing nature is crucial for understanding the impacts on sovereigns, financial institutions and businesses. This begins with evaluating the sector's dependency on natural resources and biodiversity. There are studies on categorizing industries based on their reliance on nature. According to WEF (2020) and the PwC report "Managing Nature Risk," globally, agriculture, forestry and construction are up to 100 percent dependent on nature for their direct operations and 60-80 percent dependent if supply chains are included. Energy and automotive are estimated to have at least 35 percent dependency on both direct operations and supply chains. On the other end, banking and IT has smaller direct dependency [Evison et al. (2023)]. Worth noting is that these estimates may not fully account for co-contribution from other factors of production, technological change and policies. They nonetheless provide a useful perspective of how much output is underpinned by nature.

In Chapter 2 of this report, a growth regression approach using various forms of physical and natural capital also uncovers the sizeable contribution of ecosystem capital. Chapter 3 highlights how natural capital can also affect credit ratings and future debt capacity of developing economies, both as a potential opportunity and a threat.

The unsustainable extraction of nature's resources for global economic development risks future growth. The degradation of nature also leads to or compounds the effects of natural disasters, pandemics, diseases, water scarcity and food insecurity with far-reaching and alarming impacts on poverty and inequalities [Taskforce on Nature Markets (2023)]. Overexploitation leads to biodiversity decline and ecosystem collapse, while pollution and emissions disrupt the climate. The loss of forests, for example, results in more greenhouse gases.

Current climate trends are pushing past the 1.5°C warming limit toward catastrophic tipping points. It is an existential threat that touches upon the

[2] See TNFD definition of nature (https://framework.tnfd.global/concepts-and-definitions/definitions-of-nature/). The World Wildlife Fund (WWF) defines biodiversity as all the different kinds of life in an area—"the variety of animals, plants, fungi, and even microorganisms like bacteria that make up our natural world. Each of these species and organisms work together in ecosystems, like an intricate web, to maintain balance and support life" (https://www.worldwildlife.org/pages/what-is-biodiversity).

very future of life itself. The relationship between nature and climate stability is a complex nexus, each profoundly influencing the other. Conserving biodiversity is critical for limiting greenhouse gas emissions and safeguarding the planet's natural wealth.

1.3 Nature as Infrastructure: A Transformative Development Concept

Drawing upon the understanding of the economic value of nature and its role, "Nature as Infrastructure" is emerging as a transformative approach. Nature as infrastructure leverages natural ecosystems strategically to meet infrastructure needs conventionally addressed through man-made solutions. It overlaps with the concept of nature-based solutions but goes deeper in reframing nature itself as a vital infrastructure form. For instance, instead of constructing barriers for flood control, wetlands can be preserved or restored to serve the same purpose. Green spaces in urban areas can be strategically designed to mitigate the impact on nature and provide recreational services.

Restoring nature also improves the productivity of agriculture and fisheries, leading to economic benefits. Tree planting improves the local environment and health and can help rehabilitate abandoned industrial land (e.g., disused mines). Nature is fundamentally humanity's largest carbon sink. Its preservation is as important—if not more so—than our investments in physical infrastructure to mitigate climate change. The report documents and discusses the impacts of various nature as infrastructure projects in China, Indonesia, Bangladesh and Egypt more extensively in Chapter 4.

A fundamental reset of the terms of trade between nature (including biodiversity) and the global economy is required. To truly understand the dependency between nature and human activities, we must carefully evaluate the impact that our actions, both as individuals and industries, have on the environment [UNDP and UNEP (2021)]. This understanding is crucial for identifying risks and creating strategies to reduce negative impacts and enhance positive contributions to nature.

1.3.1 Measuring the State of Nature

The state of nature refers to the overall state or health of the natural environment at any given time. This encompasses the condition of various ecosystems, the diversity and quantity of species, the quality of air and water and other variables that describe the natural world's general well-being. Within the state of nature lies natural capital, defined as the world's stocks of natural assets, which include geology, soil, air, water and all living creatures.

Biomarkers are quantitative indicators that diagnose the state of natural capital within the context of nature. Species numbers, soil nitrogen and pollution buildup are a few examples. The standardization of important biomarkers allows for comparative insights into ecosystem health. The state of nature is a foundational concept that sets the stage for understanding the specific components and dynamics of the environment. This is vital for developing a comprehensive understanding of our dependence on complex ecosystems. Proper monitoring and measurement of the state of nature, through assessing natural capital using biomarkers, are essential for sustainable management.

Nature metrics such as the SEED Index, Global Biodiversity Score (GBS), Living Planet Index (LPI) and Biodiversity Intactness Index (BII) are some of the tools that provide comprehensive approaches for assessing the state of nature and biodiversity.

1.3.2 Quantifying Nature's Value and Challenges

After measurements of the state of nature comes the determination of nature's value. This is necessarily complicated and challenging due to the dynamics of ecosystems, their widespread distribution and the unique characteristics of diverse resources. Placing a value on essentials like air, water, land and living organisms is challenging. These services are often more intangible and intricate than tangible resources like timber, making them harder to quantify. Changes in one part of an ecosystem can have far-reaching effects elsewhere, and understanding these relationships requires sophisticated modeling and analysis.

Furthermore, accurately valuing nature also poses challenges related to the lack of data availability and methodological gaps. Incomplete or imprecise data can result in misleading metrics, while methodological inconsistencies hinder comparability and integration. To tackle these challenges in quantifying nature's value, various frameworks, data tools and metrics have emerged to guide impact measurement and valuation and thereby aid in implementing the GBF framework.

1.3.3 Building Up Nature Frameworks and Metrics To Guide Actions

Actions and metrics need to cascade nature frameworks to guide sovereigns and organizations in identifying, measuring and valuing their impacts on nature and their dependencies on it. These frameworks provide approaches for assessing risks associated with nature, which include:

- **Identifying Risks and Dependencies:** Understanding both the negative impacts on nature and the reliance on natural resources and ecosystem services [Cambridge Conservation Initiative and the Capitals Coalition (2020)].
- **Measuring and Valuing Impacts:** Quantifying the influence on the environment, including tangible and intangible ecosystem services.
- **Integrating Nature into Decision-making:** Guiding countries and businesses to incorporate considerations when planning, conducting operations and reporting.
- **Promoting Collaboration and Innovation:** Encouraging interdisciplinary collaboration to develop innovative solutions to environmental challenges.

Frameworks like TNFD, Science Based Targets for Nature (SBTN), Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) and Natural Capital Protocol serve as essential guides for sovereigns and organizations.[3] They offer structured methods to identify and assess risks and dependencies related to nature. These frameworks help quantify both tangible and intangible impacts on ecosystems and facilitate the integration of these factors into decision-making processes. These frameworks play a role in enabling organizations to understand their impacts, establish targets based on scientific principles and report transparently on their actions in alignment with the GBF framework.

The accelerating degradation of the natural world has prompted the development of innovative market-based methods for conserving biodiversity and ecosystems. Initiatives such as corporate sustainability reporting and policy changes seek to better account for the importance of nature in economic systems.[4]

In summary, data and metrics help us measure the state of nature. Research work to uncover the intricate dependencies within nature and its interaction with various aspects of human activity is needed to support robust valuation. Frameworks then help reorient public and private sector decisions to properly account for nature and direct investments toward it.

1.4 Protecting Nature and Development

While nature as infrastructure is a transformative concept, grey, physical or engineered infrastructure will always be needed for development. As the report will show in Chapter 6, infrastructure development will have a sizeable direct and indirect impact on nature. There is a particular need to manage the large expansion of renewable energy infrastructure, which often has a large environmental footprint. Similarly, urbanization—rapidly underway in developing economies—also impacts nature (Chapter 7). Infrastructure development must reinforce, rather than reduce, nature.

1.4.1 Natural Capital Valuation

First and foremost, all physical infrastructure must be assessed with nature considered. This is the key concept behind natural capital valuation (NCV), where the ecological services of nature (and risks to these) are expressly incorporated into a traditional

3 See TNFD (https://tnfd.global/publication/glossary/); SBTN (https://sciencebasedtargets.org/about-us/sbtn)
4 See https://www.project-syndicate.org/commentary/how-to-build-equitable-nature-positive-markets-by-sandrine-dixson-decleve-and-simon-zadek-2023-08

cost-benefit analysis (CBA). This is the first step toward improving the decision-making process, from selecting project sites, designing the infrastructure and proposing mitigating or offsetting factors. Chapter 5 of this report articulates this concept with a worked example of an AIIB project and case studies to illustrate.

1.4.2 Pricing and Regulatory Instruments

Broadly, there is a need to develop more regulatory and pricing instruments that enable firms to better internalize the impact of their actions. Disclosure and data collection will be a key part of this effort. As Chapter 8 will show, disclosures of negative impact on nature can result in negative stock price impact, which underlines the potential for markets to function as a mechanism to encourage responsible corporate behavior. These points will be expanded upon in more detail.

1.4.3 Nature-focused Financial Instruments and Markets

The financial landscape is evolving to meet these challenges through innovative instruments. These instruments aim to generate financial returns and deliver measurable environmental impact. Below are some of the pioneering tools that are reshaping the landscape of environmental finance:

- Sustainability-linked bonds and loans are financial instruments that tie predefined sustainability targets to key performance indicators (KPIs), which can include commitments to nature and biodiversity conservation and other environmental, social and governance (ESG) objectives.
- Debt-for-nature swaps (DNS) are financial arrangements that transform current debt into use of proceeds bonds with more favorable terms such as reduced interest rates and longer repayment periods. In exchange, the debtor commits to environmental conservation efforts and may receive some debt relief. These instruments can aid countries grappling with debt and environmental challenges.
- Blended finance is a financial strategy that combines public and private funding to reduce investment risks for private investors. Its goal is to address public sector objectives like protecting biodiversity and building climate resilience. By pooling resources, blended finance aims to expedite the implementation and expansion of projects.

A nature market explicitly values and trades nature [Taskforce on Nature Markets (2023)]. They use market mechanisms to encourage actions by quantifying and trading the value of nature through financial instruments and platforms. This approach fosters a balance between development and environmental preservation. One such innovative financial instrument is the biodiversity credit. Biocredits function as a currency of nature markets, serving as a unit for the conservation or restoration of biodiversity. These credits are created through investments in projects that enhance biodiversity, such as habitat restoration, reforestation or protected species.

For low-income economies—many of which are home to significant amounts of nature and biodiversity—natural resources can indeed boost short-term economic growth. However, unsustainable use can degrade long-term growth potential and create risk to future growth, debt sustainability and creditworthiness. There is also a need to develop specific instruments to support lower-income economies. These will be discussed in Chapter 9 of the report.

1.5 Responsibilities and Opportunities for MDBs

In light of the growing concerns about climate change and biodiversity loss, multilateral development banks (MDBs) are becoming even more important. As noted above, the GBF provides a guide for preserving biodiversity, offering MDBs a chance to synchronize their efforts with global goals.

Aligning investments with agreed nature targets

MDBs can play a critical role in assisting sovereign clients in aligning their National Biodiversity Strategies and Action Plans (NBSAPs) and policies with the GBF, helping them to fulfill commitments made as part of their sign-up to the Kunming-Montreal agreement. Operationalizing this might include:

- Developing and demonstrating quantitative methodologies for assessing alignment, drawing on emerging approaches and pilots, applying them to their own activities and portfolios. The application of NCV is an example.
- Growing nature restoration and related projects as a key business line; applying target-focused assessments across their own investments.
- Developing policy and regulatory frameworks that take the impact on nature into account and ensure No Net Loss for investments and broadening it to investees and partners, as well as value chains, over time.

Critically, MDBs can provide the finance to assist sovereign clients to invest and crowd in private sector investments into nature restoration projects. Well-designed projects for nature can also generate co-benefits for economic sectors, unlocking private-sector investments. As mentioned throughout the report, a major opportunity exists to integrate nature-based solutions into grey/green infrastructure investments.

Establishing natural capital as an asset class

MDBs can support the enhanced protection, investment in and economic value-creating potential of nature by developing nature-related asset classes and trading arrangements. Financial and market innovations that progress this might include:

- Supporting sovereign or private sector financing the use of sustainability-linked debt and other performance-based financing instruments, supporting enhanced performance benefits where relevant through credit enhancement and other mechanisms.
- Promoting and supporting innovative instruments like biocredit, offset and related markets.

Providing data and creating the conditions for improved governance

MDBs can play an important role in supporting the development of enabling biodata infrastructure critical to assessing the state of, managing and sustainably harnessing nature, catalyzing new nature markets and laying the foundations for effective policies, regulations and standards:

- Providing data on public and private investments to assess and inform on the impact on nature.
- Providing information on scientific and technological development that can be harnessed for projects, building capabilities for effective use in the public and private sectors.
- Supporting relevant policies and standards concerning data quality, open access, ownership, terms of monetarization, etc.

As with other investments, MDBs often provide technical assistance to clients to institute policy reforms, accompanied by suitably designed policy-based financing instruments. This must be expanded into the urgent mission of restoring nature going forward.

CHAPTER 2

DO NATURAL AND ECOSYSTEM CAPITAL AFFECT GDP? GROWTH REGRESSION ANALYSES

Highlights

- Ecosystem capital has a sizeable impact on per capita GDP growth; its effect is around one-third that of total infrastructure and non-infra gross fixed capital formation (GFCF) capital. It is essential to global GDP, estimated at USD6 trillion to USD12 trillion or USD10 trillion to USD20 trillion (PPP terms) annually.
- Ecosystem capital is highly undervalued. Investment into ecosystems is small relative to contribution, which implies high payoffs.
- Infrastructure development, while important to growth process, must not come at the expense of ecosystem capital.

As early as 1972, the then-controversial Limits to Growth report spelled out the challenges of resource depletion and emission and how these could significantly constrain or even crash growth in the 21st century. More than a decade ago, the Stiglitz-Sen-Fitoussi (2009) commission also made it clear that GDP was an income flow and would need to account for the damage to the stock of environment wealth to drive sustainable development, a point strongly reiterated in the more recent Dasgupta (2021) review. As seen, there have been longstanding concerns about how GDP growth could exhaust natural capital to threaten our own prosperity.

Nature and biodiversity were seen to be outside mainstream economics [Dasgupta (2008)]. This is clearly no longer the case. Though estimates vary, it is now widely acknowledged that nature underpins a significant part of economic activity and human well-being. There has correspondingly been a sea change in data quality for natural capital and biodiversity in recent decades. It is also clear that significant degradation of natural and human-made ecosystems has occurred, with an alarming loss of biodiversity that may cumulate to irreversible damage.

In 2022, the 15th Conference of Parties to the UN Convention on Biological Diversity (COP15) to the Convention on Biological Diversity (CBD) reached the landmark agreement to put 30 percent of Earth under protection by 2030. In 2023, nations adopted the United Nations High Sea Treaty, which would establish marine protected areas outside national maritime borders for the first time. Protecting nature is now central to sustainable development, alongside net-zero transition, to avoid catastrophic climate change.

2.1 The Importance of Natural and Ecosystem Capital to Growth

To ascertain the importance of natural capital and biodiversity to output, this research undertakes a GDP growth decomposition exercise with an assembled longitudinal dataset comprising GDP-related data and more comprehensive measures of natural capital and biodiversity. This expands on traditional growth accounting, where GDP is often only attributed to human capital, physical capital stocks and total factor productivity.

This chapter thus links GDP (a flow concept) to an expanded measure of natural capital and biodiversity, uncovers respective elasticities and estimates the contribution of natural ecosystem capital to output.

2.1.1 Nature's Contribution and Importance of Biodiversity

As highlighted in Chapter 1, nature provides materials, regulatory services and welfare value to human society. Attempts to derive monetary estimates of nature's contribution are not new, and many existing estimates exist in both the scientific and economic literature. These estimates tend to be based on bottom-up extrapolations. For example, valuations of ecological services are often estimated using local case studies, and these are then extrapolated to some global figures by assuming similar biomes would offer the same values [de Groot et al. (2012); Costanza et al. (2014)]. This approach typically produces rather high global valuations of nature's services. It is estimated that global ecosystem services could be worth as much as USD125 trillion per year (in 2007 dollars). There are also ongoing efforts to estimate the provisioning, regulating and cultural value of nature under the Gross Ecosystem Product framework.

Some studies are based on the sectoral approach. This perspective first assesses how much each sector's production inputs depend on nature's services or material provisions. This is then aggregated at various levels—sector, economy or global. UNEP (2021) reports that half of the world's GDP depends on nature. WEF (2020) arrives at a similar proportion. On a more philosophical note, it is also possible to argue that every aspect of human activity depends on nature—for example, the air we breathe and the water we drink—and hence, 100 percent of global GDP is nature-dependent by definition.

Finally, there is a modeling approach using computable general equilibrium (CGE). A World Bank study estimates that the collapse of ecosystems will result in USD2.7 trillion in lost output per year. This is small relative to global GDP or the sectoral approach, as the CGE often builds in substitutability between factors of production. In other words, there are possible technological substitutes for nature's services. To be clear, there is often a high degree of uncertainty on how substitutable nature's services can be. While USD2.7 trillion is relatively small, this World Bank estimate does show that certain sectors and poorer economies would be hardest hit by the collapse of nature [Johnson et al. (2021)].

The recent Dasgupta Review highlights various estimates of the economic benefits of nature and biodiversity, reiterating the importance of sustaining these. Significantly, the review also clarifies two related but different concepts—namely, nature and biodiversity—"A diverse gene pool is essential to provide resilience to environmental change and to pressures such as disease or climate change". In other words, the review clarifies that natural capital can be sustained only if sufficient biodiversity supports it. Biomass alone is thus not an adequate measure of nature's health.

Efforts to account for the economic contribution of nature and ecosystems are still a work in progress. Given the complex linkages within nature and the economy, estimates will always be uncertain. Such efforts are nonetheless critical to better understand how nature interacts with the economy, informs policy designs and motivates conservation actions.

2.1.2 Overcoming Data and Estimation Challenges

The recognition of the importance of nature has given rise to healthy advances in data and measurements, as mentioned. The Changing Wealth of Nations (CWON) dataset is one such key effort [World Bank (2021)]. It attempts to capture economies' stock of natural wealth, human-made physical wealth and human capital. The natural wealth data is further broken down into various components, including non-renewable natural wealth (fossil fuel, metals, minerals, etc.) and renewable natural wealth (timber, cropland, fisheries, mangrove, non-timber forest, protected areas, etc.).[5] Each iteration of CWON has improved on the previous one, and efforts are underway to improve on the estimates for renewable energy capital.[6]

These monetary estimates also give rise to further puzzles. The wealth of nations is predominantly in the forms of produced capital and human capital (31 and 64 percent of total wealth, respectively). Non-renewable extractive natural wealth (i.e., fossil fuels, mineral commodities, etc.) accounts for a significant part of the remainder. On the other hand, renewable natural capital accounts for only three percent of total wealth. Within this, ecosystem capital wealth (mangrove, non-timber forest, protected areas) is only slightly over one percent of the total wealth. These low valuations do not square with the idea that a large part of human economic output is underpinned by nature or the aforementioned estimates.

Four related issues affect natural capital valuation, contribution to GDP and related empirical work. Firstly, natural capital accounting is still relatively new, and methodologies to value natural capital (especially ecosystem capital) are still subject to some uncertainty. For example, it is still debated whether natural capital should be valued using market prices or some form of shadow price. There are also longstanding concerns about the validity of extrapolating valuations from local studies.[7]

This leads to the second issue, which is cross-dependency. Taking agriculture as an example, what proportion of output is truly nature-based, as opposed to the contribution of human labor, knowledge and physical capital such as farm machinery, warehousing and logistical infrastructure? As mentioned, existing work estimates each industry's dependency on nature, but these are also based on the subjective categorization. Estimates are often only partial.[8] Furthermore, data coverage of natural capital is not comprehensive. Such cross-dependency may cause some assets to be overvalued compared to others or for some assets to pick up the effects of non-measured assets.[9]

As a national income accounting tool, GDP does not explicitly account for factor payments to nature. It is plausible that natural capital affects the factor returns to other forms of capital (e.g., ecosystems affecting the returns to farm capital or mangrove protection affecting returns to coastal real estate). Without natural or ecosystem stocks being reflected in growth accounting, it is also possible that our traditional understanding of the returns to physical and human capital is inaccurate.

Thirdly, there is a concern about endogeneity, and there can be many sources. Consider the effects of depletion. Ecosystem capital may support growth (i.e., a positive relationship). Still, growth itself may put pressure on the environment and subsequently deplete ecosystem capital—indeed, the central concern—yielding a negative relationship.

Consider also the endogeneity from measurement. The valuation of mangroves depends on the avoided losses of real estate it protects, but the value of real estate also depends on the protection it receives from mangroves. Furthermore, GDP growth will raise asset values, and these price effects can also feed into the valuation of natural capital. We can plausibly arrive at a situation where natural capital values increase because of such price effects when, in reality, the underlying quantity or quality of natural capital is being eroded unsustainably. As capital valuation can be endogenous to GDP, it does not

5 A key use of these data is to allow one to derive net national output measures that account for the loss of natural capital [Dasgupta and Mäler (2000)].

6 See also inclusive wealth measures [United Nations (2018)]. The approach and categories of capital are similar to CWON. The key difference is that CWON relies largely on observed market price (or proxies) to value capital, while the UN inclusive wealth measures rely more on assumed shadow prices. "The use of shadow prices is theoretically obvious . . .The problem is that shadow prices cannot be observed, but a practical approach is followed by starting from market prices (whenever available) and adjusting them for externalities" [Smulders (2012)].

7 "In practice, it is very likely that per-unit demand for non-substitutable services escalates rapidly as supply diminishes, so that simple grossing up of marginal values will probably underestimate total true value. On the other hand, high local values of services such as tourism may not be maintained if extrapolated worldwide" [Balmford (2002)].

8 WEF (2020) and PwC score each industry's dependency based on the industry's dependence on identified natural processes.

9 Carse (2012) documents an interesting example of how the Panama Canal relies heavily on the surrounding watershed ecosystem for freshwater to rebalance water levels in the locks for each ship transit. Without the provision of freshwater from nature, there would be low returns to this piece of engineered hard infrastructure.

provide a true assessment of how GDP depends on such capital. Because of these potentially complex endogeneity sources, it is unclear which sign the ecosystem variable will take concerning growth and whether this can be consistently estimated.

Finally, there is still a lack of integration between natural capital and biodiversity data. As mentioned, natural capital and biodiversity are related but separate concepts. Thus far, data on biodiversity tends to be narrowly focused and "hyper-local" (e.g., number of species of certain types of flora or fauna in a defined area) and, therefore, difficult to aggregate. Aggregated natural capital data thus gives little information on biodiversity and sustainability, while richer granular biodiversity data (fragmented) provide little clues on biodiversity's contribution to natural capital or economic output.

2.2 A New Approach to Account for Natural Capital and Biodiversity

Bottom-up methods tend to result in huge estimates because these are typically partial, based on assumptions and extrapolations, and do not usually account for the effects of other factors. A regression decomposition approach in this chapter can be more robust in several ways, not least because it incorporates the effects of other factors.

Elasticities do not measure the valuation of each factor in the accounting sense but how much output changes concerning these capital measures. Even if natural capital is systematically undervalued compared to other forms of capital, elasticity measures can still pick up its effects on growth. Elasticity measures also allow one to side-step definitional issues mentioned above since one does not have to make strong bottom-up assumptions, such as how much each industry's output depends on nature.

The research further separates renewable natural capital into cultivated natural capital (e.g., cropland, fisheries) and ecosystem natural capital (e.g., non-timber forests, protected areas, mangroves). The former is human-modified, while the latter would be much more aligned with nature and biodiversity. This separation is conceptually important as cultivated capital can be at odds with biodiversity. For example, agricultural land can contribute to the productivity of food production and increase natural wealth but also accelerate biodiversity loss.

Regression approaches must deal with various sources of endogeneity—mismeasurement, omitted variables and reverse causality. This chapter takes a wide-casting approach. Natural capital is first incorporated into a traditional growth regression. A set of regressions then uses the Arellano-Bond (AB) estimator, where endogeneity is treated using past-lagged regressors or other instruments. The last set of regressions uses a pseudo-Poisson maximum likelihood (PPML) estimator to better account for heteroskedasticity, in line with more recent literature. In doing so, the chapter implements a methodology that builds on Santos Silva and Tenreyro (2006) to estimate a growth form regression with PPML.

Finally, the chapter also attempts to close the gap between natural capital and biodiversity data. The research makes use of the Biodiversity Intactness Index (BII), which is based on a geospatially granular assessment of the quality of biodiversity (i.e., intactness of the environment) and then aggregated toward a national level indicator [Scholes and Biggs (2005)]. The research uses the BII indicator essentially to adjust for the quality of ecosystem capital stocks or as a separate variable in growth regressions. For greater confidence, the regression results of the various approaches are provided for comparison in Appendix 1.

2.3 Results Show Sizeable Contribution of Ecosystem and Biodiversity

This research shows that ecosystem capital has a significant and meaningful economic elasticity of 0.063 to 0.117. The ecosystem capital coefficient is around one-third of the estimated elasticities of physical capital (infrastructure and non-infrastructure combined). This is sizeable, and it is also clear that ecosystem elasticity estimates are significantly larger than the valuation of ecosystem capital stocks in the CWON dataset.

When endogeneity is accounted for, the coefficients for infrastructure and non-infrastructure GFCF are higher. Consider simultaneity as the source of endogeneity. Where the dependent variable reverse causes the regressor positively, the general effect is one of attenuation, which is observed here. In other words, the true effect of infrastructure and non-infrastructure on growth is higher once the simultaneity is accounted for in the AB regressions.

A subtler point here is that the AB estimator also shows a higher coefficient for the unadjusted ecosystem capital (0.88 in R8 compared to 0.63 in R3). Recall the "price effect" discussed in the introduction. The growth effect on the valuation of unadjusted ecosystem is likely positive and hence detected through this attenuation bias outside of the AB estimator. Conversely, the AB coefficients for the adjusted ecosystem capital are more similar to a fixed effects panel or PPML (0.83 to 0.117 in R9 and R10, compared to 0.102 and 0.105 in R4 and R14, respectively).

The conjecture is that the BII-adjusted ecosystem variable is less prone to growth or price effects. While the BII variable is not standalone significant when used separately (as in R5 and R15), the sign for BII is negative. When BII is included as a standalone variable, the coefficients of unadjusted ecosystem capital also become higher at around 0.101 (compared to around 0.63 when BII is excluded).

This is unsurprising in hindsight, as the BII-adjusted ecosystem variable by design accounts for depletion. Including BII, whether directly adjusted for ecosystem capital or as a separate variable, increases the relevant coefficients. Furthermore, the BII-adjusted ecosystem variable appears to work well, improving the goodness of fit compared to the unadjusted one. The coefficients are also higher than the unadjusted ones. This, too, is informative and highlights the value of making BII adjustments to ecosystem capital.

Consistent with earlier AIIB research by Han et al. (2020), the elasticity coefficient for infrastructure is also sizeable and larger than non-infrastructure GFCF across all specifications. The combined elasticities of physical capital are around 0.37 in R8 with unadjusted ecosystem capital and 0.38 and 0.36, respectively adjusted with BII in R9 and R10. This is broadly in line with the literature, which has often taken the elasticity of all capital to be around one-third, although there will be economy-to-economy variation [Hall and Jones (1999)].

The growth elasticity of non-renewable natural capital (i.e., commodities and fossil fuels) is small and mostly negative throughout the analysis. This is not to say that commodities and fossil fuels are unimportant for economic output. Indeed, these may even be critical. The interpretation here, given that this is a panel study of economies, is that such endowments have not systematically improved the growth of the endowed economies [Venables (2016); Caselli and Michaels (2013)]. Similarly, cultivated natural capital (i.e., cropland, pastureland, fisheries) also has a relatively negligible impact on economic growth.

The inclusion of natural or ecosystem capital did result in some changes to the elasticities of infrastructure and non-infrastructure GFCF. Broadly speaking, coefficients for infrastructure capital increased, and coefficients for non-infrastructure GFCF declined or remained essentially unchanged. This is, again, informative.

Consider another source of endogeneity—omitted variables. The omitted variable interpretation implies that natural or ecosystem capital has a negative correlation with infrastructure capital, thus resulting in a downward bias of the latter when the former is omitted. On the other hand, the direction of bias for non-infrastructure GFCF is less clear-cut. This hints that infrastructure development has indeed compromised natural or ecosystem capital (i.e., negative correlation), underscoring the longstanding concern that large-scale infrastructure developments have negatively impacted nature and biodiversity [IISD (n.a.)].

However, this does not have to be read as a negative message. Instead, the upshot here is that developing infrastructure to enhance natural ecosystems can boost the returns to infrastructure.[10] Omitted variables could also be in the form of institutional quality, which has often been found to affect growth positively. As robustness checks, World Bank governance indicators are added as additional controls, and the elasticities are broadly unchanged.

10 The log production function in this chapter implies factor substitutability, which is debatable. If there is less substitutability between ecosystems and other forms of capital, there will be a tighter "limit to growth" as natural capital is depleted [England (2000); Meadows et al. (2005)].

2.3.1 Translating Elasticities into GDP Impact

Based on the results here and assuming a global GDP of 164 trillion (in 2022 international PPP dollars), a conservative elasticity of 0.063 would imply an ecosystem contribution to global GDP of around 10 trillion per year in PPP terms. Using the highest estimated elasticity (0.117), this figure would rise to around 20 trillion in PPP terms. If current USD estimates are used, these would be USD6 trillion to USD12 trillion, respectively. The estimates in this chapter fall between the sectoral approach and CGE modeling, pointing to the substantial contribution of natural capital to prosperity.

2.4 Nature Is Still Undervalued and Investments Should Be Scaled Up

This chapter incorporates various ecosystem capital measures into a traditional growth regression framework and uncovers elasticities that point to the importance of the ecosystem. Ecosystem capital affects around one-third of all physical investment capital (including infrastructure).

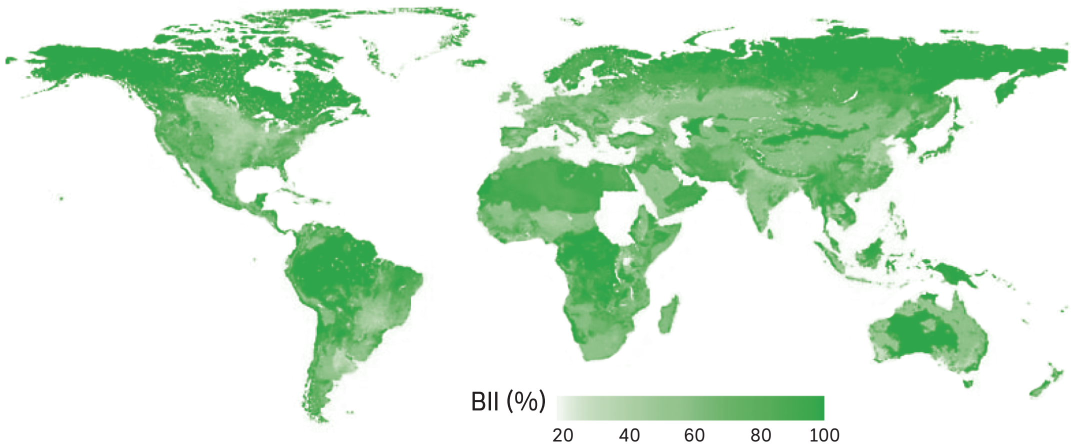
The contribution of the ecosystem to global GDP is sizeable, 6–12 trillion annually in current USD terms and 10–20 trillion in PPP terms. This also suggests that ecosystem stocks are hugely undervalued as they are measured today.

The message of this chapter is that ecosystem capital is vital to output and growth. The United Nations report that financing for nature would need to reach more than USD536 billion a year by 2050, representing a four-fold increase from today [UNEP (2021)]. While this required financing may seem large, it is fairly small relative to the contribution of ecosystem capital to global GDP. Seen in the context of the sizeable contribution from nature, this also suggests even an accelerated expenditure on nature would still be small relative to its true value and could have high payoffs.

Box A: How BII Correlates with EPI Indicators

As described in the chapter, the BII provides a granular, geospatial assessment of the intactness of natural ecosystems that can then be aggregated at the economy-wide level. A visual sample of BII is provided in Figure A1 below. By regressing the BII with various EPI and other indicators, it is possible to discern correlation or potential causal relationships. This provides a more contextual understanding of BII.

Figure A1: Geospatial BII Estimate in 2020



Source: Natural History Museum, UK

The EPI dataset provides 40 performance indicators over three broad categories—climate change, environmental health and ecosystem vitality. For climate change, the indicators include emissions of carbon dioxide, methane, greenhouse gas emissions per capita, among others. For environmental health, indicators include levels of air pollution, use of household solid fuels, sanitation, recycling rate, water safety, solid waste management, etc. For ecosystem vitality, indicators include the level of land or marine environment placed under protection, sustainable nitrogen use, strength of species protection, wastewater management, etc. The result of the stepwise regression is provided in Appendix 1. Only variables meeting the cutoff of P=0.1 are displayed.

Land size is the single most important variable correlated with the BII. Unsurprisingly, population and income (as measured by per capita GDP in PPP) have negative correlations with BII. This also underscores why treating for endogeneity is important, as explained in the main chapter, as there will be a concern that income growth itself (the dependent variable) is depleting natural or ecosystem capital stocks.

The positive and strong coefficient for recycling shows that economies that have strong recycling practices are also those that conserve the ecosystem. While the sign of the correlation is not surprising, the strength of this indicator is. Unsafe sanitation has a small negative correlation with BII, providing some hint that investments in infrastructure to provide safer sanitation can positively impact the ecosystem too. Methane growth and particulate exposure (PM2.5) are all unsurprisingly negatively correlated with BII.

A few variables seem to be "wrong-signed" but can be explained by the tension between state of current endowments (which is measured by BII) and actions (which is measured by EPI). Economies with more use of household solid fuels, more exposure to sulfur dioxide and tree cover loss tend to be emerging markets and developing economies (EMDEs) where BII remains relatively more intact but simultaneously present greater opportunities for exploitation (compared to advanced economies). This also highlights the need to aid EMDEs for sustainable development and preserve natural ecosystems as a global public good.

CHAPTER 3

NATURE AND SOVEREIGN DEBT

Highlights

- Nature and biodiversity loss risks are not sufficiently factored into existing creditworthiness and debt sustainability assessments. The impact of nature and biodiversity loss on the GDP, sovereign credit ratings, debt distress risks and interest costs is not negligible, particularly for vulnerable developing countries.
- Proper conservation and valuation of nature can increase debt capacity of developing economies by allowing them to borrow against nature's productive services. Conversely, the destruction of nature can harm future GDP and hence debt capacity.
- Innovative financing solutions in the sovereign debt space can be and are being developed, which can improve both nature and debt and better commit sovereigns to conservation efforts. To realize the upside offered by the nexus of sovereign debt and nature, governments must bring nature risks into public financial management, including by improving coordination and data.

This chapter discusses the nexus between nature loss and sovereign debt. It models the impact of a partial collapse of ecosystem services on the creditworthiness of countries and their debt service. It also discusses how nature loss and biodiversity considerations can be integrated into public financial management to help harness sovereign debt markets toward better debt and nature outcomes.

Nature loss is now becoming an existential threat to many economies, with complex, evolving and nonlinear dynamics that remain a source of great uncertainty. According to estimates used in this chapter [Johnson et al. (2021)], the GDP impact of a partial ecosystem collapse affecting just marine fisheries, wild pollinators and tropical timber production would exceed that caused by the COVID-19 pandemic in around half the countries analyzed.

This would have wide-ranging economic and social repercussions. One of them, of particular interest to governments, finance ministries and the financial sector, is the impact on countries' finances, debt, creditworthiness and credit ratings. After all, the pandemic has been the biggest ever single trigger for an unprecedented wave of sovereign downgrades [Tran et al. (2021)], while for many economies, nature loss can lead to even more severe consequences.

However, market actors face a fundamental challenge. Despite growing evidence of the economic consequences of ecological decline, there is still no agreed strategy for translating information about environmental degradation into actionable financial metrics. It is not enough to know that nature loss is bad. Firms, investors, financial institutions and regulators need scientifically credible information on how ecological decline translates into material financial risks and how to price and manage those risks.

3.1 Nature Loss and Climate Change

The slow progress in acknowledging and understanding the consequences of nature and biodiversity loss contrasts somewhat with the substantial consideration given to climate change. For example, the Intergovernmental Panel on Climate Change was established in 1988, while its nature-oriented counterpart, the Intergovernmental Panel on Biodiversity and Ecosystem Services, was not established until 2012. Similarly, the Taskforce on Climate-related Financial Disclosure was established in 2015, whereas the Taskforce on Nature-related Financial Disclosure was only in 2021.

One potential reason for this could be that climate change and its contributing factors are inherently easier to summarize in simple measures: tons of emission and the atmospheric concentration CO_2 equivalent. In contrast, nature and biodiversity are as complex and varied as the genetic code of life on Earth. Moreover, whereas greenhouse gases are uniformly mixing pollutants, nature loss is more locally determined. Accordingly, the science and economics of identifying, pricing and managing the risks they create will be distinct.

Nonetheless, there is potential, if not momentum, for improvement. The literature on the economic impact of nature loss is growing. The root causes of biodiversity loss are typically well understood by ecologists, and progress in satellite surveillance has made it easier to track developments such as land use change at ever finer spatial resolution. While greenhouse gas emissions are harder to track (and can be hidden), the loss of nature and biodiversity is more physically evident. This may create the opportunity for greater ownership, better verification processes and alignment that underpin key financial products such as nature KPI-linked bonds.[11]

Furthermore, given constantly improving information and the potential size of the related economic risk for individual sovereigns, including nature risks into sovereign risk frameworks is not only expedient but inevitable.

3.2 Public Debt, Creditworthiness and Ratings

Public debt has grown five-fold since 2000, compared with a three-fold increase in GDP. In principle, rising public debt need not be a cause for concern. Debt is the main mechanism through which nations invest in themselves, supporting long-term investments in infrastructure, social development and other productive sectors. However, past overspending and the spike because of the pandemic in 2020-2021 have sent debt levels to new highs and sparked concerns about a debt crisis in many economies. Public debt is more of a burden for developing economies than advanced ones. For example, interest payments as a share of revenues are 7.9 percent in developing economies, compared with just 4.0 percent in the developed world.

A key determinant of the cost of public debt is the perceived creditworthiness, which reflects the government's ability and willingness to meet its debt obligations in a timely manner. Creditors typically assess various economic, fiscal and political factors to assess creditworthiness to determine the interest rate at which they are willing to lend. Credit rating agencies are key players in this process, working to identify, assess and quantify risks. They combine objective data with subjective assessments and

[11] Voluntary carbon markets have yet to be wholly successful in part due to the difficulty of verification and concerns over greenwashing. With improved technology, there should be improved mechanisms to monitor nature's health, which will also be vital to supporting the development of nature financing.

assign a standardized "sovereign credit rating," translating the relevant information into a set of codified metrics. Even though sovereign ratings apply to governments only, they impact all debt markets by effectively imposing a ceiling on ratings of other issuers in a jurisdiction. Sovereign downgrades often trigger immediate downgrades of corporates and financial institutions [Almeida et al. (2017)]. Thus, to the extent that nature loss reduces sovereign creditworthiness, there are indirect impacts on all economic actors and asset classes.

3.2.1 Nature Loss and the Financial System

Markets are waking up to the risks posed by nature and biodiversity loss. While climate concerns have dominated the World Economic Forum's Global Risks Reports and annual risk perceptions surveys, biodiversity loss is now ranked fourth by severity in the most recent issue [WEF (2023)]. For example, recent work by the Bank Negara Malaysia and the World Bank shows that some 54 percent of the commercial lending portfolio of Malaysian banks is exposed to sectors that depend to a large extent on ecosystem services [World Bank (2022)].

Investors are trying to incorporate these risks into decision-making. Firms, industry groups, NGOs and international institutions are developing toolkits, sustainability strategies, and ESG criteria to monitor and help mitigate nature-negative impacts. Understandably, these efforts start with designing disclosure and reporting requirements.[12] Efforts seem more advanced at the level of individual corporates, trying to assess exposures to and impacts on nature and biodiversity with a view to reducing regulatory, reputational and operational risks.

However, scrutiny over sovereign debt is much less developed. There could be several reasons, including lack of ultimate supervision over sovereigns (unlike over financial systems), difficulties in tracing nature and biodiversity loss risks to macroeconomic outcomes to debt metrics, and lack of applicable and coherent methodologies.

Indeed, an analysis of USD783 billion worth of sovereign bonds issued in 2020 with long maturities found that three-quarters of analyzed prospectuses did not disclose any climate or nature-related risks [NatureFinance (2022)]. Significant economic and financial risk is unaccounted for by overlooking nature, therefore understating the threat of debt crises.

3.2.2 Modeling the Nexus between Nature Loss and Sovereign Creditworthiness

Nature-related macro-fiscal risks can manifest in myriad ways. In addition to lower future GDP, the loss of biodiversity and critical ecosystem services can erode direct and indirect taxes on agricultural production, fisheries and tourism [Johnson et al. (2021)]. The losses from climate change and nature's degradation can also be mutually reinforcing—e.g., loss of mangroves as carbon sinks on the one hand and greater physical destruction from storms on the other.

Spending pressures can also arise from outlays to compensate economic actors whose livelihoods are adversely impacted, for investments into nature conservation or for remedial action to restore damaged ecosystems.

If nature loss can severely impact macroeconomic performance, sovereign credit risk assessments must begin incorporating nature-related risks. Failing to do so would undermine their credibility, usefulness in financial decision-making and, ultimately, financial stability. Yet, the science behind measuring the impact on a sovereign's creditworthiness and ability to service its debts remains nascent.

[12] The Taskforce on Nature-related Financial Disclosure consists of 40 senior executives from financial institutions, corporations and market service providers. The Network for Greening the Financial System consists of 127 central banks and financial supervisors to develop environment and climate risk management in the financial sector. In March 2022, jointly with INSPIRE, it issued recommendations to (1) recognize the potential economic and financial risks, (2) build capacity to analyze these risks, (3) assess exposure through scenario and stress tests, (4) explore new supervisory standards and (5) help build the necessary financial architecture to mobilize investment for a biodiversity-positive economy [NGFS (2021)]. The Kunming-Montreal GBF aims to put biodiversity on a path to recovery by 2030 by calling on financial institutions to act on nature. The 23 targets of the Framework provide for the alignment of financial flows toward reversing nature loss, either deterring flows into harmful activities or directly encouraging flows into activities that protect biodiversity.

Background research for this report, summarized in this section, adds to the literature by developing a set of biodiversity-loss-adjusted sovereign ratings. It is done by measuring and incorporating the impact of a partial ecosystem collapse on ratings and interest payments.[13]

Following Agarwala et al. (2022), who developed a procedure for re-constructing sovereign ratings while incorporating results from integrated environmental economic research, the modeling process is as follows:[14]

- **Step 1:** Training a machine learning model to predict credit ratings based on historical data.

Data and credit ratings (for 2015-2020) are from S&P, a major credit rating agency. The six variables chosen as the basis for predictions are measures of current account balance, net government debt, fiscal balance, net external debt, real GDP growth and GDP per capita.[15] The data is used to train a machine learning algorithm (formally, a random forest classification model) to "predict" past credit ratings. The accuracy is high, and the model has sufficient predictive capacity to subsequently derive new credit ratings with new data adjusted for nature loss.

- **Step 2:** Adjusting the data on economic performance for the impact of nature loss.

Country-specific GDP impact due to the depletion of natural capital and ecosystem services are taken from the newly published Johnson et al. (2023), which is our innovation upon Agarwala et al. (2022), who use earlier estimations from the predecessor study [Johnson et al. (2021)].[16] Both of these studies examine the potential impact of changes in the provision of three selected biodiversity-dependent ecosystem services—wild pollination, tropical timber production and marine fisheries—on GDP across a range of economies. Two scenarios are explored: a "business-as-usual" baseline and a "partial ecosystem collapse," leading to a rapid deterioration in the provision of ecosystem services.

To adjust variables other than GDP, an auxiliary model is estimated on a relationship of how GDP losses translate into changes in these variables based on methods and data in S&P (2015) and Klusak et al. (2023).

- **Step 3:** Running the model (outlined in Step 1) with adjusted data (outlined in Step 2) to derive biodiversity-adjusted sovereign credit ratings.

- **Step 4:** Using the new credit ratings to estimate the associated increase in debt service payments.

This is done by estimating the relation between ratings and spreads on sovereign bonds and multiplying the resultant increase in spreads due to rating changes by total debt outstanding.[17]

3.2.3 Results

First, according to Johnson et al. (2023), a collapse of the three selected ecosystem services could lower global annual GDP in 2030 by some USD2 trillion (or 2.3 percent).[18] The impact ranges from

13 More specifically, this section expands on the existing analysis by Agarwala et al. (2022), by applying refined estimates of the impact of the ecosystem collapse on GDP, as presented in Johnson et al. (2023).

14 The conceptual framework builds on that presented in Klusak et al. (2023), which has a similar model to produce the world's first climate-adjusted sovereign credit rating for 109 countries.

15 In addition to predictive capacity, the criteria for selecting variables are relevance to sovereign credit ratings, scientific and economic evidence for adjusting the variable for nature loss, and availability for a broad range of countries.

16 The main difference between Johnson et al. (2021) and Johnson et al. (2023) is that in the former, the economic losses associated with ecological decline are further interacted with economic growth, whereas in the latter, recognizing that economies are still expected to grow, growth is allowed to continue unabated to 2030 with the impact of nature loss then subtracted. The 2023 version has a global GDP shortfall of some USD0.7 trillion lower than the 2021 version.

17 "Spread" means an interest rate (yield) on a sovereign bond minus the risk-free rate (that is presumably the same for everyone). The data on spreads for each rating bucket (AAA through to CCC) is taken from the Federal Reserve. A third-degree polynomial fits the data well.

18 Results from this modeling process require careful interpretation. First, the losses referred to here are counterfactual losses, representing subtractions not from today's GDP but from the higher levels that can be expected in the future. There is no prediction of negative GDP growth. Second, the risks described here are stochastic in nature and exceedingly difficult to predict. Thus, the ecosystem collapse scenario could appear before 2030, in 2030, after 2030, or never. No probabilistic statement is made about the date such an event could occur. However, these ecosystem services were selected because there is evidence that they could be nearing a tipping point.

Table 1: Description of the Ecosystem Service Scenarios Used in the Analysis

	Business-as-usual	Partial ecosystem collapse
Brief description	Nature continues to decline at its current rate out to 2030. Nature loss reduces ecosystem service provision, with knock-on effects for the rest of the economy.	Nature suffers a partial collapse. Key ecosystems face tipping points. Domino effects of ecosystem service loss on the rest of the economy.
Key biophysical effect	Conversion of 46 million hectares of natural land between 2021 and 2030 to managed forests (+17m ha), pastureland (+15m ha) and cropland (+13m ha)	Loss in agricultural productivity due to pollinator loss, loss in marine fisheries productivity due to reduced biomass, widespread conversion of tropical forest to savannah
Ecosystem projections	· 0.3% reduction in global forestry production · 2.8% reduction in global marine fisheries production · 791m metric tons of CO_2 (additional) · 2.8% increase in pollinator-dependent agriculture (due to agricultural land expansion)	90% reduction in the flow of ecosystem services value of: · wild pollination · marine fisheries · timber provision
Economic projections	Global loss of GDP of USD75 billion	Global GDP in 2030 lower by USD2 trillion (compared to the baseline)

zero to 15 percent of GDP and is significantly higher for developing economies like Bangladesh, Pakistan or Viet Nam. This is consistent with the consensus that developing economies will bear the greatest adverse impact of environmental changes, as they rely more on sectors vulnerable to physical risks and natural resource depletion, such as agriculture and tourism.

Second, the simulated credit ratings suggest that countries experiencing ecosystem collapse could be downgraded between zero and six notches. An interesting feature is that the GDP loss and the associated downgrades do not follow a linear relationship—namely, countries with larger GDP loss could be downgraded less than those with lower GDP loss—depending on the initial credit rating and other variables.[19]

Finally, the estimated increase in the annual interest costs related to the downgrades due to nature loss ranges from zero to USD43 billion. This represents between zero and 1.2 percent of today's GDP for the economies considered under the study. It is important to remember that it comes on top of the nature-loss-related decline in fiscal revenues and potentially higher expenditures to mitigate the impact. As nature loss reduces economic performance, it will become harder for countries to service their debt and finance the critical social, infrastructure and other development spending.

3.3 Nature and Biodiversity Loss in Debt Sustainability Analysis

The International Monetary Fund (IMF)'s debt sustainability analysis (DSA) is a centerpiece of the global development finance architecture, guiding borrowing countries and their official lenders on safe debt levels and serving as an early warning system to preempt debt crises. A DSA comprises a series of standardized stress tests and scenario analyses to evaluate the country's vulnerability to a payment crisis. It is thus critical that all material risks are considered, including climate and nature loss.

Indeed, in recent years, the IMF has been ramping up its capacity to address the challenge. It has begun considering climate risks within the DSA and other macroeconomic surveillance processes. It has also created a new lending mechanism, the Resilience and Sustainability Trust, with the explicit mandate to help countries face long-term global challenges,

[19] This is a common finding in the emerging literature on sovereign ratings and environmental decline [Agarwala et al. (2022)].

starting with the climate change agenda. However, the explicit and systematic consideration of nature risks in existing sovereign debt surveillance exercises is still lacking.

In an early effort to reduce this gap, Kraemer and Volz (2022) describe how the DSA could address nature and biodiversity risks more rigorously. Attempting to remain as close as possible to the original DSA methodology, they employ a procedure similar to the one described in the previous section and apply it to six countries (Bangladesh, Brazil, Canada, Indonesia, Nigeria and Viet Nam) to evaluate the impact of a partial nature collapse scenario alongside existing standard IMF stress tests. In half of these economies, the nature loss shock turns out to be on par or more severe than the otherwise most severe "combined macroeconomic shock" scenario—both in terms of debt levels and gross financing needs—potentially tipping some of these countries into a higher debt distress risk category. These results call for a more systematic consideration of nature risks in debt assessments.

3.3.1 From the Point of View of a Sovereign Issuer

Nature risks are not only increasingly material for sovereign debt investors. As sovereign debt issuers, governments are also pressured to factor nature into their fiscal policy frameworks and debt management strategies. This stems both from a growing awareness by debt management offices (DMOs) housed within finance ministries about the macro-fiscal risks emanating from nature and biodiversity loss, as well as demands from market participants (investors, rating agencies) and civil society.

DMOs are tasked with identifying possible funding sources; managing debt portfolio risks; and managing relationships with investors, rating agencies, underwriters and other market participants. They evaluate different debt issuance strategies to finance pre-defined fiscal deficits and select the optimal composition of debt instruments based on the implied borrowing costs and the impact on relevant risk indicators. To that end, public debt managers employ various techniques and analytical frameworks, including DSAs and sovereign rating analysis (the conclusions drawn in previous sections about the implications of nature and biodiversity loss in sovereign risk assessments apply equally to them). In particular, sovereigns could see significant disruptions to their funding plans as nature risks are factored into DSAs, credit ratings and investors' risk perceptions. Such disruptions can manifest through several channels:

- **Macro-fiscal risks:** Nature loss can generate larger-than-planned fiscal deficits requiring additional funding to cover the shortfall, possibly on less favorable terms than under the original borrowing plan.
- **Refinancing risk:** Macro-fiscal risks can lead investors to reassess their sovereign risk exposures and reprice bonds to the point of locking vulnerable sovereigns out of international capital markets. This may be because the nature risks have crystallized, such as when critical ecosystems like reefs rapidly degrade, or because bond investors have gained a greater appreciation for sovereigns' nature impacts and dependencies. If refinancing to roll over maturing obligations is not forthcoming or too costly, then sovereigns may be pushed into debt distress.
- **Market risk:** Aside from widening spreads, public debt dynamics can be adversely impacted by fluctuations in exchange rates. Economies with high dependencies on natural assets for hard currency liquidity are particularly vulnerable. A country that derives a significant share of its foreign exchange earnings from nature tourism or extraction from nature could experience significant currency depreciation if that natural asset is impaired.

In addition to the challenges of integrating nature into liability management, sovereigns also need to consider its impact on the asset side of the balance sheet. To the extent that the government's holdings of financial assets depend on nature, they face the same calculus as investors in their debt: assess and mitigate the exposure to nature loss or suffer potential write-downs and deteriorations in net creditor positions and, by extension, creditworthiness.

3.4 Nature as an Asset – A Key Opportunity

So far, this chapter has focused on risks posed by nature loss to debt management and sustainability. However, there is substantial upside potential for sovereign's balance sheets, debt and credit.

First, nature can serve as a buffer against climate shocks by reducing physical vulnerabilities (e.g., coral reefs or mangroves as flood prevention), as discussed in many places in this report.

Second, nature constitutes a physical asset on the sovereign's balance sheet in the form of renewable capital, such as terrestrial and marine reserves, although this fact is still mainly a theoretical construct. Few countries currently produce sovereign balance sheets, let alone ones that recognize nature [Johnson et al. (2021)]. However, in principle, proper conservation, valuation and accounting for nature can increase the debt capacity of emerging economies by allowing them to borrow against nature's productive services. There is a great interest among developing countries to use nature assets to unlock more development finance, create new drivers of growth and improve resilience. More work and attention directed to this area is necessary to make this possible.

Finally, nature can enable sustainability-linked sovereign financing. As discussed in the last chapter, it can be the basis for obtaining credit enhancements for debt instruments from development banks and finance institutions. Credit enhancements can meaningfully improve the risk characteristics of sovereign debt by lowering the cost of funding, extending tenors and attracting more "patient" sustainability-oriented investors, which mitigates refinancing risk [Willems and Zoltani (2022)]. For example, thanks to nature assets, structures such as debt-for-nature swaps are possible, with the potential to both contribute to conservation efforts and improve debt sustainability.

The Belize case study (see Box B) demonstrates the power of nature risks to exacerbate debt vulnerabilities or even trigger debt distress—a cautionary tale for DMOs whereby past debt sustainability assessments clearly discounted the risk of future macro-fiscal shocks. But Belize's case also shows the potential for innovative sovereign financing solutions such as debt-for-nature swaps and credit enhancement to improve both nature and debt. This particular structure became the template for subsequent debt for nature swaps in Ecuador (May 2023) [Campos and Jones (2023)] and Gabon (August 2023) [Savage (2023)].

3.4.1 Bringing Nature Risks in Public Financial Management

As economies small and large confront escalating nature risks due to accelerating biodiversity loss, nature risks must feature more prominently in sovereigns' medium-term fiscal frameworks, financing plans and debt management strategies, especially since nature risks tend to crystallize gradually rather than as shocks. And because nature risks inevitably touch on issue areas under the purview of other ministries, notably of the environment and the central bank, effective coordination and information sharing around nature risk management is critical.

Bringing nature into public financial management necessitates enabling data infrastructure and tools that can accurately measure the state of nature and extract meaningful and actionable insights for decision-makers. Nature data sets, such as geospatial imagery or ground-sourced remote sensing, are frequently unstructured, large and dispersed across public- and private-sector databases. Many finance ministries lack the data systems and governance arrangements to effectively mine these unconventional data sources. This limits the extent to which they leverage nature risk data for monitoring, analysis and reporting, as well as the range of nature-based solutions that can be developed.

For example, sustainability-linked sovereign debt, or any performance-based financing mechanism incorporating KPIs, be it nature-oriented or otherwise, needs robust pipelines that guarantee the quality of the data coursing through them. Investors are unlikely to purchase KPI-linked instruments that raise doubts about the integrity of indicators that determine whether performance-based penalties or rewards are triggered.

Transparency and traceability are key, as is a secure, single source of truth about performance that can be sustained throughout the life of the linked debt instruments. For this, governance frameworks need to lock in data sharing and reporting protocols over successive political cycles. This applies as much to other line ministries supplying data and to third-party providers such as satellite imaging companies. Failure to establish durable quality assurance processes would likely lead investors to offload the instruments or refrain from buying them.

Aside from KPI-linked financing, nature data measurement, verification and reporting by sovereigns will likely become increasingly salient for other reasons. As investors internalize the importance of nature as a risk factor, and with the growing adoption of sustainable reporting regulations such as the EU's Sustainable Finance Disclosure Regulation (SFDR) and standards such as TNFD, demands on sovereign issuers to disclose their nature dependencies and impacts will grow. Issuers will likely need to disclose the nature risk management practices in future bond prospectuses.

Sovereigns will also be under increased pressure to credibly demonstrate alignment with biodiversity commitments and be held to account for failing to deliver. One of the best ways of doing so would be via sovereign debt markets, which are known to have a strong disciplining effect. For example, commitments could be embedded into performance targets of KPI-linked debt via coupon step-ups or step-downs. Hence, the importance of the nexus between nature loss and sovereign debt.

Box B: Belize's Nature Dependence, Debt Distress and Debt-Nature Solutions

Tourism accounts for around 40 percent of GDP, employment and exports in Belize. Tourism-related taxes (e.g., cruise ship passenger taxes, accommodation taxes, etc.) comprise a substantial portion of the fiscal revenue base. Most tourism activity centers on biodiversity hotspots like the Barrier Reef Reserve System and mangrove reserve. These have been buffeted by hurricanes, rising sea temperatures and overfishing. Heavy dependence on nature tourism creates acute macro-fiscal risks for the sovereign, as four successive debt restructurings since 2000 have shown.

Each restructuring event was driven by a combination of catastrophic hurricanes and downturns in tourism activity on top of persistent fiscal and external vulnerabilities. Until 2022, none of them meaningfully eased the debt burden. By the time of the COVID-19 pandemic in 2020, Belize's debt had climbed to 133 percent of GDP, a significant portion of which (30 percent) was in the form of a so-called "superbond," an instrument consolidating previous external debt into a single issuance.

A meaningful resolution of the debt problems was finally achieved in 2022, when the government extinguished the superbond (at a discount) via a debt-for-marine protection swap with The Nature Conservancy, thereby cutting public debt by 12 percentage points of GDP in 2021 and generating significant savings in debt service over the long term. A "Blue Bond" issued by a subsidiary of The Nature Conservancy and wrapped with a credit enhancement from the US Development Finance Corporation provided low-cost funding for the buyback while also channeling nearly USD200 million into conservation funding over the next 20 years. As part of the arrangement, the government also committed to protecting 30 percent of its ocean, including parts of the reef, by 2026.

CHAPTER 4

NATURE AS INFRASTRUCTURE

Highlights

- Nature provides essential services. Restoring nature—or nature as infrastructure—thus provides the restitution or enhancement of important services. This overlaps and relates to nature-based solutions (NBS), where natural processes are harnessed with traditional infrastructure to provide the best results.
- Tree planting in the northern counties of China is found to have a small beneficial impact on dust conditions for counties further south without compromising agricultural productivity. In Indonesia, mangroves are found to reduce losses from tidal floods. The wetlands of Bangladesh support critical primary industries and livelihoods.
- Testing the best solutions customized to the local environment is crucial for nature infrastructure. Successfully harnessing nature as infrastructure combines scientific research, effective implementation and consultation with local communities.
- The local governance of nature infrastructure is critical. Engaging local decision-makers and communities is vital to the project's sustainability in the long run. This will require a combination of policy incentives, including short-term fiscal support and commercialization of ecological services values from nature infrastructure.

Infrastructure comprises basic facilities or organizational structures needed for a society's operation. By this account, nature is arguably the most significant infrastructure sustaining human civilizations. Different ecological systems such as oceans, rivers, forests, mangroves or coral reefs continue to bring critical but largely unpriced ecological services. For example, four billion people still rely on medicines originally found in the natural world, 75 percent of food production depends on pollination by animals in the wild, and land and ocean systems are the most important carbon sinks [IPBES (2020)]. Investing in nature as infrastructure should be as important as investing in conventional grey infrastructure, especially in light of the on-going degradation of the natural environment and climate change.

There are two concepts worth elaborating on. Nature-based solutions (NBS) are "actions to protect, sustainably manage, and restore natural or modified ecosystems" to address societal challenges.[20] For example, developing wetlands alongside rivers to reduce flood risks is considered NBS. On the other hand, nature infrastructure focuses more on the ecological systems and landscapes, providing valuable ecosystem services. One example is planting trees or reforestation. These two concepts are not mutually exclusive. There is overlap, and NBS and nature infrastructure are often used interchangeably to describe efforts to restore ecological systems. This chapter will showcase examples of NBS and nature infrastructure (allowing some overlaps between the two). There will be descriptions of projects and also more quantitative analyses of their impact.

4.1 China's Sanbei Program

Historically, there are only a few cases where restoring nature as infrastructure was carried out on a massive scale. China's Sanbei Program is one of such sizeable ecological restoration or conservation programs in the world.[21] Officially launched in 1978, the program aims to restore plant coverage in almost all parts of northern China, particularly the arid areas in the northwest to improve adverse environmental conditions in northern China, such as severe soil erosion and frequent episodes of sand and dust blowouts that had long disrupted local agricultural activities.

As of 2020, Sanbei had completed the first two phases of its 1978-2050 plan. Now in its third phase (until 2050), the program has evolved from the massive planting of single tree types in the early stage to more science-based, comprehensive approaches that involve restoring various plant species tailored to local environments. Between 1978 and 2017, the forest coverage rate in the Sanbei area increased from 5.1 to 13.6 percent. Grass and forest coverage rate increased from 31.7 to 42.4 percent [NFGA (2019)]. Studies also show that the frequency of sand and dust weather declined. The area plagued by soil erosion declined by 66.6 percent or 44.7 million hectares. Furthermore, deserts in northern China seem to have stopped further expanding since 2000, with some areas becoming less severe deserts [CAS Earth (2020)].

Official statistics are also consistent with an international study published by the US National Aeronautics and Space Administration (NASA) using global data from the leaf area index (LAI).[22] LAI in China, particularly the north, has increased significantly between 2000 and 2017, where forest plantations contribute 42 percent to the greening [Chen et al. (2019)]. As a result, carbon sequestration capacity in China has been enhanced by Sanbei Program in the past two decades. It estimated that over 900 teragrams of carbon (TgC) sequestration were added by plant growth in northern provinces in China from 2000 to 2018 [Hu et al. (2022)].[23]

Table 2: Sanbei Program Total Investment 1978-2018 (USD Billion)

		Total	Central	Local	Rural Volunteer
Phase	Subphase	**13.52**	3.50	2.91	7.11
Phase 1	1978-1985	**1.37**	0.04	0.01	1.32
	1986-1995	**3.01**	0.09	0.08	2.84
	1996-2000	**2.53**	0.10	0.22	2.21
Phase 2	2001-2010	**2.86**	1.20	1.23	0.43
	2011-2018	**3.74**	2.07	1.37	0.31

Source: Official report of Sanbei Program [NFGA (2019)]. The value is converted to USD billion.

20 International Union for Conservation of Nature and Natural Resources: Nature-based Solutions | IUCN

21 三北防护林工程 Sanbeifanghulin. Sanbei translates into "three norths," referring to the three northern regions of China: the northwest, northeast and north.

22 Leaf area index is a widely used measure of green coverage on Earth's surface. In short, it measures the thickness of leaves per unit ground area. A higher LAI value indicates a greater amount of leaves. LAI typically ranges from 0 to 10, with 0 meaning no leaves on the ground (e.g., desert). Sometimes, the LAI data provider scales the range from 0 to 1000, which is more readable than decimal digits.

23 In Hu et al. (2022)'s Figure 7, the authors estimated total carbon change for northwest, north and northeast China to be around 300 TgC each between 2000 and 2018. Hence, the sum of the three areas would total more than 900 TgC.

Sanbei has primarily been funded by public finance resources, with subsidies for key inputs (e.g., seeds) and payments for workers. In earlier stages, workers were essentially volunteers from local communities, but this has evolved into more former work under the government's guidance.

Existing studies mainly focus on the overall trends of some key outcomes—plant coverage, dust weather frequency [Chen et al. (2019); Qiu et al. (2017); Li et al. (2023)]. But changes in these indicators are subject to non-human factor efforts. For example, changing climate conditions like wind speed have reduced dusty weather in north Asia in the past twenty years [Wu et al. (2022)]. Hence, careful selection of comparable groups is required to better understand and evaluate the impact attributable to Sanbei.

This analysis adds to existing knowledge by examining the impact of Sanbei on three main outcomes—plant coverage, agricultural production and sand dust weather—using difference-in-difference (DID) methods. This is followed by a discussion on the practical aspects of the Sanbei Program in terms of design and implementation and the challenges ahead.

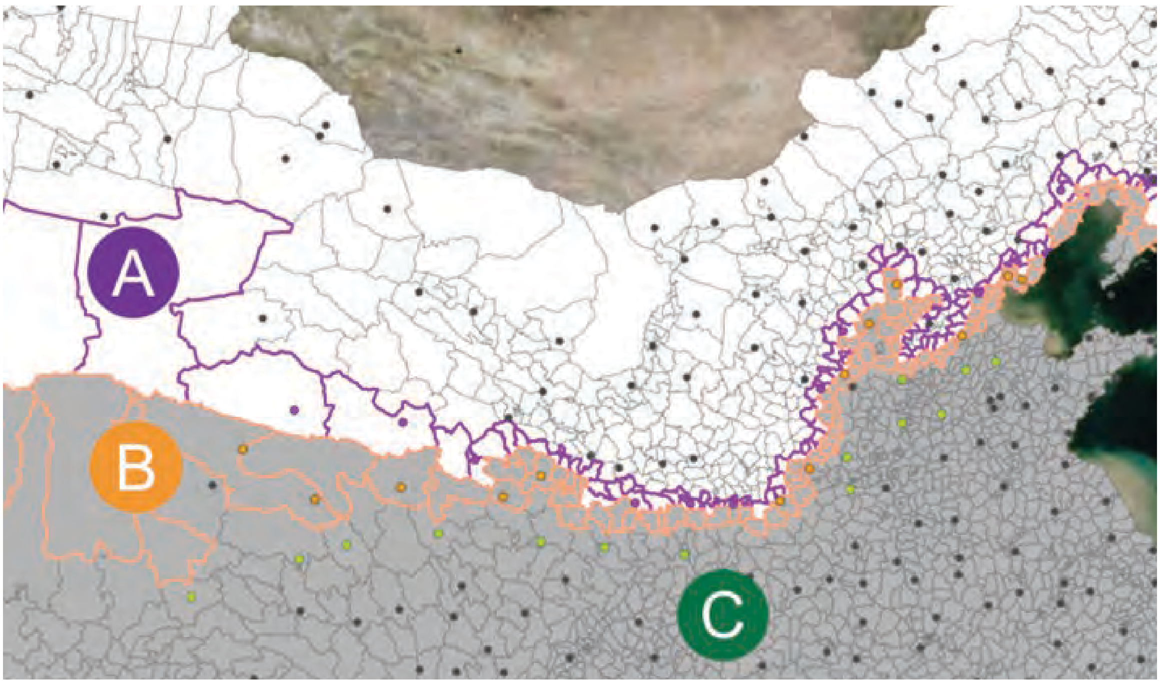
4.1.1 Empirical Analysis

Due to data availability, the analysis focuses on Phase 2 of Sanbei (2001-2020). During these two decades, 725 county-level administrative areas were assigned to be part of the program, including all the 551 counties that already participated in Phase 1 during 1978-2000. The key research design is one of border discontinuity, exploiting the differences between the program counties (A) and bordering non-program counties (B) (see Figure 1). As explained later, there is also a need to check against data in counties further south (C).

Overall greenness improved. Planting forests and grasslands takes time for impact to emerge.

Based on consolidated global LAI data, the analysis compared the annual average LAI of two groups of comparable counties, Group A and Group B. The participating counties (Group A) are compared to the non-participating counties (Group B). Counties in the sample (Group A and Group B) are bordered at least once to control for geography, and weather conditions are similar.

Figure 1: Sanbei Program, Phase 2 Counties



Source: Open source of China's county-level administrative polygons and official report of Sanbei Program [NFGA (2019)].

Note: The official report offers a complete list of historically participating counties in the Sanbei Program. AIIB staff cross-checked with other studies analyzing the Sanbei Program to ensure the administrative boundaries are accurate.

The average LAI increased 38 percent from 0.33 to 0.46 between 2001 and 2020 for all participating counties in the Sanbei Program's Phase 2 (Figure 2). This suggests that the layers of green leaves per unit area increased, including forest, grass and cropland. Visually, increases in LAI came from Sanbei areas in Shaanxi, Shanxi and Heilongjiang provinces (Figure 3). Growth of LAI in Phase 2 Sanbei participating counties appears to be faster than the other counties south of Sanbei's border, where LAI increased by 22 percent from a higher base of 1.31 in 2001.

A difference-in-difference (DID) analysis is conducted to compare LAI in Group A versus Group B. The results suggest that in the first few years of Phase 2, Group A LAI appears slightly higher than Group B (Figure 4). Higher LAI speaks to the impact of Sanbei's afforestation efforts at the Sanbei border.

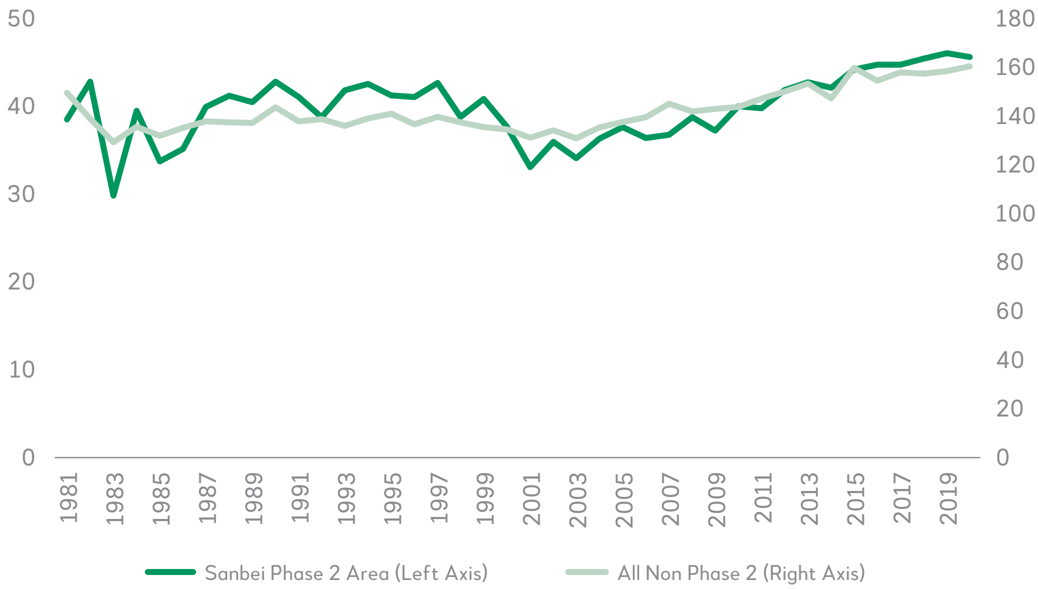
LAI only measures the unit area greenness of land surface, which can be affected by not just forest/grassland but also agricultural cropland. To understand how this major plant coverage developed during Phase 2, the analysis also looked at the European Space Agency's Land Cover data. Similarly, a DID analysis is conducted (see Figure 5). The forest growth rate of Group A is faster than Group B, but the difference became statistically significant only 12 years after Phase 2 implementation. Quite simply, forest growth took time. For grassland growth, the results are more mixed, with Group A counties experiencing a similar growth rate to Group B.

Group A counties also saw lower agricultural land growth, though not statistically significant. This is consistent with a major environmental policy—"return cropland to forest." Development of agricultural cropland was then restricted, and existing ones were required to be converted to forest or grassland. Encouragingly, the slower growth of agricultural cropland did not seem to slow agricultural production (see Figure 6).

The program reduced dust conditions in counties south of the planted trees, outside of the Sanbei area.

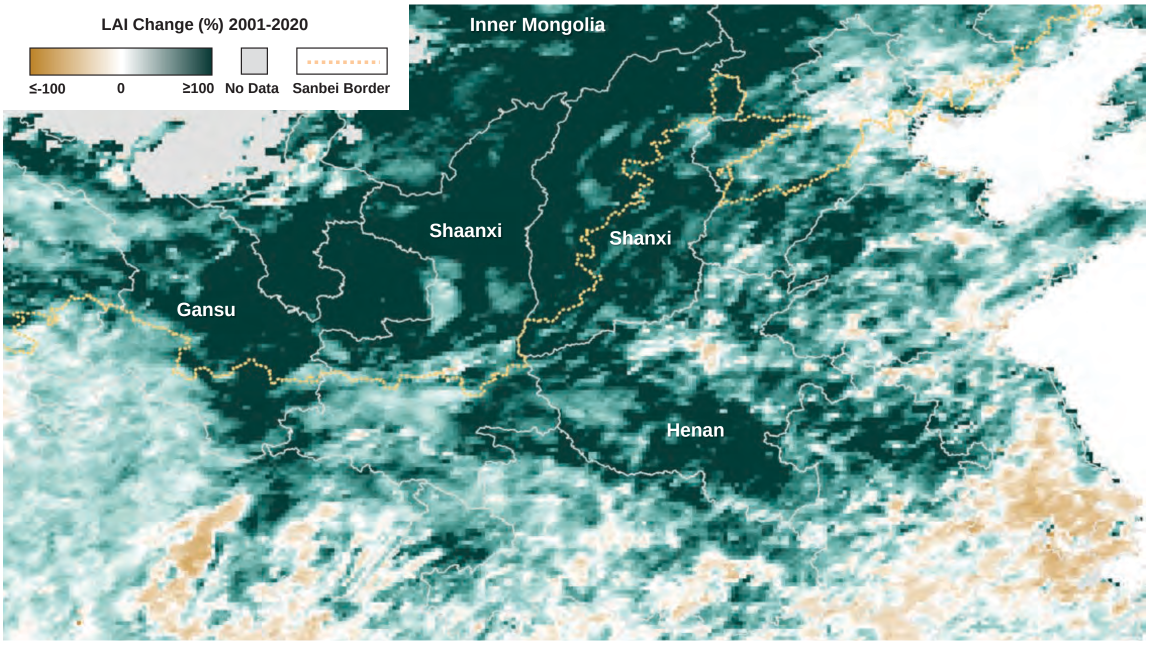
From the beginning, restored forests and grasslands were expected to control desertification and sand dust weather in northern China. Green barriers formed by trees, bushes and grass on the ground can help weaken the speed and strength of surface wind. Also, root systems can hold sand in place, weakening sand dust conditions. As restored plant coverage grew, local soil conditions, such as humidity and

Figure 2: Average LAI 1981-2020



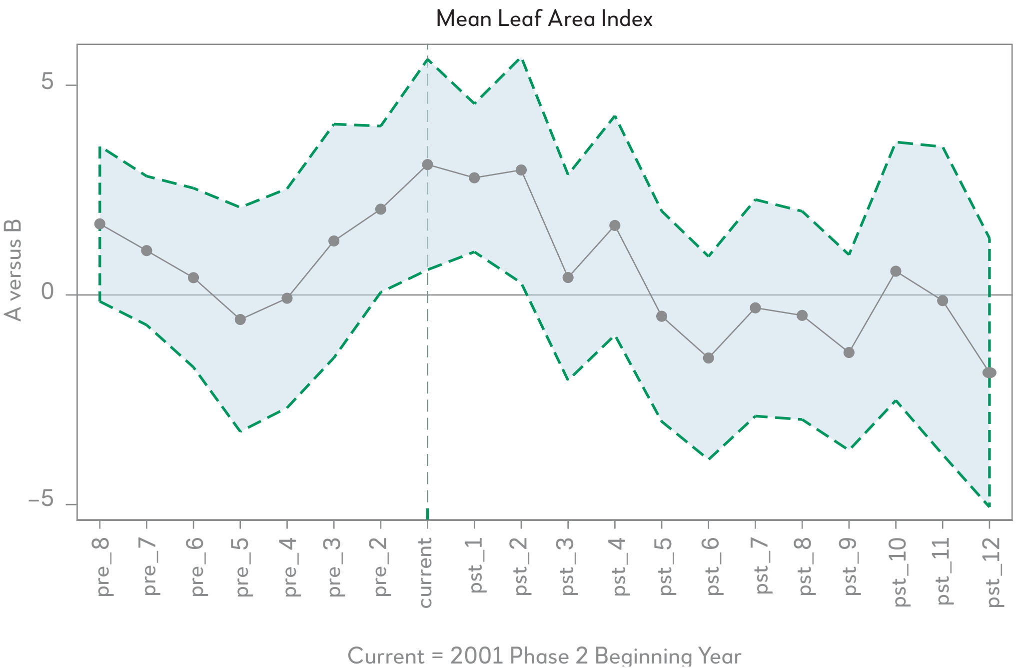
Source: AIIB calculation based on a consolidated leaf area index (LAI) time series by Liu et al. (2012). The LAI is the annual mean of eight-day or half-month periodical values of an eight-kilometer pixel global map.

Figure 3: LAI Change between 2001 and 2020



Source: AIIB calculation based on a consolidated leaf area index (LAI) time series by Liu et al. (2012). The LAI is the annual mean of eight-day or half-month periodical values of an eight-kilometer pixel global map. The yellow dashed line is the border of the Sanbei Program Phase 2 area.

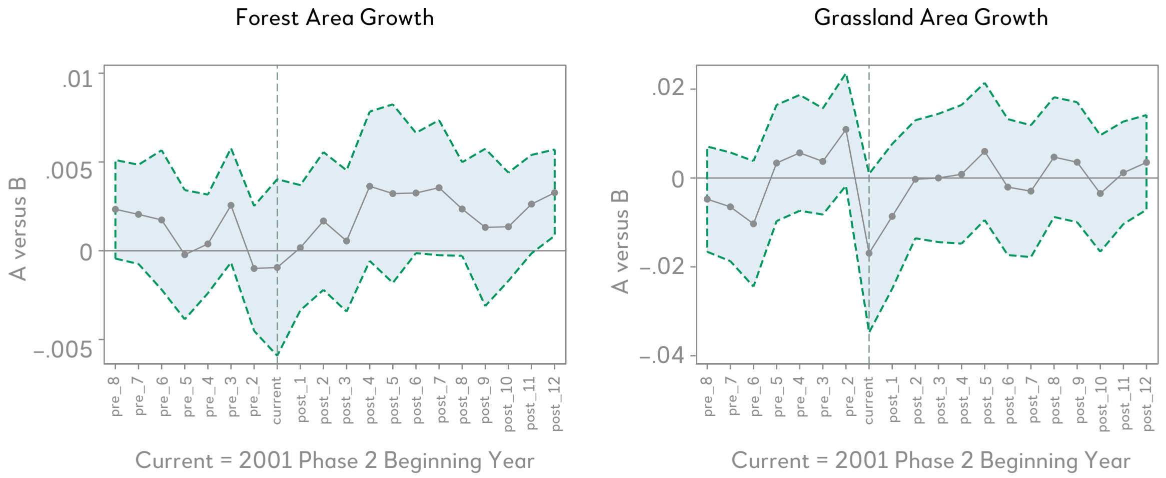
Figure 4: Leaf Area Index—Group A and Group B



Source: AIIB calculation based on a consolidated leaf area index (LAI) time series by Liu et al. (2012). The LAI is the annual mean of eight-day or half-month periodical values of an eight-kilometer pixel global map.

Notes: The policy year (current) is 2001, the starting year of the Sanbei Program's Phase 2. The LAI here is scaled to values between 0 and 1,000. The y-axis refers to the relative difference in average annual LAI between Group A and Group B.

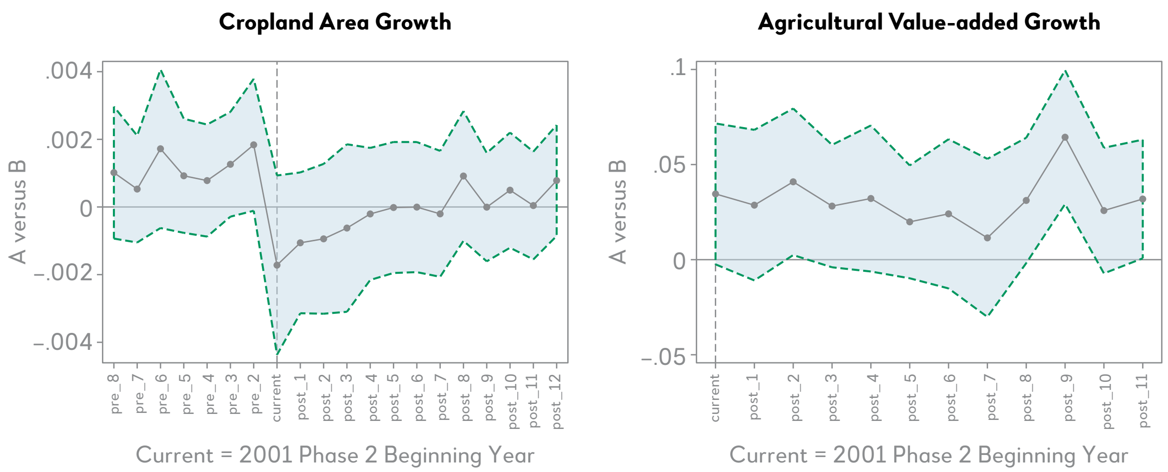
Figure 5: Forest and Grass Area Growth



Source: AIIB calculation based on the European Space Agency (ESA)'s Land Cover data. Forest and grassland areas are defined by the ESA classification [ESA (2017)]. Growth is annual.

Note: Policy year (current) is 2001, the starting year of the Sanbei Program's Phase 2.

Figure 6: Agricultural Cropland Area and Value-added Growth



Source: AIIB calculation based on European Space Agency (ESA)'s Land Cover data. Agricultural area is defined by ESA classification [ESA (2017)]. Growth is annual.

Note: Policy year (current) is 2001, the starting year of the Sanbei Program's Phase 2.

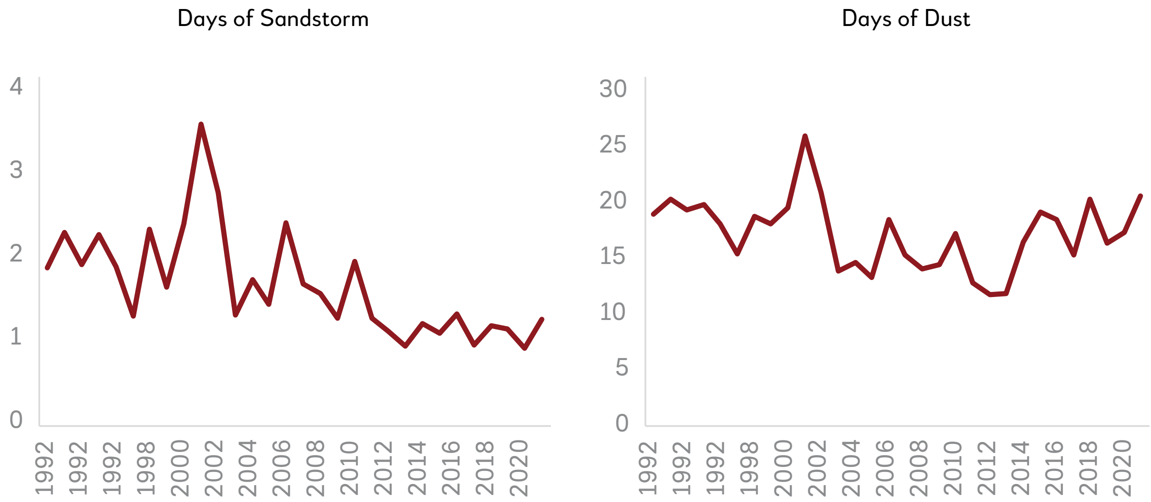
Source: AIIB calculation China's county-level economic data. Agricultural value-added time series at this level is available only from 1999. Growth is annual.

Note: Policy year (current) is 2001, the starting year of the Sanbei Program's Phase 2.

nutrients, would gradually improve, allowing more plants to survive. This should result in a virtuous cycle to slow desert expansion.

Official data shows that sandstorms in the region declined between 1978 and 2015, from roughly six days per year to less than three [NFGA (2019)]. This is confirmed with meteorological station data in this analysis, where average annual days of sandstorms recorded by stations in Phase 2 counties fell between 1992 and 2021. For less severe sand-related weather like sand dust, the Sanbei area saw declining days between 1992 and 2013, from 20 to 12 days. Since 2014, dust weather days have picked up and reached 20 days again in 2021.

Figure 7: Phase 2 Area Annual Days of Sand Dust Weather



Source: AIIB calculation based on monthly sand dust weather data from the National Meteorological Information Center under the China Meteorological Administration.

Notes: Annual days refer to the total number of sandstorm/dust weather days per station. The figures above show the mean total number of days from these sand dust weather stations located in the Sanbei Program's Phase 2 counties.

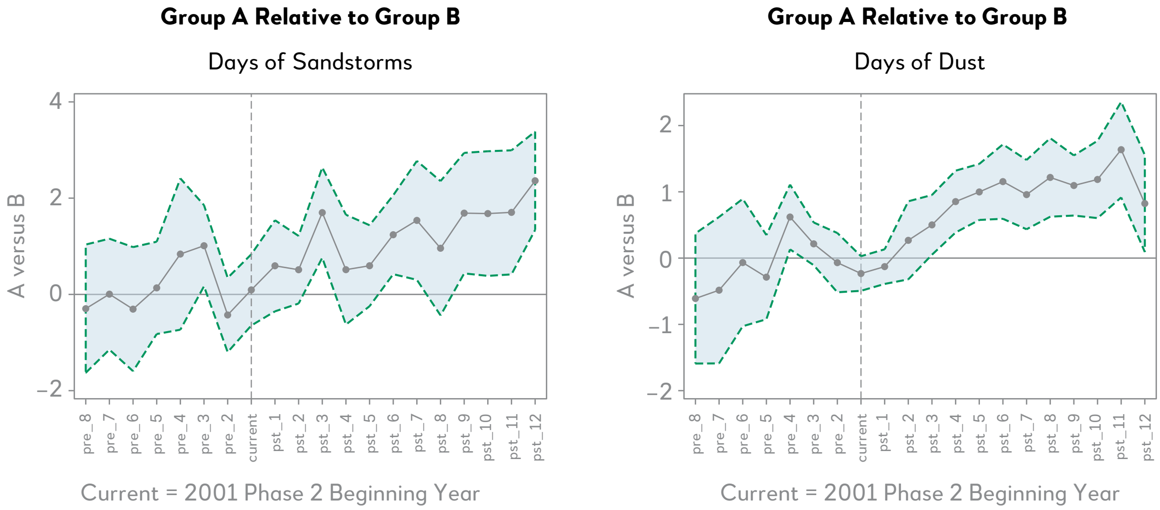
A more formal analysis is conducted by comparing the sand dust frequency recorded by stations located in three groups of counties. Group A and Group B counties are as per earlier descriptions. Group C counties are located further south of Group B while still close to the Sanbei area. Group C is included in this analysis as additional controls because the effects of tree planting in the north (Group A) can potentially benefit non-participating counties in the south (Group B).

At first glance, sandstorm and dust frequency in Group A counties appears to have increased significantly relative to Group B. However, a higher frequency of such weather existed before 2000 (Figure 8). The analysis also underscores the challenges of measuring and evaluating the impact of ecological conservation projects. The outcomes, such as sand dust, are often deeply affected by broader climatic factors (e.g., changing atmospheric pressure, precipitation) where human greening efforts have little control. It also highlights how the benefits of tree planting are not necessarily reaped by the counties themselves—i.e., the treated group.

This naturally leads to the question of whether tree-planting benefits are felt further south in the non-participating countries. Figure 9 shows that compared to similar Group C counties a little further to the south, counties in Group B saw significantly fewer days of dust and mild dust annually starting from 2004 to 2005. Before Phase 2, dust frequency did not differ much between the two groups. In other words, the Sanbei Program appears to effectively control dust weather in Group B. For sandstorms, the impact seems less clear, as there was little significant change after 2000.

This set of analyses based on the event study method reveals a fuller picture of the Sanbei Program—i.e., its policy impact can go beyond the participating counties, with positive externalities to others not included in the Sanbei program. The results also show how the impact can vary depending on the severity of sand dust weather. It is easier to control milder sand dust by restoring surface plant coverage than sandstorms.

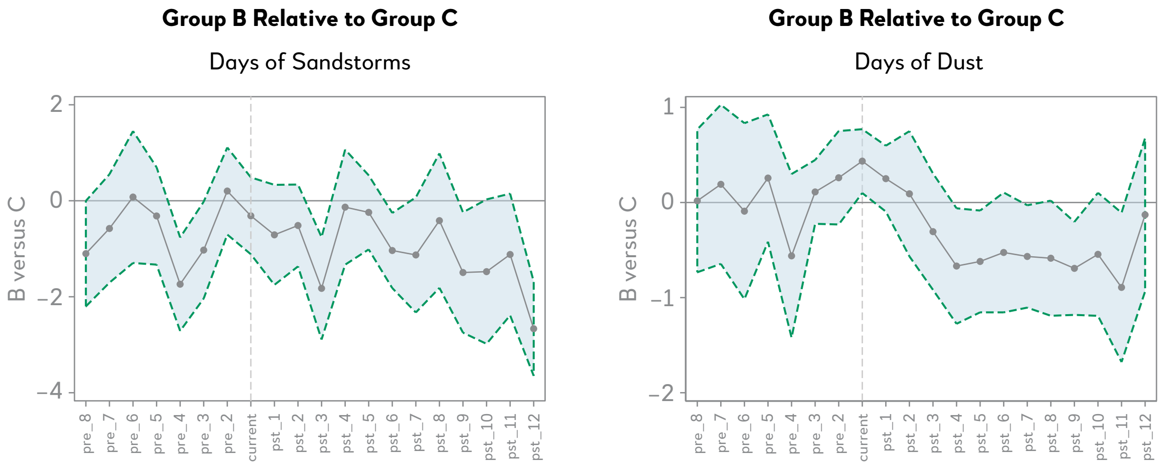
Figure 8: Sand Dust Weather (Group A vs. Group B)



Source: AIIB calculation based on monthly sand dust weather data from the National Meteorological Information Center under the China Meteorological Administration.

Notes: Annual days refer to the total number of sandstorm/dust weather days per station. The figures above show the mean total number of days from these sand dust weather stations located in Group A versus Group B counties.

Figure 9: Sand Dust Weather (Group B vs. Group C)



Source: AIIB calculation based on monthly sand dust weather data provided by the National Meteorological Information Center under the China Meteorological Administration.

Notes: Annual days refer to the total number of sandstorm/dust weather days per station. The figures above show the mean total number of days from these sand dust weather stations located in Group B versus Group C counties.

Box C: Sanbei Knowledge from the Field[a]

Restoration of forests and grasslands on such a massive scale, particularly in those ecologically vulnerable areas, has been physically and financially daunting over the past four decades. Plant coverage in the Sanbei area has improved over time, with other positive externalities such as shrinking areas of soil erosion and declining dust weather in some places. Yet, challenges are evolving. To understand implementation challenges and local adaptations, the AIIB team visited three sites: Ordos, Bayannur in Inner Mongolia and Minqin County in Gansu province. These locations are surrounded by adverse desert or semi-desert areas. The field trip involved interviews and seminars with local stakeholders, including villagers, officials and experts.

Ordos is surrounded by several major desert or semi-desert areas, particularly the south (Mu Us Desert) and northwest (Kubuqi Desert). The buckthorn industry has been promoted as a good practice combining its direct agricultural value and indirect value of preventing soil erosion in dry areas that have desertification risks (Figure C1).

Figure C1: Buckthorn

Buckthorn trees

Buckthorn fruits

Photo credit: AIIB staff

- **Local engagement.** On average, it takes buckthorn seeds three years to become fruits. Most of the buckthorn is planted by local villagers, who are paid daily. It is unlikely that buckthorn plantations contribute fully to local villagers' income. Local officials indicated that even without cash compensation, many villagers volunteered to plant buckthorn trees near the river to stop riverine floods from damaging their cropland.
- **Private sector development.** Buckthorn fruit plantations are managed by local small agri-businesses collectively founded and owned by local villagers. These small firms organize and hire local villagers to plant, water and pick buckthorn fruits or cut leaves for pharmaceutical purposes. These require government support.
- **Abandoned coal mines.** Buckthorn is also being planted in the abandoned coal mines in Ordos. The plants not only improve soil but can use the coal drainage that otherwise would become a source of water pollution. The plants also serve to restore mined lands back to agriculture.

The Xinhua Forest Farm area in Bayannur was plagued by encroaching desert and salinized land (Figure C2). The farmers and scientists developed many valuable techniques to fix sand and maximize the survival rates of plants. To date, 26 square kilometers of forest have been planted using 4.3 million trees, following an investment of CNY16.5 million. The forest coverage rate of the forest farm reached 65 percent. Thanks to the restored plant coverage, the local environment has been gradually improving, such as the rising water storage of nearby lakes, declining sand dust weather and increasing biodiversity.

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Box C *continued*

Challenges remain.

- **Economic and financial viability.** The farm primarily relied on government subsidies to build and maintain forests, paying for materials and labor costs. After a policy change in 2018, it was asked to rely more on its own by generating more revenue cash flows. For example, the firm now sells tree seeds and plants some fruits and medical herbs. Still, the revenue from these sources appears to be limited.
- **Conventional infrastructure.** The farm indicated a need for more water management and road infrastructure to further scale up the farm's forest/grass. Such basic infrastructure is a prerequisite if the firm wants to industrialize its forestry products in the future to irrigate and transport more agricultural goods from the farm.

Figure C2: Xinhua Forest Farm

Grown trees

Sand dunes

Photo credit: AIIB staff

Minqin County (民勤县) is located in Gansu Province. Compared to Ordos and Bayannur, Minqin is surrounded by much more adverse deserts, with a scarcer water supply. In the east is the Tengger Desert, and in the west is the Badain Jaran Desert. The county is famous for its sand-fixation project that successfully blocked the convergence of the Tengger and Badain Jaran deserts. Sand fixation is a technique that keeps sand from being blown away by wind, thus stopping the existing deserts from further expanding. As of 2021, 300 kilometers of Minqin's 408 kilometers of desert border is covered with sand-fixation grass layers. The total desertification area was reduced to 90 percent in 2021 from 96 percent in the 1990s.

- **Caofangge techniques.** These are sand-fixing methods. The idea is to insert grass-made straws deep into the sand to hold sand in square-shaped grids. This reduces the chances of sand being blown away in windy conditions. The technique has evolved with different materials than grass-made straws (Figure C3).

Figure C3: Caofangge Illustration

Caofangge grids in Shazuidun, Minqin County

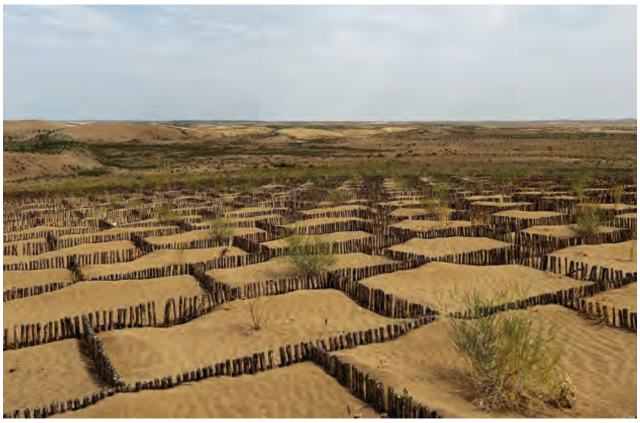

Photo credit: AIIB staff

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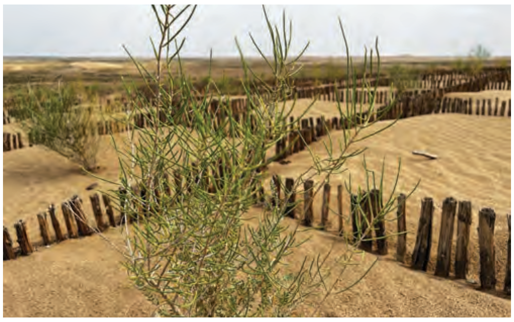
Box C *continued*

- **Saxaul grass planting.** In addition to building caofangges, residents planted some highly resilient plants in the grids, notably saxaul grass. Its root system can hold the sand firm and keep water. Over time, caofangge grids covered with saxaul grass can gradually transform the sand to more a more nutrient-rich land surface, allowing more options for plant species to be planted in the area. With time, saxaul grass can be replaced by other plants. This is one example where interventions facilitate the land surface evolution from arid toward grassland (Figure C4).

Figure C4: Saxaul Grass

Small saxaul grass



Big saxaul grass

Photo credit: AIIB staff

- **Funding and infrastructure challenges.** There is a funding gap for caofangge–related conventional infrastructure. Although building caofangge is part of central Sanbei–related funding, the funding for water management (irrigation), road and electricity infrastructure, etc., is not considered as related to ecological conservation. This infrastructure relies on the general fiscal spending of the Minqin government, which needs fiscal support. Funding gaps delay progress on caofangge construction. Exploitable underground water is low and limited. Water infrastructure is needed to bring in water from the Yellow River or other areas.
- **Climate change.** Local experts share that the total annual precipitation has increased in recent years. But the monthly rainfall during the growing season of grass in spring has declined. This has led to slower growth and lower survival rates of plants in caofangge grids. Also, sandstorms from the Tengger and Badain Jaran deserts have become more frequent and stronger. Existing caofangges, mostly made of rice grass, are quickly wearing down. As a result, some caofangges are vanishing, and sand expansion is taking over again.

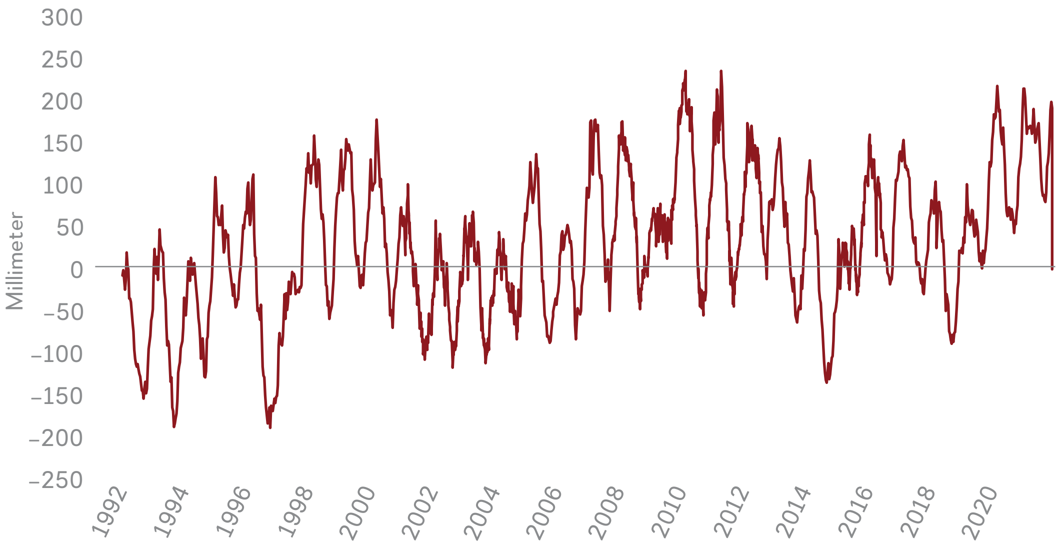
[a] AIIB staff and experts from China Biodiversity Conservation and Green Development Foundation (CBCGDF) jointly visited the Sanbei area for this field study. CBCGDF helped select field locations and arrangement of meetings with local stakeholders.

4.2 Indonesia's Mangroves

Rising sea levels have increased the risk of tidal floods in recent decades. Coastal populations worldwide, especially in Indonesia, the largest archipelago in the world, face significant risks. As of 2022, Indonesia's sea level has surged by a staggering 200 mm above 1992 levels (Figure 10), while the coastal population has increased from 35 to 55 million in the last three decades (Figure 11). These two concerning trends significantly elevate the vulnerability of coastal communities to tidal floods. As per Indonesia's disaster data, at least 257 houses were flooded and damaged due to tidal flood disasters in 2022 alone, inflicting substantial losses on people living in coastal areas.

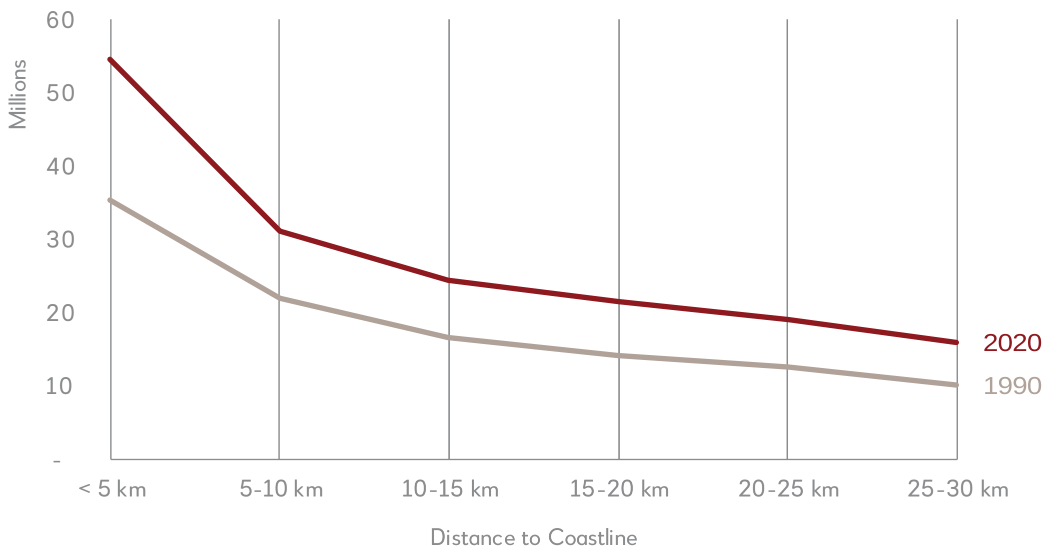
Scientific evidence suggests that mangroves are essential for mitigating the risks posed by tidal floods. Mangroves increase the frictional resistance of the land surface, slowing the rate at which water flows inland and steepening the surge front [Resio (2008)]. Site–specific studies show that mangroves reduce the water level in wetland areas during hurricanes in Florida [Krauss (2009)]. Additionally, mangroves also buffer the water surface from the effects of wind, thus reducing the generation of wind waves, wave set–ups and wind run–ups [Westerlink (2008)]. The World Bank developed an innovative mangrove valuation framework attributing value to mangroves based on their capacity to mitigate flood risks. Indonesia has

Figure 10: Mean Sea Level in Indonesia



Source: NOAA Climate

Figure 11: Coastal Population in Indonesia



Source: Analysis from GHSL Population and OSM Island

emerged as one of the countries experiencing the highest surge in the value of mangroves between 1995 and 2018, primarily attributed to the country's elevated flood risk.

The analysis in this section exploits local disaster data from Indonesia's National Disaster Management Agency to test the relationship between tidal flood occurrence and damages with mangrove cover and conservation. This section also looks into the role of governance in mangrove conservation to provide insights on sustainable interventions that may contribute to the preservation of mangroves and the resilience of coastal communities.

4.2.1 Do Mangroves Reduce Tidal Flood Occurrences?

According to the Global Mangrove Watch, Indonesia has about 23 percent of the world's total mangrove area, equivalent to about 3.5 million hectares in 2008. This presence is distributed along the coastlines of 265 out of 301 coastal regencies in Indonesia.[24] Yet, areas without mangrove cover, predominantly located on the southern side of Java Island and the northwest region of Sumatra Island, remain vulnerable due to their lack of natural coastal defense from heightened tidal flood risks compared to other areas (Figure 12). On average, approximately 25 percent of the regencies lacking mangrove coverage encounter tidal flood disasters at least once every five years, while only 16.5 percent of the regencies protected by mangroves have the same frequency of flood occurrence (Figure 13).

A regression analysis on the probability of flood occurrence (controlling for climate variables such as sea-levels and other socio-economic variables such as coastal population, literacy, GDP and agriculture activities of the regency) shows that a one percent increase of mangrove coverage in a five-kilometer buffer area from the coastlines decreases the probability of tidal floods by 11 percent, although the effect is not statistically significant.[25] Tidal floods can occur due to different meteorological and ecological conditions and may not be related to the presence of mangroves. Then, the next question would be, do mangroves reduce damage when a tidal flood hits?

Our analysis finds a statistically significant correlation between mangrove coverage within a five-kilometer buffer area from the coastline and lower damage.[26] On average, a regency with higher mangrove cover by 5.6 percentage points saves one amenity from being damaged during tidal floods.

Fatalities are an important indicator of the intensity of floods. Although there could be many factors like local infrastructure, disaster response and local governance that may have a stronger impact on fatalities during floods, we find that in regencies covered by mangroves, the probability of a single death is 0.63 percent and 0.37 percent in regions with no mangroves (Figure 14). However, during more intense tidal flood disasters, which cause elevated damages and greater fatality risks, mangroves have a more pronounced impact. The probability of four fatalities in mangrove-covered regencies is only 0.05 percent, whereas in regions without mangroves, the probability is 0.37 percent.

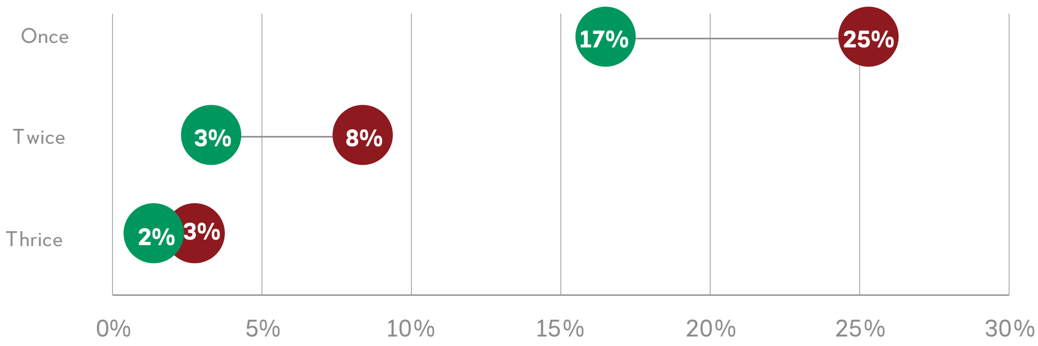
Thus, while the presence of mangroves does not reduce the incidence of tidal floods, their significance emerges in mitigating the extent of damage and reducing fatalities during such events.

Figure 12: Regencies With and Without Mangrove Cover

Source: AIIB calculation based on the Global Mangrove Watch data and Regencies boundaries provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA)

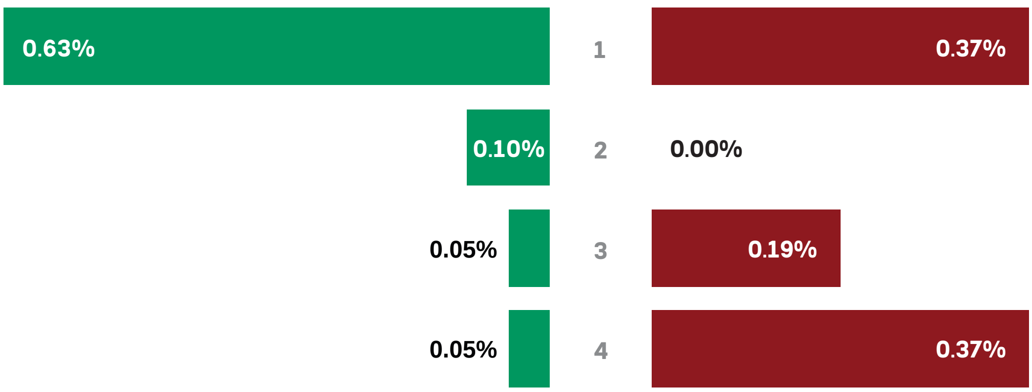
24 Coastal regencies are defined as regencies where parts of its borders are coastlines.
25 Details are provided in Appendix 2.
26 Ibid.

Figure 13: Frequency of Tidal Floods by Regencies With (Green) and Without Mangroves (Red), 5-year Period



Source: AIIB calculation based on Indonesia Disaster Data (Data Informasi Bencana Indonesia – DIBI) provided by the Indonesia National Disaster Management Agency; mangrove data provided by Global Mangrove Watch

Figure 14: Tidal Flood Death Probabilities With (Green) and Without Mangroves (Red)



Source: AIIB calculation based on Indonesia Disaster Data (Data Informasi Bencana Indonesia – DIBI) provided by the Indonesia National Disaster Management Agency; mangrove data provided by Global Mangrove Watch

4.2.2 Low-income Households Are More at Risk

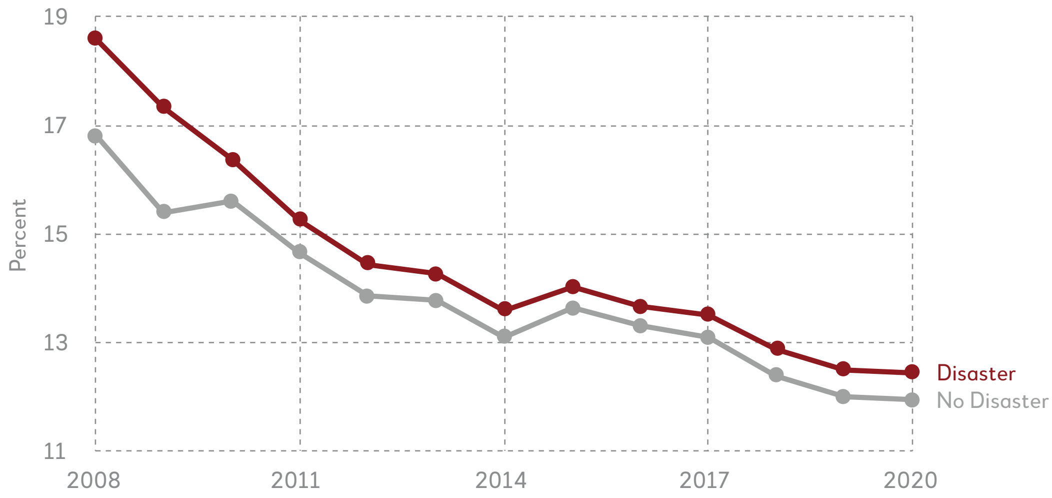
Notably, regencies with tidal flood disasters exhibit a discernibly higher average poverty rate.[27] In 2008, the poverty rate in these regencies stood at an average of 18.6 percent compared to the average poverty rate of 16.8 percent in coastal regencies without such disasters (Figure 15). These statistics underscore the need for effective mitigation measures to prevent vulnerable populations from plunging further into poverty due to tidal flood occurrences.

Zooming in further into the regions with tidal flood disasters, the flood damage is the highest in the poorest regions with no protection from mangroves (Figure 16). On average, approximately eight units of amenities are damaged per one million inhabitants in these impoverished regions. By contrast, regencies endowed with mangroves experience only 0.3 units of amenities damaged per one million population.

Thus, mangrove preservation in these regions takes on heightened importance, acting as a shield against the worsening of poverty resulting from the destructive impacts of tidal flood disasters.

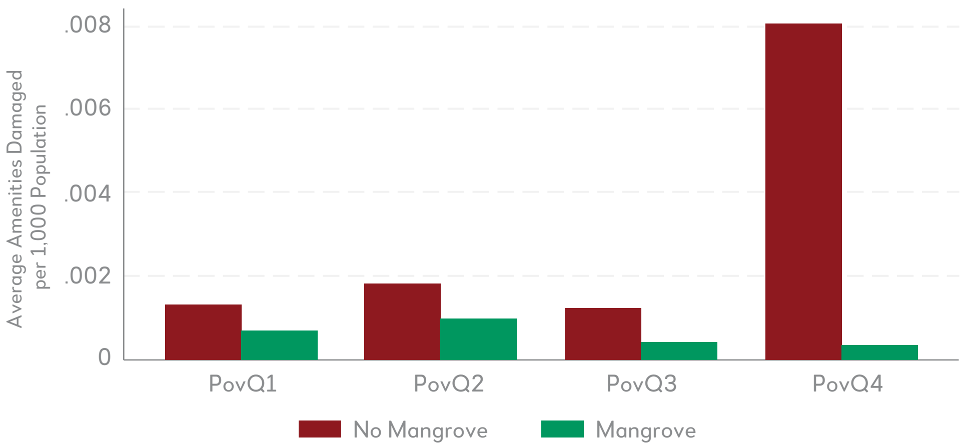
[27] Regencies with tidal flood disasters are defined as regencies that experienced a tidal flood disaster at least once between 2008 and 2022.

Figure 15: Average Poverty Rates in Regencies With and Without Tidal Flood Disasters (%)



Source: AIIB calculation based on Indonesia Database for Policy and Economic Research provided by the World Bank and Indonesia Disaster Data (Data Informasi Bencana Indonesia – DIBI) provided by the Indonesia National Disaster Management Agency

Figure 16: Average Amenities Damaged per 1,000 Population



Source: AIIB calculation based on Indonesia Disaster Data (Data Informasi Bencana Indonesia – DIBI) provided by the Indonesia National Disaster Management Agency and mangrove data provided by Global Mangrove Watch

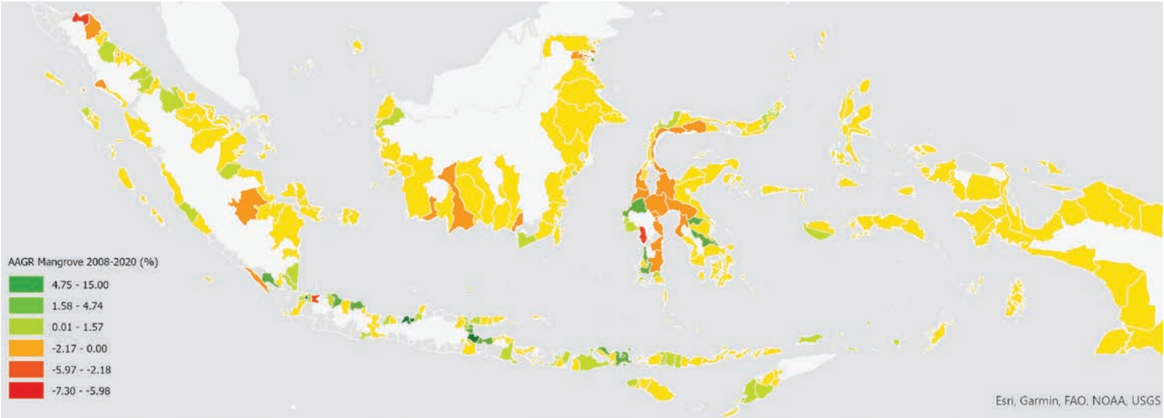
4.2.3 Does Mangrove Depletion Lead to More Damage?

Despite having the world's largest mangrove area, Indonesia lost over 60,000 hectares of mangroves between 2008 and 2020. This depletion was most severe in regions undergoing rapid industrialization and mining, predominantly on the islands of Sulawesi and Borneo (Figure 17).

Our analysis finds that the correlation between damaged amenities and mangrove cover is stronger in regencies with growing mangroves (the first subset) compared to those with depleting mangroves (the second subset),[28] both relative to regencies with no mangroves (Figure 18). For each one percentage point increase in mangrove coverage within a five-kilometer buffer area from coastlines, there is a reduction of 0.4 units

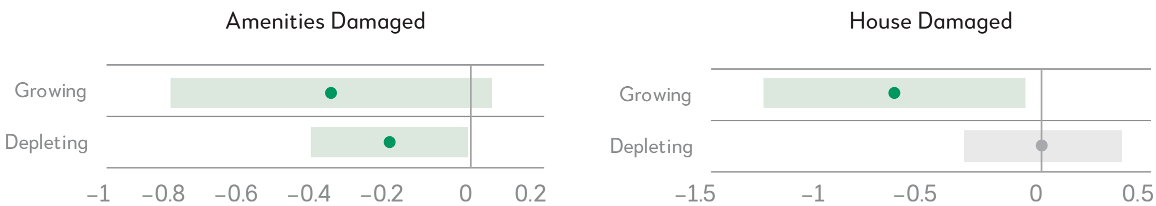
[28] Controlling for climate and other socioeconomic variables as discussed in Section 4.2.1.

Figure 17: Average Annual Growth of Mangrove Area by Regencies



Source: AIIB calculation based on mangrove data provided by Global Mangrove Watch and Regencies boundaries provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA)

Figure 18: Estimated Correlation Between Mangrove Cover and Tidal Flood Damage in Regencies with Growing and Depleting Mangrove Cover



Source: AIIB calculation based on mangrove data provided by Global Mangrove Watch, Regencies boundaries provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), climate and sea level data provided by the ECCO Consortium, population distribution data from the Global Human Settlement database provided by the European Commission, and socio-economic data from the Indonesia Database for Policy and Economic Research provided by the World Bank.

Note: Grey colored dots and bars indicate the correlations as statistically insignificant at a 95 percent confidence level.

of damaged amenities in regencies with growing mangroves. In contrast, in regencies experiencing mangrove depletion, there is a reduction of 0.2 units of damaged amenities for each percentage point increase in mangrove cover.

A more striking difference is found between the two subsets when observing the number of houses damaged by tidal floods. In regencies with growing mangroves, each incremental increase in mangrove coverage significantly correlates with 0.6 fewer houses suffering from tidal flood damages. Conversely, this correlation is absent in regencies with depleting mangroves.

This difference between regencies with expanding and shrinking mangroves may be attributed to the spatial distribution of built-up development and mangrove conservations. Regencies lacking effective conservation measures might experience population growth within high-risk tidal flood areas, encroaching upon mangrove habitats. This phenomenon heightens the vulnerability of these areas while depriving the area of mangrove protection capacity.

4.2.4 Role of Governance in Mangrove Conservation

Effective mangrove conservation requires a collaborative and transparent governance structure [Thuy (2022)]. Given the transboundary nature of mangroves, cross-sectoral and multistakeholder collaboration is essential for successful preservation, including local and central government bodies, planning agencies, environmental organizations and disaster management authorities. This collaboration is enabled by establishing clear mandates and responsibilities among these entities.

On the ground, enhanced local government capacity facilitates efficient allocation of resources, reduces information asymmetry and promotes synergistic collaborations, thus bolstering the efficacy of mangrove conservation. In this analysis, we exploit a governance dataset that focuses on local government financial audit scores, ranging from 1 to 4, as a proxy for governance quality.[29] An audit score of 1 signifies adherence to accounting principles, indicating robust financial reporting and better governance, compared to those with larger score values. The average of these scores was computed for each regency from 2008 to 2018. These regencies were subsequently divided into quartiles based on these average scores, with smaller quartiles indicative of higher government capacity.

Among regencies classified within the quartile reflecting the lowest government capacity, roughly 62 percent experience mangrove depletion (Figure 19). On the other hand, only 33 percent of regencies in the quartile denoting the highest government capacity group, Q1, experience mangrove depletion.

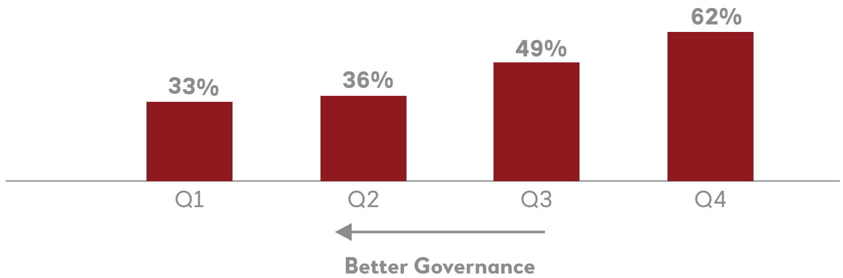
For other socio-economic development indicators, we find that regencies with an audit score of 3, indicative of lower government capacity, exhibit significantly lower mangrove growth rates than regencies with the highest audit score of 1 (Figure 20).

Interestingly, regencies with higher literacy rates correlate positively with increased mangrove growth. This phenomenon can be attributed to the informed choices made by educated inhabitants who are more likely to inhabit in low-risk areas and refrain from activities that contribute to the degradation of mangrove habitats. Additionally, this observation illustrates how the involvement of local communities in the protection and conservation of mangroves can significantly amplify the effectiveness of conservation efforts [Mursyid (2021)].

4.2.5 Mangroves as Infrastructure to Minimize Damage and Casualties

Rising sea levels and growing coastal populations have increased the vulnerability of coastal communities to tidal flood risks. Using extensive local disaster data, this analysis shows that mangroves do not decrease the occurrence of tidal floods, but their significance lies in their capability to minimize damage and casualties during such events. The findings also highlight the importance of mangrove conservation especially in the marginalized regions with tidal-flood risks to shield vulnerable populations from adverse impacts of the disasters. Effective mangrove conservation requires collaborative efforts spanning governmental bodies, institutions and local communities. To this end, financial and technical capacity building at different administrative levels become important.

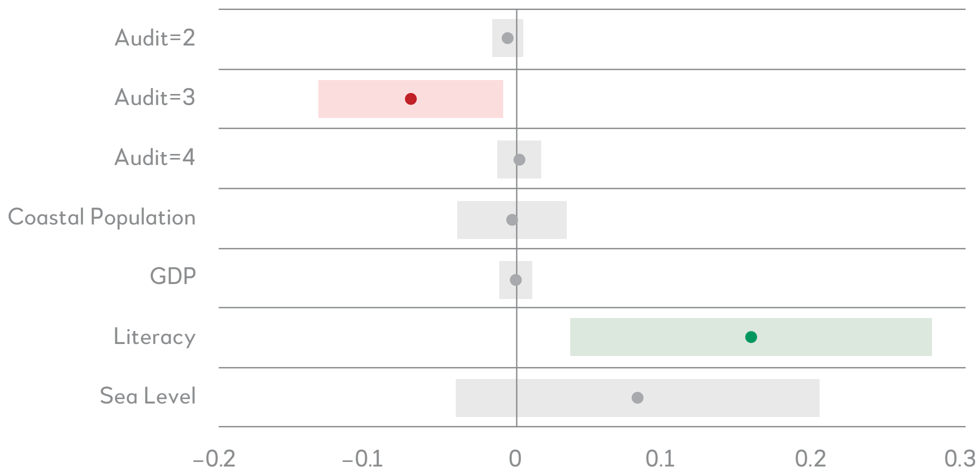
Figure 19: Regencies with Mangrove Depletion by Local Governance Quality Group (%)



Source: AIIB calculation based on mangrove data provided by the Global Mangrove Watch and governance data provided by the World Bank

29 Data collected from the World Bank's Indonesia Database for Policy and Economic Research.

Figure 20: Estimated Correlations with Mangrove Growth

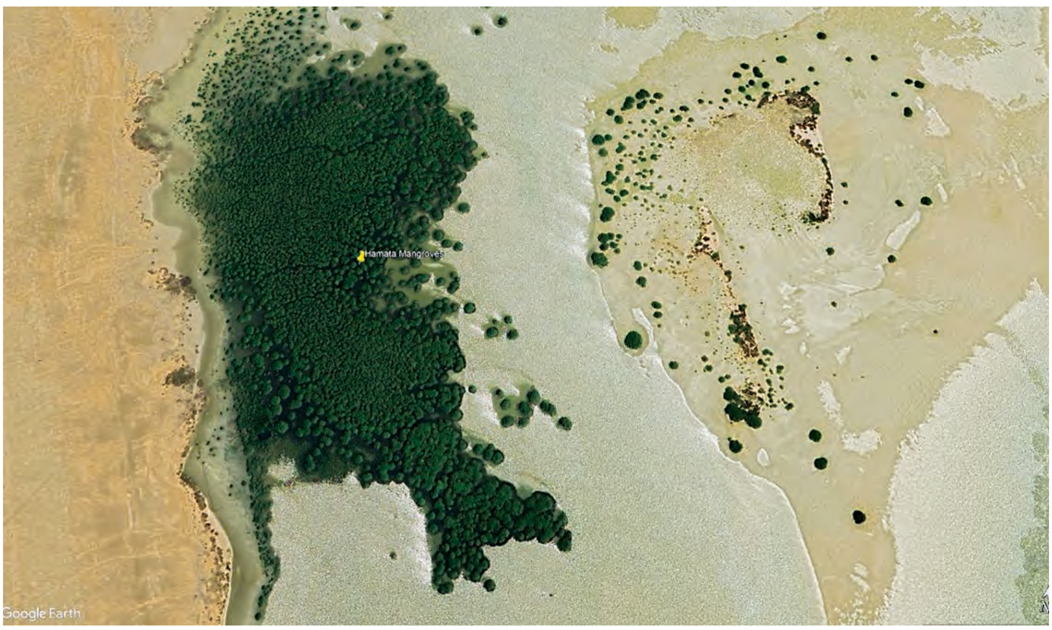


Source: AIIB calculation based on mangrove data provided by Global Mangrove Watch, Regencies boundaries provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), climate and sea level data provided by the ECCO Consortium, population distribution data from the Global Human Settlement database provided by the European Commission, and socio-economic and governance data from the Indonesia Database for Policy and Economic Research provided by the World Bank.

Box D: Mangroves in Egypt's Red Sea Coast

In 2020, Egypt announced a plan to rehabilitate about 210 hectares of mangroves along the country's Red Sea coast.[a] The project aims to plant mangroves in six areas, including Hamata, Safaga, and Shalateen, as well as the Nabq nature reserve in the South Sinai Governorate. To this end, four mangrove nurseries have been established to produce over 50,000 seedlings annually and supply them to the replanted areas.

Figure D1: Hamata Mangrove



Source: Google Earth

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Box D *continued*

Figure D2: Safaga Mangrove

Source: Google Earth

Figure D3: Shalateen Mangrove

Source: Google Earth

The replanted mangroves are intended to restore local biodiversity lost in the past few decades and use the carbon sink capacity of mangrove forests as a climate mitigation measure for Egypt. Besides buffering against tidal floods, mangrove forests also serve as haven for over 200 endangered animal species and can absorb five times more carbon than land forests. Egypt currently has a total mangrove forest of 5.1 square kilometers located on the Red Sea coast due to a more suitable climate there.[b] These are the only remaining mangrove forests after over 40 years of destruction as a result of climate change and human activities (particularly coastal tourism).

Like other nature infrastructure, mangrove restoration is financed by government support in Egypt, with limited direct cash revenue to local communities. In Safaga, local communities have been trying to find ways to create direct economic benefits by growing beehives in mangrove forests. Honey produced from beehives here appears to have a special flavor, which can be a source of income for local residents.[c] Meanwhile, bees can help pollinate mangrove trees.

continued on next page

Box D *continued*

Figure D4: Beehives Farm in Safaga Mangrove

Source: Alamy

Looking ahead, replanting mangroves on Egypt's Red Sea coast faces implementation challenges like other nature infrastructure. For example, insufficient transportation network, a lack of policy coordination and security issues in the area have reportedly hindered the progress.[d]

[a] Egypt replants mangrove 'treasure' to fight climate change impacts (france24.com)
[b] UNESCO
[c] One Earth report: A sweet solution: bees are saving threatened mangroves in Egypt | One Earth
[d] A mangrove revolution: How Egypt is prioritising climate projects in the run-up to COP27 | Euronews

4.3 Bangladesh's Wetlands as Infrastructure

4.3.1 What Ecosystem Services Do Wetlands Provide?

Wetlands are crucial ecosystems, covering approximately nine percent of the Earth's surface and housing around 35 percent of the planet's terrestrial carbon. They act as vital carbon sinks (Fischlin et al., 2006). Moreover, wetlands offer agricultural benefits—supporting soil fertility, reducing erosion, providing shade, buffering wind and assisting in mitigating drought.

Wetlands, known as the "biological supermarket" are rich in biodiversity (and genetic wealth) and support a large food web. They are also known as "kidneys of the landscape" because of their ability to store, assimilate and transform contaminants from the land before they reach waterways. Wetlands can stabilize the water supply, purify sewage and recharge groundwater. They are excellent climate stabilizers as well [Mitsch and Gosselink (2000)]. Wetlands have also been shown to enhance a variety of ecological, biological and hydrological functions, which provide economic, aesthetic, recreational, educational and other values to society [Mitsch and Gosselink (1986); Heimlich et al. (1998)].

Wetlands are rich in aquatic resources which are vital for the livelihoods of rural communities worldwide, including those in Bangladesh. Fish, prawns, crabs, mollusks and clams are significant components of wetland ecosystems, with their life cycles intricately linked to these habitats. The fishing industry provides livelihoods for 80 percent of people in developing countries. Wetlands, especially in economies like Bangladesh, Myanmar, Thailand, Cambodia and Viet Nam, where rice cultivation is prominent, play a vital role as rice consumption can reach up to 70 percent of the food basket. Overall, wetlands are invaluable ecosystems that sustain biodiversity, support food security, provide livelihoods and offer essential resources for human societies worldwide.

This case study examines the importance of wetlands in Bangladesh's natural ecosystem. The study emphasizes how wetlands act as a form of natural infrastructure. This is followed by a discussion of management practices in the context of conserving the wetlands.

4.3.2 Wetlands in Bangladesh Are an Integral Part of the Ecosystem

According to the Ramsar Convention, more than two-thirds of Bangladesh can be classified as wetlands. About 6.7 percent of the country is consistently submerged, while 21 percent experiences deep flooding (over 90 cm), and 35 percent faces shallow inundation. The wetlands cover approximately seven to eight million hectares, accounting for roughly 50 percent of the country's land surface. Bangladesh's wetlands consist of diverse ecosystems, including mangrove forests, natural lakes, artificial reservoirs (such as Kaptai Lake), freshwater marshes, oxbow lakes (locally known as baors), freshwater depressions, fishponds, tanks, estuaries and seasonal inundated extensive floodplains [Khan et al. (1994)]. The association between water and wetlands holds immense significance for the fate of Bangladesh, its people and its prospects for sustainable development, as they form the central pillar of the country's natural resource base.

Wetlands, also known as haors, are crucial in sustaining ecosystems and providing various ecosystem services. These ecosystems are defined as areas of land that are permanently or temporarily saturated with water and support a wide range of plant and animal species. The wetlands of Bangladesh can be categorized into two principal regions: the Ganges-Brahmaputra flood basin and the haor basin in the northeast region. Haor's unique hydro-ecological characteristics are large bowl-shaped floodplain depressions in the northeastern region of Bangladesh covering about 1.99 million hectares (19,998 square kilometers) and accommodating about 19.37 million people. Among these wetlands, Tanguar Haor and Hail Haor are of particular significance.

Tanguar Haor is located in the Surma River floodplain, one of the main tributaries of the Meghna River in Bangladesh. Tanguar Haor lies in the northeast, adjacent to the Indian border. During the monsoon season (June-September), Tanguar Haor is entirely flooded, except for villages on hillocks and small islands. During this season, the area is dominated by water and characterized by abundant fish, boats, fisherfolk, birds and unusual plant life, all adapted to the unique spectacle of deep annual flooding. In the dry season, when waters recede into the major rivers, all that remain are about 54 beels, which cover about 25-30 percent of the haor, with 16 being perennial [IUCN (2015)]. Tanguar Haor directly supports the livelihoods of over 70,000 people from 88 surrounding villages and contributes significantly to the country's food production and security [IUCN (2016)].

The wetlands provide a wide range of services. For example, ecosystem services from Tanguar Haor are estimated at 1.45 million Bangladesh Taka (BDT) per person annually [Solayman et al. (2018)]. The major benefits include provisioning services, comprising crop, vegetable and fish provisioning, fresh water, fodder and migratory birds. Other benefits comprise carbon sequestration, water purification, waste treatment, soil formation and retention, nutrient recycling and various cultural services.

Hail Haor is a shallow permanent lake isolated and surrounded by Balishira and Barshijora Hills on the east, Satgaon Hills on the west, other low hills on the south and flood control embankment in the north [Ilyas and Thompson (2018); Ali et al. (2007); Thompson and Chowdhury (2007)]. This haor covers an area of fewer than 4,000 hectares comprising about 130 beels and narrow canals in the dry season. This haor does not have any formal conservation status. However, a permanent wetland sanctuary was declared in 2003 and named Baikka Beel Sanctuary. This haor has also been an Important Bird and Biodiversity Area (IBA) since 2004.[30] Over 172,000 people from 30,000 households living in the surrounding 60 villages primarily depend on this haor [Mazumder et al. (2016)]. More than 80 percent of these households are involved in fishing.

[30] BirdLife International (2023). Important Bird Area factsheet: Hail Haor. http://datazone.birdlife.org/site/factsheet/15225. Retrieved on 03/07/2023.

Using satellite data from the European Space Agency, this analysis finds that Tanguar Haor, which covers a larger area than Hail Haor, faces depletion of the blue cover (sum of water and wetland cover), while the blue cover has improved for the Hail Haor. Both wetlands faced a depletion of biodiversity (Figure 21) (measured by biodiversity habitat index) in the two decades of 2000-2010 and 2010-2020. Encouragingly, the depletion rate has been (Figure 22) much slower in both haors in the recent decade. Although the slowing depletion could be attributed to the change in ecological factors, increased awareness, better management and efficient conservation efforts may have played active roles.

Although the haors are rich in natural resources, development in the region has not been uniform.

In Bangladesh, the haors are predominantly in the country's northeast, covering seven districts. The haors account for 43 percent of the area of these districts. The main economic activities of the region primarily include rice production and fisheries. The region is also very rich in natural gas and other minerals. The haor region contributes around six to eight percent to Bangladesh's GDP.[31] However, the region has not developed uniformly. Poverty rates across some haor districts are significantly higher than the national average, while others have performed better (Figure 23).

The income of Tanguar Haor residents is significantly influenced by the season, climatic conditions, natural disasters and price fluctuation of their products like crops, fish and cattle. The residents of Tanguar Haor are engaged primarily in the agricultural and fishery sectors. The occupational structure underwent significant change over the last two decades, with residents shifting from agriculture to fisheries. Similarly, more than 50 percent of the population (Figure 24) around Hail Haor is dependent upon fishing as their main source of livelihood. Fishing intensity has significantly increased, with the quantity of fish caught more than doubling from 205 kilograms per hectare in 2000-2001 to 406.6 kilograms per hectare in 2015-2016: [Ilyas and Thompson (2018)].

Several haors in Bangladesh are experiencing a shift from agriculture to fisheries. A key factor driving this change is frequent flash flooding during the monsoon season, which inundates the agricultural land and causes damage to standing crops. For example, during the flash flood of 2017, 26,220 hectares of agricultural land was flooded. Despite the shift toward fishing, the fishing community continues to face livelihood struggles. Tikadar et al. (2022) compare the livelihood status of the fishing community in Tanguar Haor with nearby areas and find that the community is suffering from a significant lack of human and financial capital.

Figure 21: Share of Water and Wetland Cover

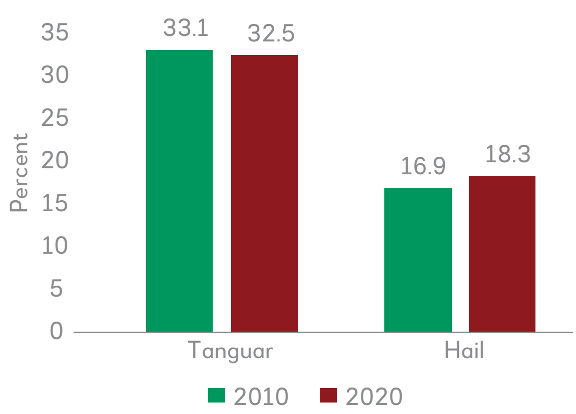
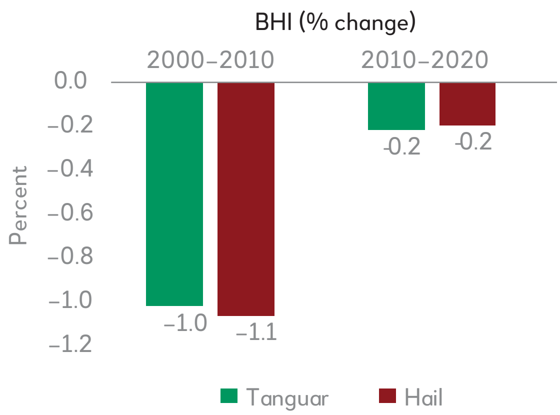


Figure 22: Change in Biodiversity Habitat Index



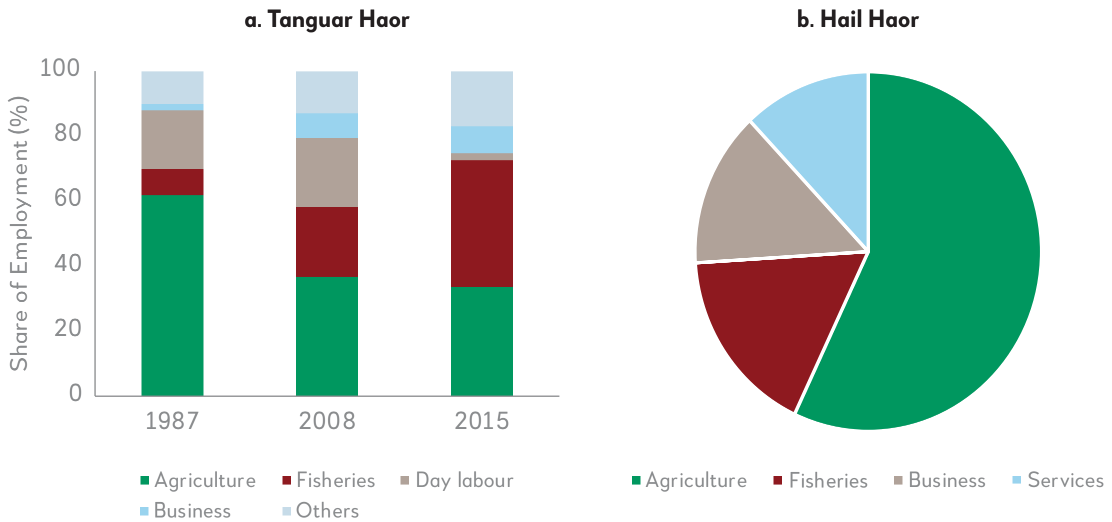
Source: Staff calculations based on CSIRO (2023) and ESA (2023)

31 https://www.bids.org.bd/page/researches/?rid=164#:~:text=Over%20the%20last%20couple%20of,at%20around%206%2D8%25

Figure 23: Percent of Population and Poverty Line

Source: AIIB staff computation based on Bangladesh Bureau of Statistics

Figure 24: Employment Share of Various Sectors



Source: Sultana et al. (2022) and Majumder et al. (2013)

Governance is vital to balance the tradeoff between the revenue generation capacity of haors and the conservation efforts.

Over the last two centuries, the management of wetlands in Bangladesh focused primarily on revenue earnings. In the pre-colonial period, fishermen enjoyed customary fishing rights in rivers and wetlands. The local communities had access to various aquatic resources to support their livelihoods [IUCN (2016)]. The post-colonial management regime has been structured by approaches that are scientific and technology-based, top-down, centralized, and production and efficiency-oriented, with the poor local communities being regarded as a threat to natural resources. This approach ignores the significance of other dimensions, such as the social, ecological and cultural aspects of resource management. Thus, the local resource users have limited or no role in resource management [Khan and Munjurul (2012)].

Marginalization of local communities from access to and control over resources resulted in various governance issues. To overcome these issues, a co-management approach was initiated, which has addressed the pressures exerted on wetland ecosystems since the mid-1990s [IUCN Bangladesh (2016)]. Two major initiatives were taken for over a decade in Tanguar Haor and Hail Haor.

In Tanguar Haor, the Ministry of Environment Forest and Climate Change (MoEFCC) started a three-phase project named Community Based Sustainable Management of Tanguar Haor with technical support from IUCN and financial support from Swiss Agency for Development and Cooperation (SDC) in December 2006. This project came to an end in August 2016. Later, MoEFCC initiated the Tanguar Haor Bridging Phase project through government allocations with technical support from IUCN to continue sustainable fish harvesting, benefit-sharing and resource protection activities till 2018.[32]

Subsequent studies evaluating this approach reveal that co-management can promote greater local community participation in resource management. However, establishing such governance mechanisms is time-intensive and critically depends on the capacity of local community organizations [Newaz and Rahman (2019)]. It was found that establishing co-management remains a challenge in Tanguar Haor, as a lack of leadership at the local level reduced the effectiveness of the existing community organization. Thus, there is an imminent need for strengthening the community organization through a collaborative process.

In Hail Haor, the Management of Aquatic Resources through Community Husbandry (MACH) project was implemented from 1998 to 2007. Then, the Integrated Protected Area Co-management (IPAC) and Climate-Resilient Ecosystems and Livelihoods (CREL) projects promoted a co-management approach in Baikka Beel to reduce the overuse of wetland resources and to preserve them from degradation within the project sites till 2016. The key challenges facing co-management organizations in the Baikka Beel of Hail Haor include a dearth of financial support from the government to the local resource management organisation and a lack of effective monitoring. Consequently, the biodiversity in the region has become significantly vulnerable.

Both Tanguar and Hail haors have witnessed a decline in biodiversity due to the depletion of bird, fish and tree populations. The number of fish species in Tanguar Haor declined from 134 in 2015 to 58 in 2021: [Sultana et al. (2022)]. The decline in bird population can be attributed to the destruction of wetland trees and the food crisis, while intensive fishing, dewatering of waterbodies, shift in wetland management rights and expansion of aquaculture bunds have resulted in a reduction in fish population.

Overall, the fundamental goal is to develop people-centric and eco-friendly initiatives that benefit the local community without harming the vital haor ecosystem, ensuring a sustainable and prosperous future for the region. Implementing an effective program to sustain the livelihoods and the natural resources offered by the haors would entail government-entrepreneurial collaboration, public-private partnerships and government-university partnerships. Efforts to monitor quality, performance and achievement indicators need to be strengthened. Evidence-based research focusing on local employment, food value addition and sustainable solutions for the community must be encouraged.

[32] No notable conservation initiative is currently underway to protect the region's immense fish biodiversity involving the participation of fishers and community members.

Box E: Gender and Biodiversity

Access, use, management and biodiversity conservation are not gender-neutral, and structural inequalities between women and men place the former in a less resilient position [Samandari (2017)]. Across regions and cultures, men typically use natural resources for cash-crop-based agriculture, hunting, logging and harvesting of high-value products. Women are more focused on subsistence agriculture and collecting wild resources for household use, especially for consumption [Sunderland (2014)].

Women, like men, are vulnerable to biodiversity loss but face different challenges due to their specific roles and socio-economic status. Land degradation and reduced biological or economic productivity can result from unsustainable loss of biodiversity assets [Samandari (2017)]. Extension services, which provide technical advice to farmers, often disproportionately target men, partly due to male ownership of land and capital goods. Gender norms restricting women's interaction with male service providers further limit women's knowledge [FAO (2011)]. In the 97 economies assessed by FAO, only five percent of all agricultural extension services are received by women farmers [FAO (2011)].

Land degradation, in turn, results in worsened livelihoods and more competition for good soil. Women become more vulnerable to poverty and dependent on males with control over and access to land [Jahan (2008)]. Further, as women are less likely to own land, they face more significant barriers in the credit market and thus adapt less to land degradation [Jahan (2008)]. Land degradation is additionally a push factor for male out-migration, leaving women with even greater household responsibilities and exposure to the effects of land degradation [UN CC: Learn (2023)]. In a non-agricultural setting, biodiversity loss also endangers the livelihood of indigenous women, who are often responsible for foraging for food and medicinal plants [UN CC: Learn (2023)].

On the other hand, women are essential in the initiatives to conserve biodiversity. UN Women (2018) argues that without considering gender, conservation initiatives can disregard women's specific needs and responsibilities, fail to use women's ecological knowledge and exacerbate women's existing unpaid work burden. Further, as women often do not have rights over land, conservation efforts are less directly aligned with women's incentives than men.

Different gender roles performed by women and men lead to different ecological knowledge sets. Women's knowledge tends to be more linked to household, health and food consumption. For example, indigenous women from the Amazons can identify 45 more species of plants and more usable plant parts than men. This knowledge is critical during food shortages [Shanley (2001)]. A study in Sierra Leone finds similar evidence. Women could list 31 uses of trees while men just eight in the same environment [UN CC: Learn (2023)]. In the Philippines, experienced women are responsible for selecting the best seeds for cultivation for the following season [Bossa-Castro (2016)]. In a study in Malaysia, gender-differentiated roles led women and men to pay greater attention to different types of fruits, leading to varying assessments of relative abundance and conservation needs [Muhammad (2017)].

Some conservation initiatives disproportionately use women laborers, further making the case for women's involvement in decision-making. For example, women often plant trees to combat deforestation [UN CC: Learn (2023)]. This is the case in China's Sanbei reforestation project, where women plant trees as temporary employment to augment household income. Tree planting by women was critical to the success of the Green Belt Movement in Kenya. As women reported greater difficulties performing their gendered traditional tasks, such as gathering water and fuel and securing food for the household, they were organized together to plant trees to bind the soil, store rainwater and provide firewood [Samandari (2017)].

The Small Grants Programme of the United Nations Development Programme (UNDP), implemented by the Global Environment Facility (GEF), has been a practitioner of gender mainstreaming in its approach to biodiversity conservation. The Programme collaborated with indigenous women cotton planters in Peru and lifted a government ban on planting certain native cotton species. The ban nearly drove said species to extinction based on an erroneous presumption that these species are responsible for hosting pests. Women in the program demonstrated the safety of these species by planting them on allotted land [Global Environment Facility (2016)].

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Box E *continued*

However, social norms, time constraints and poorer education make women less engaged in decision-making and management [UN CC: Learn (2023)]. Gender mainstreaming was thus agreed upon under COP 12 leadership in Nairobi in 2006. The Convention on Biological Diversity included a Gender Plan of Action for 2015-2020, which encouraged "[giving] gender due consideration in their National Biodiversity Strategies and Action Plans." This will be an important dimension of nature conservation going forward.

CHAPTER 5

VALUING NATURAL CAPITAL FOR NATURE-POSITIVE INFRASTRUCTURE INVESTMENT

Highlights

- A well-thought Net Gain approach can reconcile development versus nature and integrate nature-positive investments in infrastructure planning and implementation.
- The lack of quantitative evidence on the benefits of nature-based solutions has prevented their widespread applications.
- Planning early for No Net Loss or Net Gain and engaging stakeholders helps overcome many challenges.

The world needs to invest trillions of dollars to bridge the infrastructure gap. Figure 25 shows the country scatter for infrastructure score and biodiversity intactness, with no apparent relationship. However, countries at the top left quadrant face the need to increase infrastructure investment and protect biodiversity, underscoring the need to reorient designing and assessment of infrastructure projects.

Nature as infrastructure or nature-based solutions (NBS) can partially substitute grey infrastructure. Examples include mangroves substituting seawalls to offer protection from floods, wetlands replacing water treatment infrastructure to reduce nitrogen and organic concentration and buildings with green roofs and facades replacing grey infrastructure needed to provide shade and cooling. Moreover, investment in nature-based infrastructure (NBI) can be cost-effective and provide additional benefits and risk reduction opportunities. According to estimates by IISD (2021), swapping just 11 percent of the global infrastructure need with NBI would save USD248 billion every year and add benefits worth USD489 billion.

However, not all grey infrastructure—transmission lines, roads, metro projects—can be substituted with NBI. In such cases, it is important to mainstream nature considerations into investment decisions and ensure that infrastructure investments are nature-positive. Nature-positive investments would seek to reverse the drivers of nature loss and promote the protection, restoration and sustainable use of nature and its services to the people.

Figure 25: Infrastructure Quality and Biodiversity Across Low- and Middle-income Economies

Source: Global Competitiveness Index, World Economic Forum and Newbold et al. (2016)

5.1 Challenges in Fostering Nature-positive Infrastructure Investment

Fostering nature-positive investment is challenging for a variety of reasons. These include:

- **Aligning infrastructure investments with nature-positive goals:** Nature-positive investments are most effective when there is collaboration across all actors at the landscape level. For example, in the case of water basins or watersheds, water quality and quantity improvements can be achieved only if users in the river basin work together. Some challenges include accurately identifying the landscape, defining the nature-positive goals at the landscape level and measuring the investment's specific contribution to achieving these goals.
- **Valuing natural capital assets:** Monetary valuation of natural capital is particularly challenging due to the lack of direct market prices and the need to apply non-market techniques. At the same time, the absence of tools and methodologies makes it difficult to accurately calculate the quantum of biophysical stocks and flows that will be affected by the investment decision.
- **Assessing natural capital risks and opportunities:** Investors wishing to determine the value of their investment to natural capital risks face a lack of information on (a) how infrastructure projects depend on the environment and (b) consequences when that relationship is disrupted by environmental change.
- **Making nature-positive investments bankable:** There is less experience and expertise in identifying opportunities for nature-positive investments and making them bankable.

5.2 A Model to Value Natural Capital across Infrastructure Projects

Correctly assessing the value of nature and the services it provides is fundamental to making decisions on how to use or invest in it. The valuation needs to facilitate understanding both the benefits of action and costs of non-action (OECD, 2023). The most commonly applied frameworks to assess an infrastructure project include cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA). While the former identifies the lowest-cost investment option to achieve a desired objective, the latter estimates the economy-wide net benefits of the investment. However, in these analyses, the benefits of natural capital and the costs linked with degrading natural capital may not be adequately captured.

This chapter focuses on the natural capital valuation (NCV) model developed by Arcadis and European Bank for Reconstruction and Development (EBRD). It is one of the few microeconomic biodiversity-risk-assessment approaches [OECD (2023)]. The NCV model builds upon the SEEA EA framework to provide quantitative and, where possible, monetary information on the state of nature at a landscape level [United Nations (2014)].[33] The NCV model recognizes that the stock of natural capital is an indicator of future levels of utility, and both the flow of services from natural capital and the stock of natural capital need to be assessed jointly.

The model can be applied to (a) identify investment opportunities as part of the business origination process and (b) appraise existing projects. The scenario-based model compares a baseline scenario with a project scenario and a sustainable or nature-positive scenario.

The chapter applies the NCV model to a project being designed by AIIB in Inner Mongolia. The Inner Mongolia Ulanhot Green and Climate Resilient Urban Development Project (henceforth Inner Mongolia project) will improve the resilience of urban infrastructure like roads, water supply and drainage systems (Box F). The project will also ecologically restore the Tao'er River and its wetland by integrating NBS. Box F highlights the main components of the Inner Mongolia project.

Box F: Inner Mongolia Ulanhot Green and Climate Resilient Urban Development Project

Ulanhot City is the largest city in the Hinggan League, a prefecture-level area in the Inner Mongolia Autonomous Region. It spans over 772 square kilometers. Located in the Songhua River Basin and the Nenjiang River system, two main rivers run through the city—the Tao'er River and the Guiliu River. The total river basin covers an area of 31,000 square kilometers.

Strong economic growth and rapid urbanization have exacerbated the pressure on the existing infrastructure and degraded natural resources. This has been reflected in high transportation costs, worsened road safety, inefficient drainage, poor water supply quality and sanitation systems, rising occurrences of waterlogging, flood and drought, and biodiversity loss. The share of green cover in the total area has declined by more than four percentage points over the last two decades, while the area covered by wetlands has shrunk by 40 percent, translating into a depletion of biodiversity.

The Inner Mongolia Ulanhot Green and Climate Resilient Urban Development Project will support the Ulanhot Municipality's effort to improve the resilience of urban infrastructure, including roads, the water supply and drainage systems, and public spaces. It will also restore the Tao'er River and its wetland by integrating nature-based solutions and engineering design. The project consists of four key components:

- **Climate Resilient Urban Infrastructure Improvement.** The project will support the improvement of key public infrastructure, such as a road network along with accompanying pedestrian and non-motorized transport pathways, an underground drainage system, the water supply and sanitation, and heating pipelines in selected low-income communities.
- **Integrated Nature-based Solutions.** Nature-based solutions will be integrated into the design features, including rainwater harvesting and storage, which will help recharge the groundwater to enhance local ecological systems. The project will also support greening and improving the resilience of public spaces such as parks and plazas.
- **Ecological Enhancement of Tao'er River and Wetland–Riparian.** Areas along the Tao'er River and wetland will be restored. This will strengthen the ecological and biodiversity conservation and increase the storage capacity of the basin, reducing floods and waterlogging risks. The project will also support the ecological treatment of abandoned quarries and factories to reduce soil erosion and pollution.

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[33] The SEEA Ecosystem Accounting (SEEA EA) constitutes an integrated and comprehensive statistical framework for organizing data about habitats and landscapes, measuring ecosystem services, tracking changes in ecosystem assets, and linking this information to economic and other human activity.

Box F *continued*

- **Climate Smart City Management Platform and Capacity Building.** The project will support the adoption of digital technologies such as GIS and big data analysis to manage water resources, enable flood and drought prevention and mitigation measures, and introduce a smart water supply system.

Figure F1: Green Cover

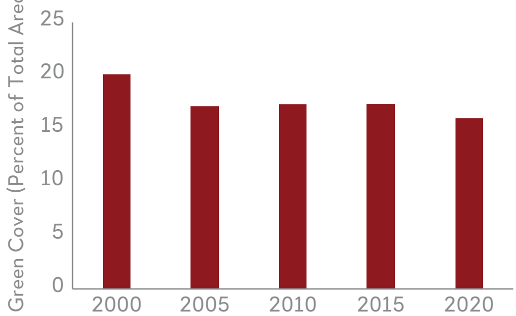


Figure F2: Wetlands

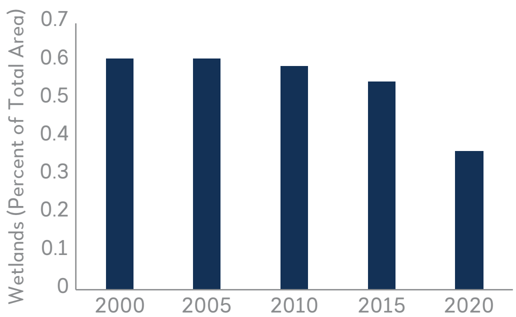
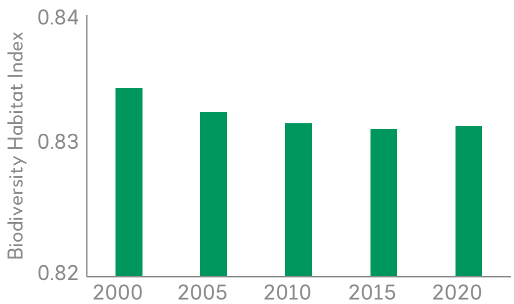


Figure F3: Biodiversity Habitat Index



Source: AIIB staff computation based on ESA and CSIRO data

5.2.1 Application of the NCV Model

The NCV model can be applied to identify new investment opportunities and evaluate existing investments. First, the model is handy for investment origination in economies, areas or sectors with a high potential for nature-positive investment or significant environmental risks that limit the range and scope of economic activities. Second, the model can be applied during the due diligence process of designing a project. Projects with strong nature-positive potential should be adapted to maximize such potential. In contrast, projects that trigger negative environmental impacts should either be adapted to be at least compatible with nature-positive goals or be screened out if the negative impact cannot be significantly mitigated. The NCV model consists of three main parts, each comprising multiple steps.

Defining the natural capital baseline

This part involves evaluating the project's landscape, including getting a clear idea of the risk themes and areas related to natural capital in the landscape and the priority ecosystems. It includes six steps, not all of which can be completed for every project owing to data limitations and scope restrictions (Figure 26).

In Step 1, the spatial boundaries of the assessment landscape are defined. This is based on landscape characteristics such as watersheds or mountain ridges, but administrative boundaries can also be necessary (e.g., for data collection). For the Inner Mongolia project, the delineation of the assessment area is based on the area covered under the Environmental and Social Impact Assessment (ESIA) (Figure 27).

Figure 26: Steps of Part I of the NCV Model

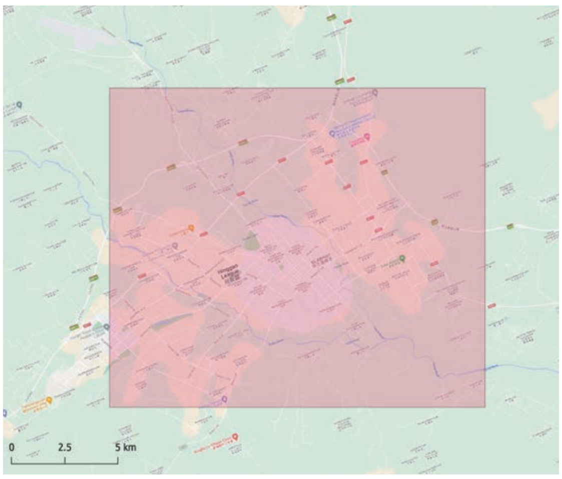
1. Delineate the **spatial boundaries** of the landscape to be assessed.
2. Map local stakeholder **dependencies and impacts** on natural capital in the assessed landscape.
3. Map (changes in) the **extent of ecosystem assets** in the assessed landscape.
4. Assess (changes in) the **condition of ecosystem assets** in the assessed landscape.
5. Asses (changes in) **physical ecosystem** service flows in the assessed landscape.
6. Asses (changes in) **monetary ecosystem** service flows in the assessed landscape.

Overall goal: Determine **natural capital risk themes** (e.g., water), **risk areas** (e.g., water quality), and **priority ecosystem services** in the assessed landscape.

Source: AIIB staff computation based on Arcadis' NCV Model

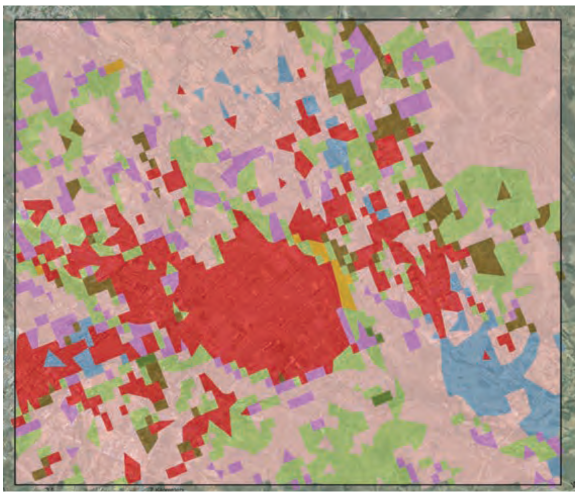
Figure 27: Assessment Area and Land Cover

Assessment area



Project contour

Land cover in the assessment area



2018

Cropland, Grassland, Urban, Wetland
Shrubland, Forest, Sparse veg., Water

Source: AIIB staff computation based on Arcadis' NCV Model

In Step 2, the goal is to scope stakeholder activities within the landscape and to understand how these are related to natural capital in terms of dependencies and impacts. The NCV model links natural capital dependencies and impacts to well-defined land cover classes through the natural capital/socio-economic activity matrix. The key is obtaining such usage data with primary surveys or through secondary sources. Based on field surveys and interviews, the project's key stakeholders were identified under the ESIA.

Step 3 focuses on ecosystem extent and how this has evolved. This helps planners understand various drivers of change and the related pressures. Land cover data allows the production of maps showing the class, location and extent of ecosystem types in the assessment area. This identifies significant areas of change and highlights key ecological functional relationships between different ecosystem assets. In the Inner Mongolia project, the land cover, estimated at 300 square kilometers, comprises mainly cropland (47 percent), urban area (19 percent) and grasslands (18 percent), as well as areas of shrubland, forest, sparsely vegetated area, wetland and water.

We consider the changes in the ecosystem between 1992 and 2018, with Table 3 highlighting the matrices of changes. The diagonal cells represent the unchanged land cover between 1992 to 2018. The cell values down a column represent land cover depletion during this period. For example, between 1992 and 2018, 14.84 and 6.62 square kilometers of cropland were converted to urban and grassland, respectively. The cell values across the row represent an addition to land cover. Thus, 1.63 square kilometers of sparse vegetation and 1.18 square kilometers of grassland were converted to cropland during this period.

Between 1992 and 2018, several natural ecosystem types experienced a decline, with cropland (22.1 square kilometers), shrubland (6.5 square kilometers) and grassland (5.4 square kilometers) witnessing the biggest drop. This likely led to a corresponding reduction in the ecosystem services they provided. In contrast, urban areas, the only ecosystem to expand, increased by nearly 40 square kilometers, most of which emanate from croplands, grassland and shrubland. Related impacts, such as water withdrawal, water pollution, waste generation and air emissions, are expected to have increased alongside this change.

Table 3: Ecosystem Type Change Matrix for the Period 1992-2018

		1992									
	km²	**Cropland**	**Forest**	**Grassland**	**Shrubland**	**Sparse Vegetation**	**Urban**	**Water**	**Wetland**	**N/A**	**Grand Total**
2018	**Cropland**	137.66	0.00	1.18	0.20	1.63	0.01	0.07	0.00	0.00	**140.74**
	Forest	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.67**
	Grassland	6.62	0.00	46.58	1.32	0.13	0.03	0.03	0.03	0.00	**54.73**
	Shrubland	0.38	0.00	0.17	21.01	0.06	0.00	0.00	0.00	0.00	**21.63**
	Sparse Vegetation	3.17	0.00	0.11	0.76	7.60	0.00	0.00	0.00	0.00	**11.63**
	Urban	14.84	0.00	12.07	4.78	3.81	15.79	1.32	0.89	1.93	**55.44**
	Water	0.21	0.00	0.01	0.02	0.00	0.00	13.15	0.00	0.00	**13.39**
	Wetland	0.00	0.00	0.04	0.00	0.00	0.00	0.00	1.31	0.00	**1.35**
	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	**0.05**
	Grand Total	**162.88**	**0.67**	**60.14**	**28.09**	**13.22**	**15.83**	**14.58**	**2.24**	**1.97**	**299.62**

Source: AIIB staff computation based on Arcadis' NCV Model

In Step 4, information about ecosystem conditions is collected. The conditions for each ecosystem type and how they change over time are organized in the NCV model's condition accounts, which are organized based on the SEEA Ecosystem Condition Typology classes. Dependencies and impacts on natural capital and changes in ecosystem extent guide the selection of condition indicators. Ideally, the condition accounts should include observed values for several accounting years, reference level values between which the observed values fluctuate and a value describing the change in the observed value. This enables the evaluation of whether there has been an improvement (positive change), no change (neutral) or a decline (negative change) in ecosystem condition.

Gathering granular time-series data on the ecosystem condition can be resource-intensive. Alternative methods like extrapolation and per-area estimation techniques can be used where data is unavailable. For the Inner Mongolia project, the ESIA collected ecosystem condition data for the ecosystem condition accounts. However, condition data for various variables were unavailable as time series from the ESIA. Figure 28a gives an example of the type of data collected from the ESIA, while Figure 28b shows how this data was incorporated into the model's condition account. However, this does not fully correspond to the type of account ideally included in a standard NCV model output (Figure 28c).

In addition to the absence of time series data, there was a lack of reference values for some of the variables. The reference values denote potential outer bounds of what could be expected for the ecosystem for that variable. They help to contextualize the results and are used to normalize variables into condition indicators. The condition account contained 52 condition variables. Out of these, 28 had sufficient numerical data to contribute to the condition assessment for the project. Where data was unavailable for the accounting years, attempts were made to estimate the data.

An extract of the Condition Account for the Water ecosystem is shown in Table 23 in the Appendix.[34] Data constraints have limited the extent of substantiated statements about the condition of

Figure 28: Example of Data Adjustments

a.

Soil Quality on the East Side of Tacer River South Road; year = ?; value = 17.7; unit = mg/kg.

This Project

b.

VARIABLE	UNIT	VARIABLE VALUE	REFERENCE VALUE		INDICATOR VALUE (0-1)
		YEAR 1	LOW	HIGH	
Lead (soil)	mg/kg	17.7	800	0	0.98

Full NCV Model Application

c.

VARIABLE	UNIT	VARIABLE VALUE		REFERENCE VALUE		INDICATOR VALUE (0-1)		CHANGE
		YEAR 0	YEAR 1	LOW	HIGH	YEAR 0	YEAR 1	
Lead (soil)	mg/kg	100	17.7	800	0	0.88	0.98	+0.1

Source: AIIB staff computation based on Arcadis' NCV Model

Note: Panel (a) refers to the condition data available in the ESIA; Panel (b) shows how available condition data was incorporated in the condition account (with "LOW" and "HIGH" referring to condition level); and Panel (c) highlights standard NCV model condition account (yellow highlights indicate the need for a time series of data).

[34] Other Condition Account tables are available on request.

the ecosystem in the assessment area. Concluding the evolution of an ecosystem's state is not possible for some ecosystems, as at least two data points from different years per variable are required to analyze such an evolution.

In Step 5, identifying and assessing ecosystem service flows allow a quantitative assessment of the relationship between the identified ecosystem assets, the economy and the wider society. Ecosystem services are the direct and indirect flows of goods and services from ecosystems that contribute to human well-being, like fish/water/crop provisioning, carbon storage, soil erosion control, water purification, etc. Such assessment explains why local natural capital is essential and outlines the risks and opportunities if the natural capital changes. Degradation of ecosystems and decline in related biodiversity affects nature's ability to provide for these ecosystem services.

Relevant ecosystem services are primarily identified based on actual ecosystem types in the area (each ecosystem type has its typical range of ecosystem services) and insights from Step 2 on the beneficiary groups, i.e., stakeholder groups who benefit from ecosystem service flows.

For the Inner Mongolia project, the extent of the ecosystem services included in the analysis was driven by data availability. The data was primarily sourced from ESIA, with efforts to adjust them to be more context-specific.[35] Moreover, considering the significance of wetlands in the project, additional information on ecosystem services provided by wetlands was incorporated. This supplementary data was sourced from the Ecosystem Services Valuation Database (ESVD).[36] Only wetland services data supported by studies conducted within China were selected.

The ecosystem services analyzed include (a) crop provisioning based on corn, rice and bean production, (b) meat provisioning based on pork and mutton production, (c) milk provisioning, (d) water provisioning and (e) other ecosystem services related to wetlands like air filtration service, global climate regulation services, local climate regulation services, river flood mitigation services, retention and breakdown of nutrients, soil quality regulation services and storm mitigation services.

The lack of timely data on other ecosystem services constrained their inclusion in the analysis. For example, in addition to ecosystem services indicated above, wetlands could also provide services such as wild fish and other natural aquatic biomass provisioning services; wild animals, plants and other biomass provisioning services; genetic material services; rainfall pattern regulation services; soil and sediment retention services; and solid waste remediation services, among others.

Finally, in Step 6, the NCV model assigns a monetary value to all services for each accounting year. Monetary valuation is based on the ecosystem services compiled into the physical ecosystem service flow in Step 5 and exchange values, i.e., the prices at which the services would be exchanged if a market existed. The latter is compiled in the Monetary Ecosystem Valuation Account.

For the Inner Mongolia project, the exchange values were calculated using a combination of available price data and value transfer.[37] Where value transfer was used, results were taken from the primary literature and the ESVD. Adjustments were made to the values obtained from the ESVD based on price changes over time in China using relevant inflation rates and differences in income across first-level administrative divisions within China.[38] Table 4 highlights the monetary valuation of ecosystem services and is based on Table 24 and Table 25 in the Appendix. Table 24 highlights the physical service flows, including tons of crop, meat and milk provisioning, tourist arrivals and water provisioning.[39] The extent of ecosystem services was valued for the different ecosystem types and

35 Cropland extent in the assessment area relative to the extent of cropland in Ulanhot City was used to pro-rata the crop, meat and milk provisioning ecosystem services as production data was only available at the level of Ulanhot City.

36 https://www.esvd.net/

37 Value transfer refers to applying quantitative estimates of ecosystem service values from existing studies to another context. Value transfer is not one specific method. It represents a continuum of approaches that depends on the information available.

38 Adjustments on a per-income basis are considered some of the most important in ensuring ecosystem service values reflect the situation in reality to the extent possible [Bateman et al. (2011); Johnson et al. (2021)].

39 Data constraints make it difficult to allocate tourism services to specific ecosystem types. Hence, tourism service flows were excluded when completing the monetary ecosystem asset accounts.

Table 4: Monetary Ecosystem Flows Account (USD Million)

Ecosystem Type	Year	Crop Provisioning			Meat Provisioning		Milk Provisioning	Tourism*	Water Provisioning	Air Filtration Services	Global Climate Regulation Services	Local (micro and meso) Climate Regulation Services	Peak Flow Mitigation Services; River Flood Mitigation Services	Retention and Breakdown of Nutrients	Soil Quality Regulation Services	Storm Mitigation Services
		Corn	Rice	Beans	Pork	Mutton										
		USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD	USD
Forest	Unknown															
Water	Unknown							79.96	2.68							
Cropland	2021	28.56	10.95	0.22												
Urban	Unknown							79.96								
Grasslands	2021				6.77	33.43	20.33	79.96								
Sparse Vegetation	Unknown															
Shrubland	Unknown							79.96								
Wetland	2012									0.024	0.096	0.16	0.897	0.033	0.821	0.164
	2018							79.96		0.018	0.071	0.12	0.666	0.025	0.610	0.121
Total	Latest Available Year	28.56	10.95	0.22	6.77	33.43	20.33	399.78	2.68	0.018	0.071	0.12	0.666	0.025	0.610	0.121
Users																
Agriculture	2021	28.56	10.95	0.22	6.77	33.43	20.33									
Forestry																
Fisheries																
Energy & Water Supply	Unknown								2.68							
Government & Households	2012							399.78		0.024	0.096	0.158	0.897	0.033	0.821	0.164
	2018									0.018	0.071	0.117	0.666	0.025	0.610	0.122

Source: AIIB staff computation based on Arcadis' NCV Model

mapped to various categories of users. For example, croplands primarily provided crop provisioning services, while grasslands provided meat and milk provisioning. Table 25 features the values of these ecosystem services based on related prices. Producer price data is preferred to consumer prices as they more closely reflect the value of natural assets and include fewer intermediate inputs.[40]

Nearly 80 percent of valuation of ecosystem services (excluding tourism) emanates from crop and meat provisioning, each valued at around USD40 million annually. This is followed by milk provisioning, valued at USD20.3 million. The agriculture sector is the biggest beneficiary of these services. Water provisioning services are valued at around USD2 million, with the benefits mainly accruing to the energy and water supply sectors. Finally, the household and the government sector benefit from a wide range of ecosystem services, including air filtration, global and local climate regulation, peak flow mitigation, soil quality regulation, storm mitigation and retention and breakdown of nutrients. These services are valued at around USD1.6 million.

Natural capital risk assessment

In this part, identified risks are rated, and different scenarios are analyzed. The risk assessment calculates risk scores per risk area. Under this part, three main steps can be distinguished (Figure 29).

Under Step 1, a risk profile for the baseline is established. Key drivers, pressures and national/regional/local policy responses are described. To gauge the materiality of the identified risk, indicators with quantitative/qualitative values are defined for various risks and compared to indicator thresholds based on the landscape's ecological and socio-economic thresholds. Next, based on the indicator thresholds, indicator review triggers are identified. These values are established outside of the range of normal expected fluctuations in indicator value and represent the value of an indicator at which timely stakeholder intervention would be necessary to avoid crossing the indicator threshold. Finally, risk scores between 1 and 4 (1 = low risk / 4 = high risk) are assigned to each indicator per risk. These scores consider the current indicator value relative to indicator threshold values and expected changes.

Figure 29: Steps of Part II of NCV Model

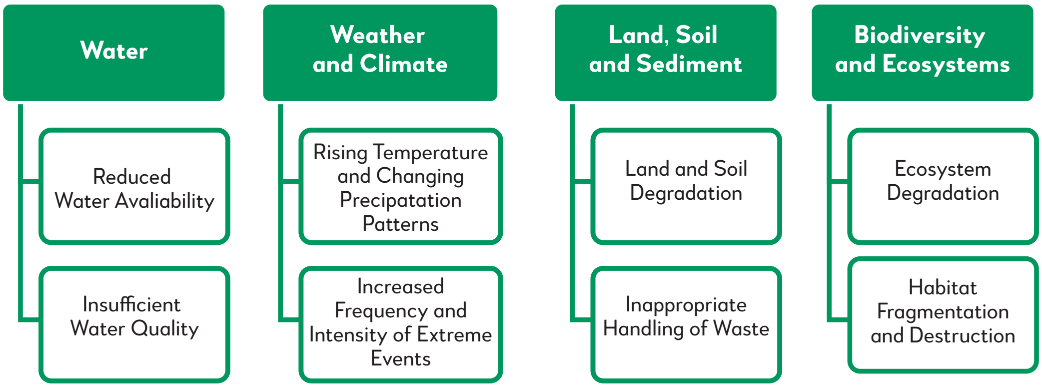
1. Establish a **risk profile** for the current baseline and categorize risks into corresponding risk theme and risk area.
2. Compile natural capital **monetary asset value accounts** by calculating natural capital asset values, incorporating an understanding of risks in the environment into relevant valuation parameters (BAU scenario).
3. Describe and assign **sustainability categories** for/to each of the **Potential Investment Areas** in the **scenario analysis**. Conduct the scenario analysis based on Potential Investment Areas (strategic priorities and material risks): BAU scenario and sustainable scenario (with climate scenario integrated).

Overall goal: Understand the **risk profile** for the current baseline and identify material drivers, pressure and risks to **inform scenario analysis** and the **design investment opportunities**.

Source: AIIB staff computation based on Arcadis' NCV Model

[40] However, even producer prices include the value of various non-natural capital inputs like labor and fertilizer, and hence the values obtained are indicative.

Figure 30: Risk Themes and Risk Areas



Source: AIIB staff computation based on Arcadis' NCV Model

The scores are considered in terms of the magnitude of loss in ecosystem service benefits likely to occur and the sensitivity of the affected stakeholders.

Based on this risk assessment, a risk heat map in terms of the risk areas is highlighted. The matrix illustrates the relationship between the likelihood of risks and their impact on natural capital and the socio-economic context. The horizontal axis indicates the severity of the impact, while the vertical axis indicates the likelihood of the risk materializing. The lower left corner of the heat map represents an optimal sustainable scenario, while the upper right corner represents the most unsustainable situation.

The risk assessment for the Inner Mongolia project integrates the data from the ESIA, the various natural capital accounts and the other selected data sources such as ThinkHazard, WWF Risk Filter Suite and IUCN Red List. Risk scores are calculated per area and grouped under overarching risk themes (Figure 30).

The key outcomes of the risk assessment are highlighted in Table 5. As can be seen, some of the major stress areas include poor quality of surface water; an increased temperature that can result in soil loss and reduced water availability; unsustainable land, soil, and sediment management; widespread illegal dumping of waste; and the presence of critically endangered and endangered species.

The risk heat map indicates that the region is highly vulnerable in the case of most of the risk areas as they lie in the top right quadrant of Figure 31. The key risk themes include a reduction in the availability of water, worsening of water quality, change in the concentration of chemical characteristics, pollution of water and soil, changes in temperature and rainfall pattern, changes in the frequency of extreme events such as floods and droughts, worsening of soil and sediment quality, salinization of water and soil and changing habitat structure.

After completing the risk assessment, monetary ecosystem asset values (net present values of natural capital assets) are modeled for various ecosystem types. The valuation is performed for robustness using multiple discount rates and two different asset lifespans. Different values can be selected for use in different contexts. For example, changes in net present value can be analyzed to estimate measures of ecosystem degradation, enhancement and conversion. Table 6 highlights the total net present values for all ecosystem types in the assessment area with a seven percent discount rate.[41] The monetary value of natural capital assets is directly related to asset lifespan and discount rates, which can be changed by avoiding crossing tipping points and improving asset quality (ecosystem extent and condition).[42]

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41 Additional robustness checks with alternate discount rates were undertaken and can be shared on request.

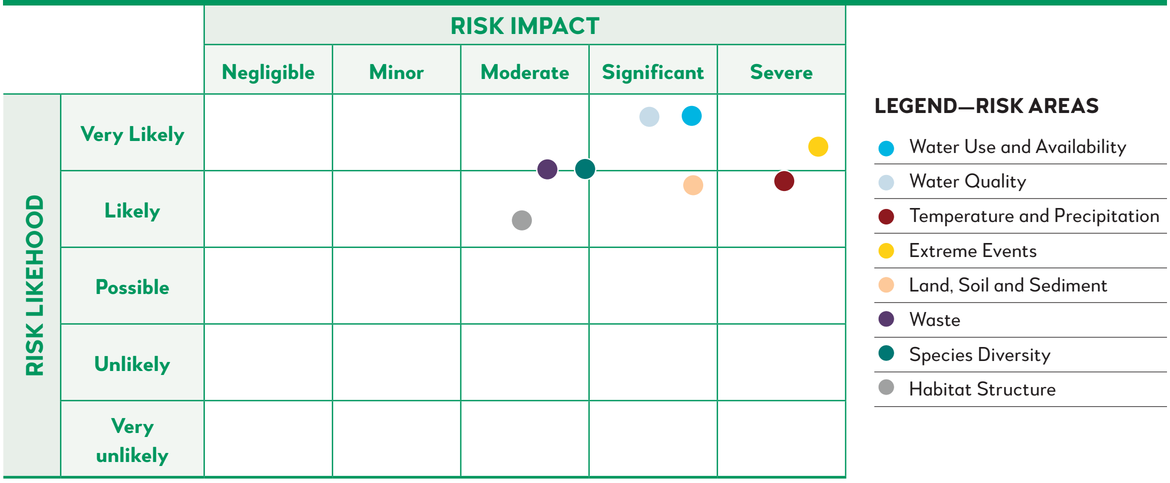
42 The construction of these values is based on the underlying principle that the value of an asset is underpinned by the future provisioning of ecosystem service flows, which is aligned with the guidance of the SEEA-EA. Hence, to increase the value of natural capital assets, efforts should be made to improve the productivity, resilience and lifetime of ecosystem assets (again, this relates to changes in ecosystem extent and condition).

Table 5: Overview of Risk Assessment Results

Risk Themes	Risk Areas	Indicators	Score	No. of Indicators Exceeding Threshold	No. of Indicators Exceeding Review Trigger
Water	Reduced Water Availability	Water scarcity level	3	0	1
	Decreasing/ Insufficient Water Quality	WWF Risk Filter Surface Water Quality Index	4	1	1
		Percentage of chemical components surpassing quality standard	1		
Weather and Climate	Rising Temperature and Changing Precipitation	Number of years with annual precipitation below 200 mm in the past 30 years	2	1	2
		Projected increased annual temperatures in the region	4		
	Increased Frequency and/or Intensity of Extreme Events	Set of hazard levels related to natural risks for seven indicators	3	2	4
Land, Soil and Sentiment	Land, Soil and Sentiment	Evidence of unsustainable land use/management	4	1	1
		Percentage of chemical components exceeding the standard for soil pollution risk control of construction land	1		
	Inappropriate Handling of Waste	Illegal dumping of waste	4	1	1
Biodiversity and Ecosystems	Ecosystem Degradation	Critically endangered and endangered species per IUCN Red List	4	1	2
		Biodiversity Risk Filter's Invasives Indicators	3		
	Habitat Fragmentation and Destruction	Percentage change in extent of forest, grassland, shrubland, sparce vegetation, water and wetland ecosystems (1992 to 2018)	1	0	1
		Proportion of forest, grassland, shrubland, sparce vegetation, water and wetland ecosystems converted into urban and cropland ecosystems (1992 to 2018)	3		

Source: AIIB staff computation based on Arcadis' NCV Model

Figure 31: Risk Heat Map Showing Risk Likelihood vs. Risk Impact for Identified Risk Areas



Source: AIIB staff computation based on Arcadis' NCV Model

For illustrative purposes, the value was also decomposed on a per-ecosystem service basis for the wetland ecosystems. The value provided by these services can be added together to obtain the value for the whole wetland ecosystem. However, note that ecosystem services values are not always necessarily additive, so care should be taken when interpreting such results.[43]

A similar decomposition on a per-ecosystem service basis can be applied to every ecosystem type. To remove any potential bias of identifying larger ecosystems as those with the highest value, the value of ecosystem services per hectare is also outlined in Table 6. Thus, while grassland ecosystems provide the overall largest value owing to meat and milk provision services, wetland ecosystems emerge as the most valuable on a per-hectare basis.

Scenario analysis

Finally, alternate scenarios can be evaluated. These include (a) the unsustainable scenario, which assumes a significant worsening of the ecosystem, (b) the business-as-usual (BAU) scenario, which assumes that the current project is not undertaken, (c) the project scenario, which includes the effect of the current project and (d) sustainable or nature-positive scenario comprising all the necessary actions needed to achieve nature-positive outcomes at the landscape level.

The risk assessment conducted above informs the scenario analysis. It indicates which sustainability category (1 = unsustainable / 4 = sustainable) should be assigned to the baseline situation for each of the Potential Investment Area (PIA). PIAs are based on key risk areas and are used to categorize investment opportunities. Similarly, a sustainability category is assigned to the Unsustainable Scenario, BAU Scenario, Project Scenario and Sustainable Scenario for each PIA. A description explaining the effect on natural capital for each of the four sustainability categories linked to the PIA is provided, along with details on (a) impact on ecosystem assets, (b) impact on ecosystem services, (c) economic indicators and (d) human health and SDG-related indicators.

For the Inner Mongolia project, the PIA "Investment in Wetland and River Restoration" was considered. The impact on ecosystem services is assessed both quantitatively and qualitatively. Qualitative assessment is represented by arrows indicating changes in value and is informed by prior assessments, especially the risk assessment. The quantitative assessment links the arrows to

[43] This refers to how ecosystem services may be correlated (positively or negatively), so their values do not necessarily add together. For example, considering how it may be possible to extract additional biomass (e.g., plant biomass) from an ecosystem, this may reduce regulating services (e.g., less nutrient cycling as plants are being removed more frequently).

Table 6: Net Present Value and Per Hectare Value of Ecosystem Services

Ecosystem Type	Year	Total Value per Year	Asset Value (7% DR, 100 Year Asset Lifespan)	Asset Value (7% DR, 50 Year Asset Lifespan)	Total Value per Year per Hectare	Asset Value per Hectare (7% DR, 100 Year Asset Lifespan)	Asset Value per Hectare (7% DR, 50 Year Asset Lifespan)
		USD Million	USD Million	USD Million	USD/ha	USD/ha	USD/ha
Forest	Unknown						
Water	Unknown	2.68	38.19	36.94	1,998.99	28,524.05	27,587.52
Cropland	2021	39.73	566.86	548.25	2,822.66	40,277.18	38,954.76
Urban	Unknown						
Grasslands	2021	60.53	863.71	835.35	11,059.32	157,808.19	152,626.85
Sparse Vegetation	Unknown						
Shrubland	Unknown						
Wetland	2012	2.19	31.30	30.27	10,707.59	152,789.28	147,772.73
Total	Latest Available Year	104.56	1,492.00	1,443.01	3,489.80	49,796.80	48,161.82

Source: AIIB staff computation based on Arcadis' NCV Model

expected changes in asset lifespan and discount rates and is expressed as net present value (USD). A key benefit of this approach is that the data was developed from the account level up, which provides a transparent means of assessing the scenarios. It allows sufficient flexibility in evaluating natural capital and will enable scenarios to be underpinned by different assumptions.

The outputs of the scenario analysis are underlined in Table 26 in the Appendix while Table 7 highlights the qualitative and quantitative outcomes. The anticipated change ranges from significant improvement (↑↑), improvement (↑), neutral (↔), decline (↓) and significant decline (↓↓).

Under the Sustainable or Nature-Positive scenario, where various necessary actions are needed to achieve nature-positive outcomes, the ecosystem extent would substantially increase for multiple natural ecosystems. A conservative estimate indicates an increase of 200 hectares compared to the baseline. This will likely significantly improve various ecosystem conditions like water quality variables, soil quality variables and species number. Ecosystem service value would increase, and new ecosystem services would be incorporated into the landscape. The extent of improvement in the Project Scenario is lower than that of the Nature-Positive Scenario, with the extent of the Tao'er River increasing by nearly 90 hectares. The ecosystem conditions are expected to have improved in this scenario but again lower than in the Nature-Positive scenario.

In contrast, under the Business-as-Usual or the Baseline scenario, the ecosystem extent and condition will likely remain relatively stable over time in the absence of extreme events and other significant pressures. The ecosystem service values are also likely to remain stable in the absence of any fluctuations in environmental or economic variables. Finally, under the Unsustainable scenario, there would be a loss of ecosystem extent and a decline

Table 7: Impact on Ecosystem Services

Sustainability Category	Provisioning Services (USD Million)				Regulating Services (USD Million)							Total (USD Million)
	Crop	Meat	Milk	Water	Air Filtration Services	Global Climate Regulation	Local Climate Regulation	Peak Flow Mitigation; River Flood Mitigation	Retention and Breakdown of Nutrients	Soil Quality Regulation	Storm Mitigation	
4 (Sustainable or Nature-positive Scenario)	↑↑ 973.49	↑ 797.87	↑ 403.51	↑↑ 65.58	↑↑ 1.09	↑↑ 4.34	↑↑ 7.14	↑↑ 40.55	↑↑ 1.49	↑↑ 37.12	↑↑ 7.39	2339.58
3 (Project Scenario)	↑ 788.48	↑ 797.87	↑ 403.51	↑↑ 65.58	↑ 0.59	↑ 2.36	↑ 3.88	↑↑ 27.21	↑ 0.81	↑ 20.18	↑↑ 4.96	2115.43
2 (BAU/ Baseline)	↔ 725.23	↔ 733.87	↔ 371.14	↔ 48.86	↔ 0.33	↔ 1.30	↔ 2.14	↔ 12.17	↔ 0.45	↔ 11.14	↔ 2.22	1908.85
1 (Unsustainable Scenario)	↓↓ 548.25	↓↓ 554.78	↓↓ 280.57	↓↓ 36.94	↓↓ 0.25	↓↓ 0.98	↓↓ 1.62	↓↓ 9.20	↓↓ 0.34	↓↓ 8.42	↓↓ 1.68	1443.01

Source: AIIB staff computation based on Arcadis' NCV Model

in the ecosystem conditions, which is associated with a loss of services. It would adversely impact biodiversity and human health.

Monetizing the ecosystem services indicates that overall ecosystem services under the project scenario are 10.8 percent higher than the BAU/baseline scenario (Table 7). The biggest benefit will accrue to river flood mitigation and storm mitigation services, whose value is more than double in the Project scenario. Various provisioning services, which account for the majority of the value of ecosystem services, also experience an increase, with water provisioning services increasing by 34.2 percent and crop, milk and meat provisioning services growing by 8.7 percent.

In the Sustainable or the Nature-Positive scenario, additional benefits accrue to crop provisioning, river flood mitigation and soil quality regulation, compared to the project scenario. Overall, under the Sustainable scenario, the value of the ecosystem services is 10.6 percent higher than the project scenario and 22.6 percent higher than the BAU/baseline scenario. In contrast, in the Unsustainable scenario, the value of ecosystem services is about 24.4 percent lower than the BAU/baseline scenario, with the value of all the ecosystem services experiencing a substantial decline.

5.3 Economic and Social Benefits of Including Biodiversity in Infrastructure Project Design

Planning early for No Net Loss or Net Gain and engaging stakeholders in its delivery effectively avoids damage to nature. The Net Gain concept not only provides multiple natural capital benefits but also provides the opportunity to generate significant benefits for communities, helping gain local support and leaving behind a genuine legacy regarding improved air quality and reduced flood risk. Below, we highlight some case studies on how infrastructure projects can incorporate nature components during construction to ensure net biodiversity gain.

5.3.1 Development of a New Airport in Southeast Asia

The project comprises building an international airport and associated access road infrastructure. The financial lenders required the project to comply with International Finance Corporation (IFC) Performance Standard 6 (PS6) and national standards.[44] The project is located within an Important Bird and Biodiversity Area (IBA) and Key Biodiversity Area (KBA). According to IFC PS6, a Biodiversity Action Plan (BAP) was produced outlining the rationale and actions for the Project's mitigation strategy to demonstrate Biodiversity Net Gain (BNG) in Critical Habitats and No Net Loss in Natural Habitat. The habitats under the project footprint include tidal mudflats (~18 percent), inundated mudflats (~35 percent), mangrove forests (~2 percent), temporarily dry and shallow fishponds (~8 percent), inundated fishponds (34 percent) and rivers (~2 percent). Mudflats, mangroves and temporarily dry and shallow fishponds are considered critical habitats for amphibians, mollusks, crustaceans, fish and various migratory birds. Construction and operational impacts have been identified as part of the ESIA.

Significant residual impacts from the project were identified, and therefore, the offsets and Additional Conservation Actions in the BAP were considered to ensure No Net Loss and BNG. The Project aims to achieve 10 percent BNG for critical habitats. The development of offset actions will follow IFC PS6 and recognized Good International Industry Practice, such as the Business and Biodiversity Offsets Programme standard. An Offset Feasibility Study and a Biodiversity Offset Management Plan are required as the Project progresses to further develop the BAP actions.

The project has undertaken key steps to adhere to the principles of IFC PS6. Based on detailed calculations of the losses and gains of critical habitats such as mudflats and mangroves, offset areas were selected and designed to achieve Net Gains. The offset areas can provide various ecosystem services with multiple benefits for local communities and maybe even the project itself.

[44] The IFC Performance Standards (PS) are an international benchmark for environmental and social risk management and aim to (a) protect and conserve biodiversity, (b) maintain the benefits from ecosystem services and (c) promote the sustainable management of living natural resources through the adoption of practices that integrates conservation needs and development priorities.

Quantifying these benefits will likely facilitate stakeholder dialogues, increase local community support to the infrastructure development (or at least reduce resistance) and finally decrease transition risks (e.g., license to operate). If offset areas are designed to benefit the project itself, then the business case gets even stronger. A good example is increased storm flood protection from restored mangroves. This might save high damage costs to infrastructure.

5.3.2 Water Supply and Sewerage in Uzbekistan

The project objective is to provide access to safely managed water and sanitation services and to strengthen the operational performance of the regional water companies in Karakalpakstan and Khorezm. The project is planned to be financed by AIIB and the Government of Uzbekistan and is expected to cost about USD488.8 million.

During the construction and operation phases, the water supply and sanitation activities are expected to result in potentially negative impacts (air pollution, noise, soil erosion, water and soil contamination, traffic disruption and access restriction), which will be identified and corresponding plans for mitigation formulated. During operations, key environmental impacts will include the discharge of effluent from the sewage treatment plan, solid waste, especially sludge from the plant, as well as community and occupational health and safety issues.

Additional information on the project's impact on natural systems, such as groundwater levels and the environment, can help identify opportunities for nature-positive investments. Furthermore, the ecosystem extent and conditions of the regional landscape will need to be studied. A comparison can then be made between different scenarios—a business-as-usual scenario, the project scenario and a nature-based solutions scenario—and achieve a nature-positive outcome.

Drawing insights from the Syr Darya Wastewater Treatment Plant project, on which Arcadis applied the NCV model on behalf of EBRD, the following categories of potential investment opportunities seem to be promising for achieving nature-positive outcomes in the landscape:

- **Investment in Wastewater Treatment** – These may include restoration (and expansion) of wetlands and forests to improve the self-purification capacity of natural rivers and biodiversity and implementation of NBS for wastewater treatment like constructed reed beds/wetlands, soil infiltration systems, riparian buffer strips, in-stream restoration.
- **Climate Adaptation Planning and Investment** – NBS can be implemented as part of wastewater treatment infrastructure to protect against mudflows and floods while minimizing negative impacts on habitats and preventing ecosystem fragmentation.
- **Conservation and Restoration of Biodiversity and Ecosystems** – These may comprise restoration of wetlands and measures to improve and implement data collection systems to monitor the state of ecosystems, which can be communicated with stakeholders.
- **Improved Land and Soil Management** – Awareness raising programs about the long-term consequences of ecosystem degradation and introducing mechanisms that impose penalties or restoration requirements for projects like mining that damage ecosystems.

5.4 The Imperative of Developing Tools to Value Nature

Overcoming the current biodiversity crisis is contingent on various development institutions mainstreaming nature-positive investments. A significant difference between traditional grey infrastructure and NBS is the latter's multifunctionality. The aforementioned wetland restoration project in Inner Mongolia not only improves the value of various provisioning services but also helps improve air and water quality, mitigates storms and helps mitigate river floods. The key challenge remains to quantify these benefits to enable the decision-makers to make the appropriate choice for future investments. Traditional methods of evaluating investment projects like CBA can become challenging as they require modeling the geospatial extent of impacts and ensuring avoidance of double counting and benefits. Thus, having the appropriate tools to accurately value the costs and benefits of NBS is imperative to promote their usage by decision-makers.

CHAPTER 6

THE IMPACT OF INFRASTRUCTURE ON ENVIRONMENT

Highlights

- Nature degradation and climate change are closely related. Yet renewable energy infrastructure—the key to addressing climate change—tends to be in places with higher biodiversity intactness (likely due to yield chase). Site-level biodiversity intactness declined significantly after installation and operation for both renewables and coal projects, but solar and wind installations caused more loss of intrinsic biodiversity.
- Approaching No Net Loss or even Net Gain for renewables will primarily rely on site location decisions. Solar and wind installations near agricultural land resulted in the least decline in biodiversity intactness. State capacity is also needed to implement best practices for renewable expansion.
- The biodiversity and growth trade-offs are acute for transport infrastructure. Two major road projects in India (the Golden Quadrilateral Highway) and Indonesia (the operational segments of the Trans-Sumatra Toll Road) are studied. The areas along the road projects were characterized as low in forest integrity and low biodiversity intactness, suggesting environmentally sensitive site selection. However, forest cover dropped in the areas close to the roads relative to those further away once construction began, whereas urban settlements expanded persistently in the areas close to the roads.
- Avoidance remains the priority for conservation in transport project development. Meanwhile, minimizing, restoring and offsetting measures are as important. Among other tools, wildlife crossings, or "ecological bridges," have been proposed as a potentially appropriate approach to minimize environmental effects and implemented by many countries.

The term "infrastructure" originated during the mid-19th century railway construction when entrepreneurs competed fiercely to lay down the tracks for powerful steam locomotives to puff through to ever-expanding new territories. The concept has broadened to capture the myriad physical structures that uphold our modern society, conventionally including networked systems that provide transportation, telecommunications, energy, water, waste management and other essential services.

Infrastructure drives economic growth and development. It matters for productivity and cost reduction. Some forms of infrastructure enable connections, such as transport and telecommunications, which link people and markets, stimulate information sharing and promote innovation. Other infrastructure services are public goods, such as flood protection, which benefit all firms and households in a non-exclusive manner. There is also abundant evidence that infrastructure affects the demand for and supply of education, health and other public services. Moreover, infrastructure is essential to minimize human impact on the environment, in particular, enabling concentrations of people to live in cities [Agénor and Moreno-Dodson (2006); Estache (2007)].

Despite such advantages, the environmental impacts of infrastructure systems can also be profoundly harmful. Today, nature is declining at an unprecedented rate because of human activities. As the accumulation of physical technology, infrastructure is often seen as the best and the worst illustration of the power of humankind over nature. Rather than merely interconnected equipment, infrastructure constitutes complex socio-technology systems, with broad lock-in effects extending beyond the assets' lifetime. Both linear and cluster infrastructure can lead to direct habitat loss and fragmentation, which is the biggest threat to biodiversity and ecosystem integrity. More indirectly, infrastructure is responsible for 79 percent of greenhouse gas (GHG) emissions globally. Climate breakdown is likely to become the next dominant cause of biodiversity loss. Finally, infrastructure can degrade habitats and threaten genetic diversity by enabling pollution, overexploitation and invasive species [Perera and Uzsoki (2017); UNEP (2022); WWF (2022)].

Globally, more than 900 million people have no access to electricity [Our World in Data (2019)] , and more than a billion people live beyond road networks [World Bank (2023)]. Most of them are in the developing world. Infrastructure is fundamental and irreplaceable for people in developing countries to meet their aspirations. More than USD42 trillion of infrastructure facilities are estimated to be built in the coming three decades [GlobalData (2023)]. Unaccompanied by deliberate considerations for nature, such rapid infrastructure expansion can accelerate ecosystem and biodiversity loss.

However, the importance of infrastructure in conservation has yet to receive consistent and sufficient attention in the broader development community. In promoting renewables for net zero, many policymakers have not fully understood the dual and intertwined challenges of nature degradation and climate change. In designing ambitious transportation networks, not all planners have sufficiently accounted for biodiversity and growth trade-offs. Despite its pivotal impact, infrastructure was removed from the 2020 Global Biodiversity Framework in the drafting stage of the document [UNEP (2022); IISD (2022)].

To highlight the imperative need for a more balanced expansion, this chapter synthesizes existing literature and provides fresh evidence on the ecological impacts of infrastructure. It starts with the stylized facts regarding the regional and sectoral variations of biodiversity intactness at the project level. It then causally assesses how much energy and transport projects influence their surrounding environment. For energy, the analysis relies on the comprehensive data of global generation projects and sheds light on the differences between renewable and fossil-fuel projects. For transportation, it zooms in on two major highway projects constructed in the last two decades in India and Indonesia. Building on safeguard solutions, it also sheds light on the heterogeneity of these impacts and points to potential ways toward nature-positive infrastructure development.

6.1 Biodiversity Characteristics of Infrastructure

6.1.1 Infrastructure Continues to Expand

According to the GlobalData Construction Projects database, the number of annually completed projects with an announced value of over 25 million reached over 3,300 in 2017, up from 2,700 in 2015, and has remained at a higher level ever since (Figure 32a).[45] In fact, the capital value of these projects peaked in 2019 and stayed above USD1.1 trillion between 2020 and 2022 (Figure 32b). As the global economy regains its growth momentum steadily, the expansion is expected to continue. Over 38,500 infrastructure projects are scheduled to be built between 2023 and 2050 for an estimated USD42 trillion.

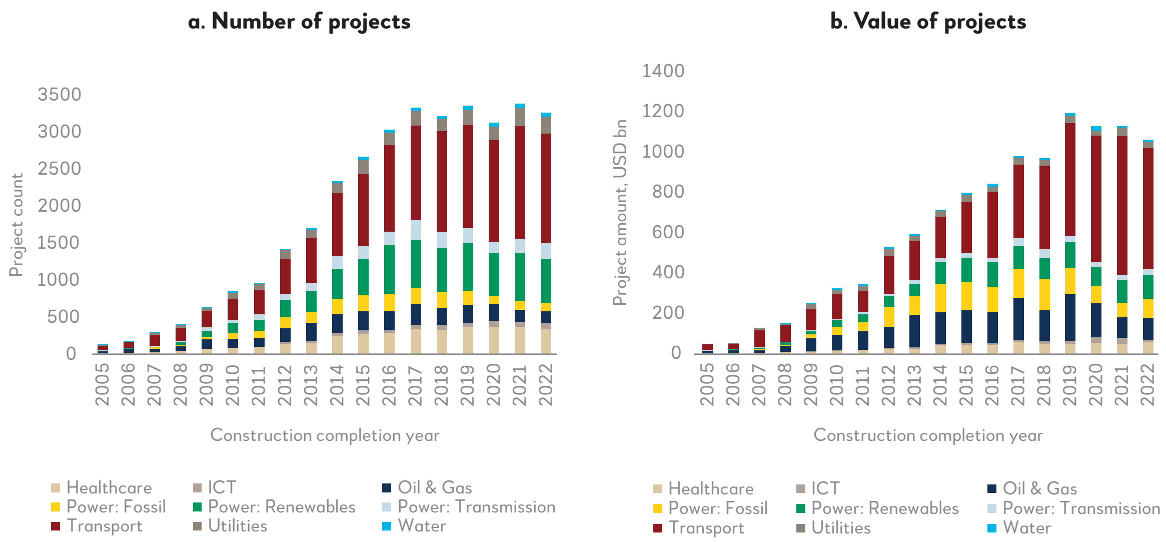
Transport projects account for the lion's share in both volume and value. More than 1,000 transport projects have been completed yearly since 2016, of which 50 percent are road and 15 percent are railway. Renewable energy generation projects stand out in volume, but fossil-fuel energy generation takes a larger share in value. Projects of other sectors account for less than five percent.

6.1.2 The Stylized Facts of Biodiversity Intactness and Infrastructure

No Net Loss and even Net Gain policies have been increasingly adopted by countries in their environmental policy frameworks and by multilateral development banks and development finance institutions (DFIs) to fully mitigate the adverse biodiversity impacts of infrastructure. These policies are often operationalized in practice by applying the "mitigation hierarchy" to biodiversity impacts—including avoiding, minimizing, restoring and offsetting.

Avoiding impacts wherever possible is strictly preferred. Compared with traditional environmental impact assessments, No Net Loss and Net Gain policies are praised for their quantitative targets and concrete rationale. However, the mitigation hierarchy often fails to be respected in practice,

Figure 32: Trend of Infrastructure Projects (2005-2022)



Source: AIIB staff computation based on GlobalData Construction Projects database (2023)

Note: The projects covered are with an announced value larger than USD25 million.

[45] The GlobalData Construction Projects database records projects with announced value over USD25 million. It covers more than 135,000 projects "in over 200 countries" as of June 2023. https://www.globaldata.com/marketplace/construction/construction-projects/

especially regarding avoidance [zu Ermgassen et al. (2019 a); zu Ermgassen et al. (2019 b); Simkins, et al. (2023)].

To shed light on the extent to which avoidance has been applied, this chapter assesses the local biodiversity characteristics of existing infrastructure projects. The GlobalData Construction Projects database reports the coordinates of 35,000 infrastructure projects completed over 2000-2022, in addition to project sector, value and other information. These projects account for 40 percent of the total construction projects covered in the database and are spread across all infrastructure sectors and 204 economies.

This chapter takes a simple but intuitive approach by overlaying the Biodiversity Intactness Index (BII) and the coordinates of these infrastructure projects. The BII is suitable for such an assessment because it models site-level pressures, landscape-scale pressures and landscape history. It reports the relative abundance of originally-present species rather than the contribution of novel species to ecosystems [Dasgupta (2021); Scholes and Biggs (2005)].[46] The Index data for 2005, 2010 and 2015 were used. The BII for the 1-, 5- and 10-kilometer buffer areas of each project were computed. Only the 10-kilometer buffer area values are presented in this section because the results are consistent across different buffer zones.

The site-level BII provides insights into a project's proximity to intact areas. Note that these simple statistics do not correspond to the actual compliance of projects. Nor do they amount to a causal inference on the impacts of projects on biodiversity, which will be conducted for selected projects in the following sections. Another caveat concerns linear projects like roads, canals and transmission lines. No polygon data are provided. The analysis is based on a fixed-size buffer area centered around the reported project coordinates.

With these caveats in mind, the BII values of infrastructure project sites were, on average, lower than that of the country (or the region). The finding is reassuring that most projects apply the mitigation hierarchy and respect the avoidance first principle. However, there are notable variations across regions and countries. Across regions, the projects in Central Asia and Northern Africa exhibited the highest site-level BII, suggesting their proximity to the intact areas (Figure 33).

At the country level, the projects in Uzbekistan, Lao PDR, Cambodia and Kazakhstan reported BII greater than 0.4 on average. The indices at such an elevated level imply that the originally present species near the sites were relatively intact but are at greater risk with the presence of the projects. Finally, it is also worth noting that country differences in biodiversity intactness were not significant once controlling for sectoral differences and time variations. Sector features were more correlated with biodiversity intactness than country characters.

As for sectoral variations, oil and gas, renewable energy generation, power transmission and water management sectors registered the highest biodiversity intactness indices (Figure 34a). The reason for oil and gas is the large-scale land excavation process.

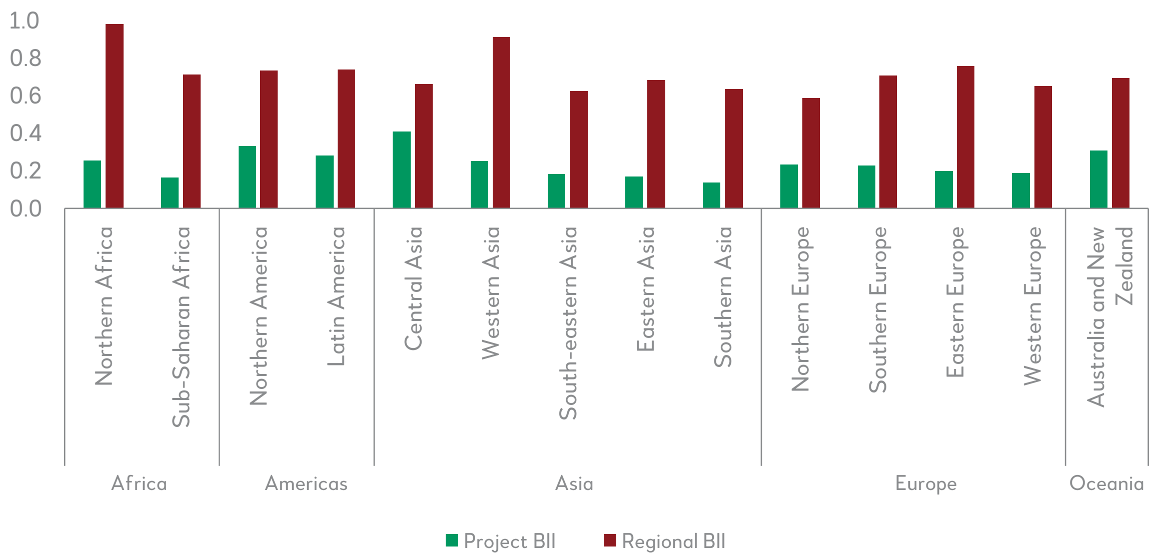
Renewable projects have a higher project-level index than fossil-fuel production sites mainly because of the more land-intensive nature of renewable generation projects. Many high-yielding renewable energy locations are also in remote areas. Therefore, positioning renewables in degraded land or away from wilderness areas is not always possible. The differences across sectors mainly persisted, even after considering country and time variations (Figure 34b). For renewables, the differences were not driven by one type of technology. Hydro, solar and wind all registered significantly higher levels of BII.

There is also suggestive evidence for the worsening of biodiversity intactness. In particular, the site-level biodiversity intactness declined slightly after the project completion time. The analysis was conducted for two selected groups: those completed between 2006 and 2009 and those between 2011 and 2014 (Figure 35).

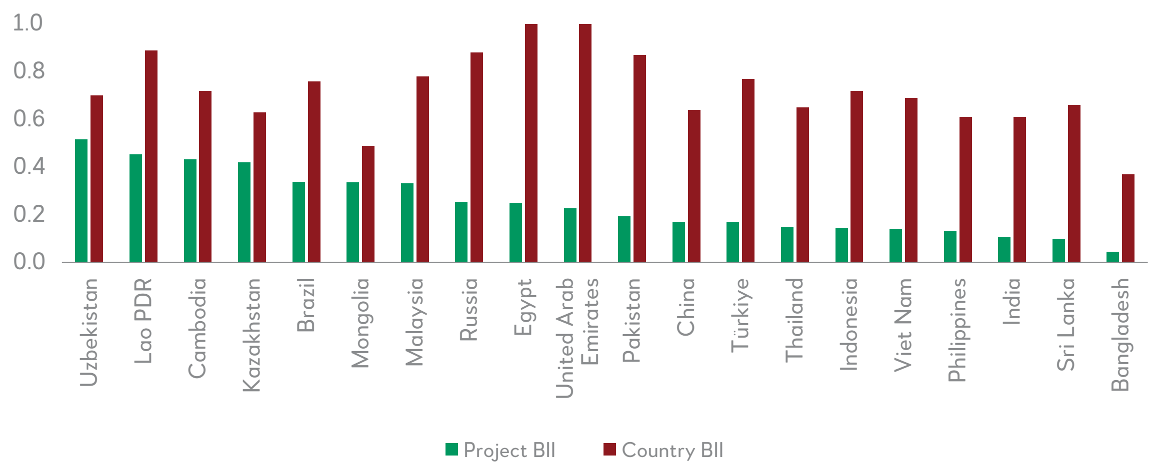
[46] The BII, calculated by the UK's Natural History Museum, is an index ranging from zero to one, measuring the proportion of species endemic to a given area relative to their natural, undisturbed levels. A value of one thus means a given area's species is the same as a perfectly intact original ecosystem. In contrast, a value of zero suggests all biodiversity has been depleted due to human activities. https://www.nhm.ac.uk/our-science/data/biodiversity-indicators/what-is-the-biodiversity-intactness-index.html

Figure 33: Biodiversity Intactness of Infrastructure Projects by Locations

a. By region



b. For selected countries

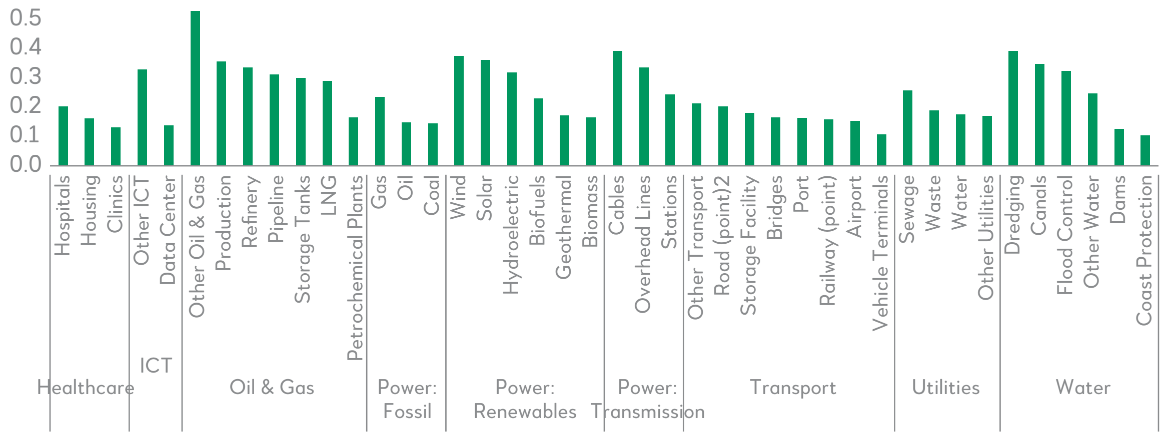


Source: AIIB staff computation based on GlobalData Construction Projects database (2023) and Newbold et al. (2016)

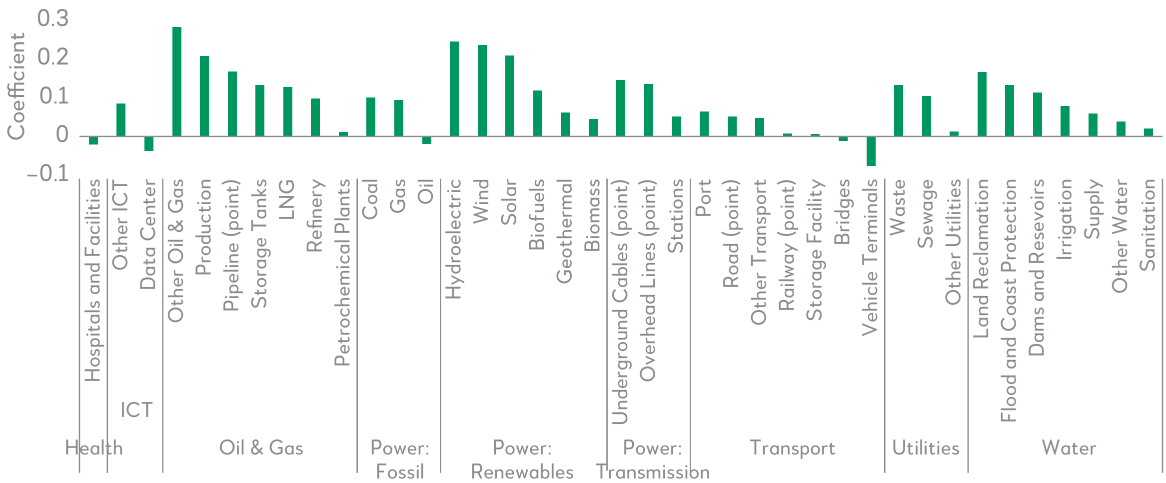
Note: Figures are based on 2015 BII.

Figure 34: Biodiversity Intactness of Infrastructure Projects by Sectors

a. Simple average



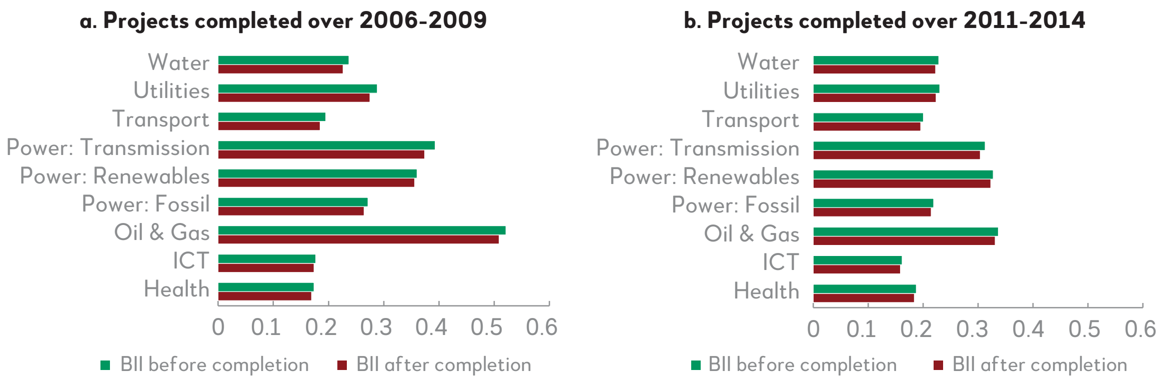
b. Relative differences, controlling for country differences and time variations



Source: AIIB staff computation based on GlobalData Construction Projects database (2023) and Newbold et al. (2016).

Note: Figures are based on 2015 BII. In figure b, the positive (negative) coefficient is interpreted as the increase (decrease) in BII of a sub-sector relative to that of the airport sector (the reference sector), after controlling for the country- and year-fixed effects. All coefficients are significant at least 90 percent.

Figure 35: Biodiversity Intactness of Infrastructure Projects Before and After Completion



Source: AIIB staff computation based on GlobalData Construction Projects database (2023) and Newbold et al. (2016).

Note: For figure a, results before completion are based on 2005 BIIs, while results after completion are based on 2010 BIIs; for figure b, results before completion are based on 2010 BIIs, while results after completion are based on 2015 BIIs.

The results are robust for both groups of observations. Although the comparison is not a causal inference, it supports the literature that large infrastructure projects contribute to biodiversity loss. In the subsequent sections, this chapter explores the impact of infrastructure more rigorously by looking into the two most important sectors: energy and transportation.

6.2 The Impact of Energy Infrastructure

6.2.1 The Dual Challenges of Nature Degradation and Climate Change

Nature degradation and climate change, the two existential risks facing the global community, are closely related. Rising temperatures are linked to more frequent and severe climatic events. Rising temperatures are also identified as one driver of declining biodiversity. The primary lever to address impacts has been reducing GHG emissions and transitioning toward net zero. While limiting rising global temperatures through GHG emission reductions has been a well-evidenced strategy, limiting the loss of natural capital and biodiversity requires a variety of drivers beyond just GHG emission and temperature rise [Diaz et al. (2019); Mellennium Ecosystem Assesment (2005); Taub (2010)].

Energy infrastructure, especially renewables, plays a key role in addressing the dual challenges. Renewable energy technologies contribute fewer CO_2 emissions across their full-life cycles than coal and other carbon-based energy sources. As the maturity and reliability of these technologies improve, a strong weight has been placed on transitioning to renewables across countries [World Nuclear Association (2023)]. As a result, renewables expanded steadily. Both solar and wind have seen a consistent rise in new installations since the early 2000s, with the total installed projects reaching 13,000 and nearly 28,000 in 2022. The expansion was as pronounced when considering total capacity, 447,000 MW, and 776,000 MW in 2022 (Figure 36).

On the other hand, renewable technologies could leave a greater environmental influence on their surroundings as they have higher land-use intensity than fossil fuels. Both renewable and fossil-fuel energy productions require significant mining operations on the back end, disposal of energy generation material within their product life cycle, and some form of geographic footprint to locate their operations and transmit energy on the front end.

However, on average, renewable energy production can be ten times more land-use intensive than fossil fuel production per MW of energy throughout their life cycles. Both hydro and solar power have a higher land-use intensity than coal and other fossil-based energy production technologies (Figure 37). According to the literature, wind power has a significantly higher land-use intensity compared to coal [Lee and Keith (2018); Rehbein et al. (2020); Trainor et al. (2016)].

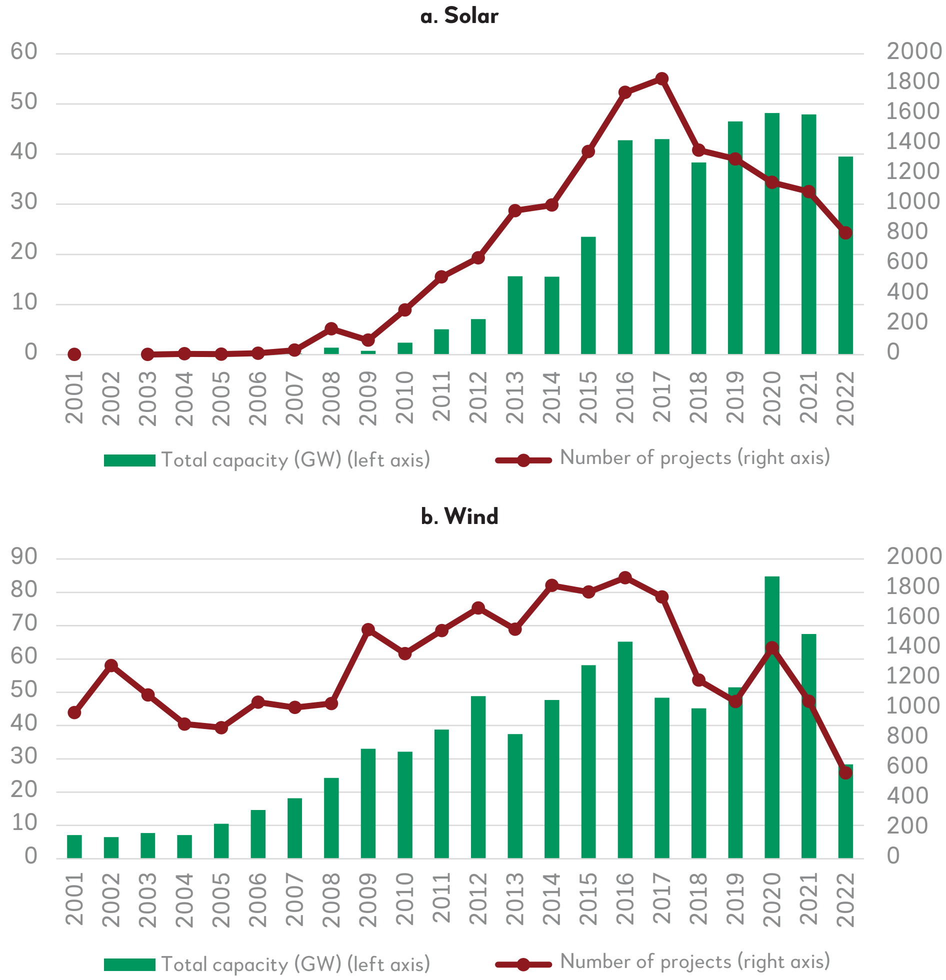
The intensive use of land by renewables may lead to the degradation of natural landscapes through vegetation removal during construction and operation, fencing, diversion of water flow and secretion of pollutants arising from maintenance. Ecosystem fragmentation may also occur, particularly in the cases of "cumulative impacts," where multiple renewable energy sites may be present within a region.

Fragmentation can be exacerbated by supporting infrastructure to renewable sites, such as service roads and transmission line development. Service road infrastructure to remote renewable energy sites is also particularly susceptible to the proliferation of invasive species [Gasparatos et al. (2017); Gillinghan et al. (2016); Hernandez et al. (2014); Niebuhr et al. (2022); Marcantonio et al. (2013); Semeraro et al. 2018)].

6.2.2 The Adverse Impact on Biodiversity

This chapter provides new evidence of energy infrastructure's impact on nature by purposely building a comprehensive data set of global energy projects and by conducting quasi-experiment analysis. Information on solar, wind and coal energy

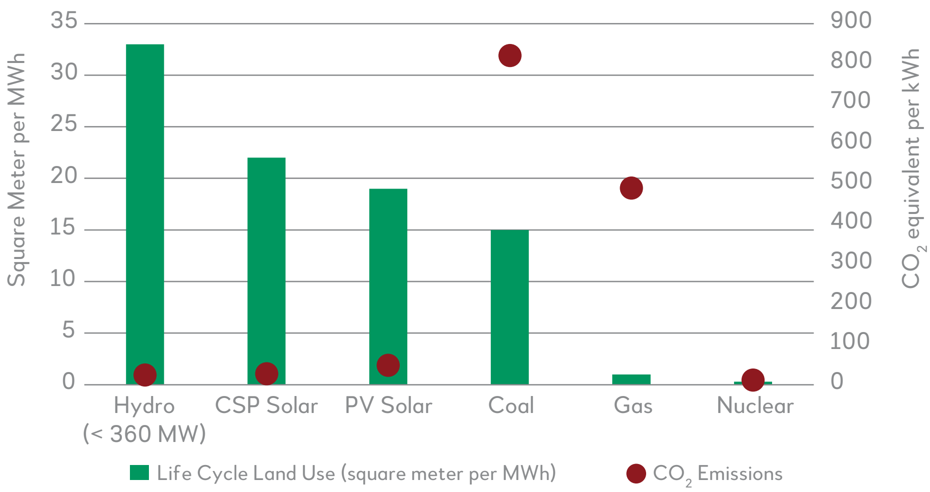
Figure 36: Trend of Solar and Wind Power Generation Projects (2001-2023)



Source: AIIB staff computation based on Wiki Solar Database (2023) and Wind Power (2023)

Note: Figures cover installed generation projects.

Figure 37: Land-use Intensity and CO_2 Emission by Energy Technology



Source: AIIB staff calculation based on UN Economic Commission for Europe (2023), Our World in Data (2023) and World Nuclear Association (2023).

Note: Figures are based on the full life cycles of technologies. For hydro, results are based on small-scale ones (below 360 MW).

generation sites were compiled from the Wiki Solar Database, the Wind Power and the Global Coal Plant Tracker, respectively.[47] Both operating and planned projects are covered, including more than 25,000 solar projects, nearly 39,000 wind projects and close to 14,000 coal projects. The location, the date of operation and the installed capacity for most projects are reported among other project characteristics. The extensive coverage of three types of major technologies across countries and over time and the detailed project information allows for rigorous quantitative analysis. The lessons drawn will be informative for all emerging and developing economies, many of which are embarking on their journeys to renewable production and net zero transition.

The BII and the coordinates of the energy projects were then overlayed to capture the site-specific outcome. As discussed in the Dasgupta Review, the BII is one of the representative measures of biodiversity as it captures the relative abundance of originally-present species and models site-level pressures, landscape-scale pressures and landscape history [Dasgupta (2021); Newbold et al. (2016); Scholes and Biggs (2005)].[48] The data from 2001-2015 were used, and the annual average BII for the 10-kilometer buffer areas of each project was computed.

For each type of power generation technology, the chapter compared the site-level BII of operating projects with those of planned projects for the periods before and after the year of operation. The energy sites starting operation in 2011 and continuing until 2015 were included as the treated units, with 2011 as the treatment year. The energy sites planned to operate after 2022 were taken as the control units. Site-specific fixed effects, year-fixed effects, and site-level temperatures, precipitation and proportions of the built-up area were included to account for other relevant factors. In addition to the standard difference-in-differences methodology, the generalized synthetic control method was used, which further narrowed the pool of controls and created synthesized control observations that matched the pre-trends of the treatment observations. Both methods provide qualitatively consistent results for the baseline specification.

Solar and wind power generation projects tend to be in places with higher biodiversity intactness than fossil fuel projects (Figure 38). The pattern is consistent with the GlobalData Construction Projects data. Installed solar projects had an average site-level Biodiversity Intactness Index of 0.30 before construction in 2011 and planned solar projects of 0.33. Wind projects registered even higher levels of biodiversity intactness: 0.35 for installed projects before construction in 2011 and 0.50 for planned projects. In comparison, coal projects showed significantly lower biodiversity intactness in the site area (at 0.17). The finding supports the idea that renewables are more likely to be located in remote areas in the search for higher yield, which are also further afield from transmission and other existing infrastructure.

Solar and wind technologies had more adverse impacts on biodiversity than fossil fuels, even though all types of energy generation sites contribute to biodiversity loss. Site-level biodiversity intactness declined significantly after installation and operation for both renewables and coal projects (Figure 39). However, the magnitudes of the impacts differ. Wind installations registered the most adverse impact, whereas coal was the least adverse. These results are robust when applying the synthetic control method.[49] The finding corroborates with existing studies. Around the power generation site, renewables have accelerated nature degradation and the loss of intrinsic biodiversity more than fossil fuels, likely because of the higher land intensity and favor of remote areas [Dickinson et al. (2010); Gasparatos et al. (2017); Niebuhr et al. (2022)].

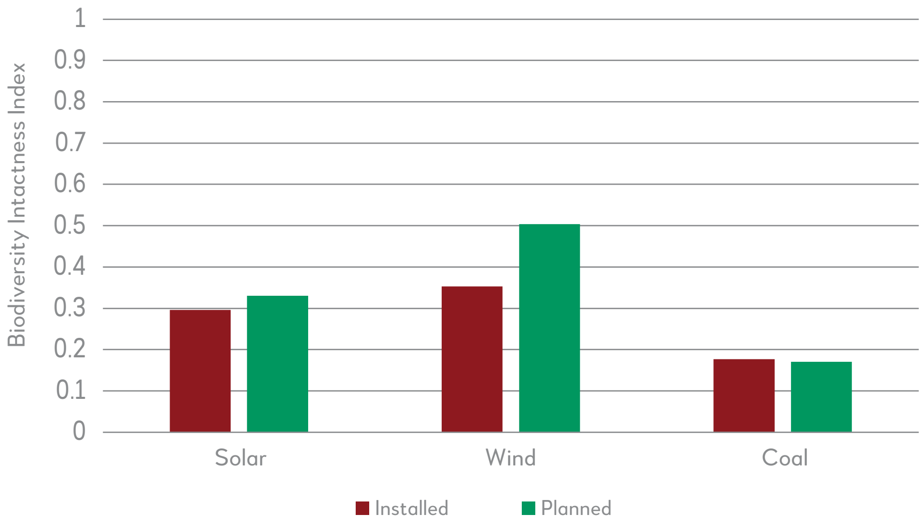
Some studies suggest that large-scale and high-capacity renewable facilities are even more harmful to nature [Gasparatos et al. 2017); Walston et

47 Please see more details at https://wiki-solar.org/data/contents.html for the Wiki Solar Database, at https://www.thewindpower.net/ for the Wind Power, and at https://globalenergymonitor.org/projects/global-coal-plant-tracker/ for the Global Coal Plant Tracker.

48 The BII, calculated by the UK's Natural History Museum, is an index ranging from zero to one, measuring the proportion of species endemic to a given area relative to their natural, undisturbed levels. A value of one thus means a given area's species is the same as a perfectly intact original ecosystem. In contrast, a value of zero suggests all biodiversity has been depleted due to human activities. https://www.nhm.ac.uk/our-science/data/biodiversity-indicators/what-is-the-biodiversity-intactness-index.html

49 The results are consistent when expanding the treated group to projects installed in 2010, 2011 and 2012 and using staggered difference-in-differences analysis. The results are available upon request.

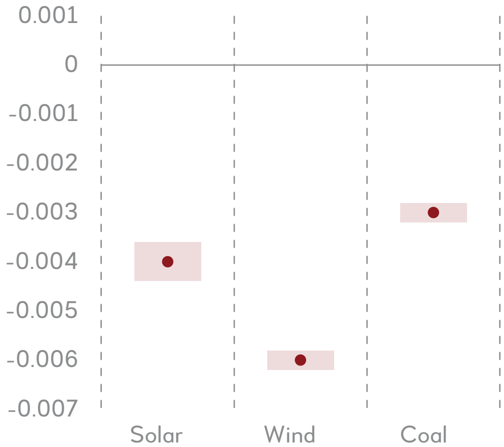
Figure 38: Biodiversity Intactness of Energy Generation Projects by Technology



Source: AIIB staff calculation based on Newbold, et al. (2016), Wiki Solar Database (2023), Wind Power (2023), and Global Energy Monitor (2023).

Note: Figures are based on 2008 BII to show pre-project construction values. Red bars indicate BII of projects that are newly installed in 2011; green bars indicate BII of projects planned for 2022 or later.

Figure 39: Energy Generation Projects' Impacts on Biodiversity Intactness by Technology



Source: AIIB staff computation based on Newbold et al. (2016), Wiki Solar Database (2023), Wind Power (2023), Global Energy Monitor (2023), ESA Landcover (2023) and NASA (2023)

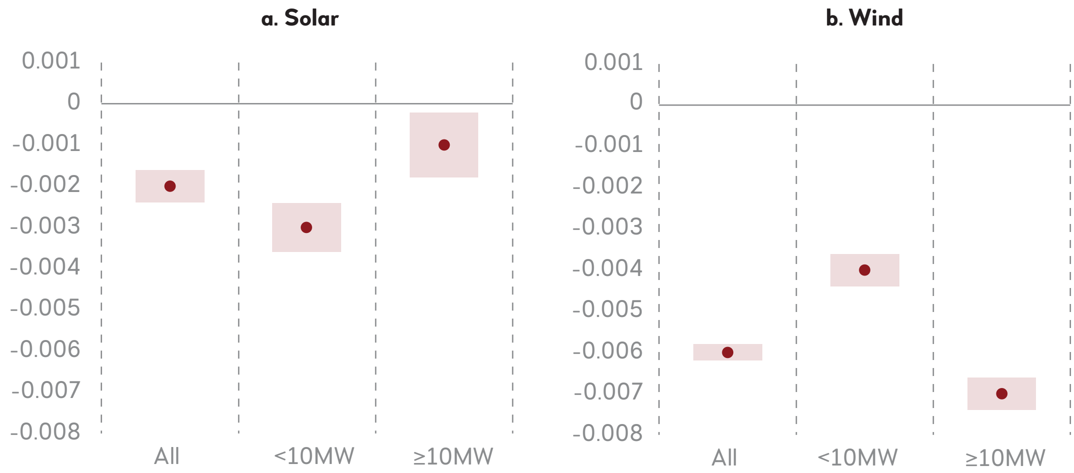
Note: The figure reports estimated impacts of energy generation projects on BII, applying the difference-in-differences method and controlling for site-specific fixed effects; year-fixed effects; and site-level temperatures, precipitations and proportions of the built-up area.

al. (2016)]. To shed light on this discussion, this chapter classifies solar and wind projects by their installed capacity into two groups—those with lower than 10 MW and those with greater than 10MW—and replicates the analysis for each group separately. However, the relationship between capacity and nature impact is more complex than previously assumed. For solar projects, projects with a higher capacity led to more decline in biodiversity intactness. For wind, the results suggested that the opposite was true (Figure 40). Capacity clearly matters but cannot be the only lever in mitigating renewables' impacts on nature.

6.2.3 The Promise of Agricultural Sites for Nature-positive

Moving forward, approaching No Net Loss or even Net Gain for renewable generation facilities will primarily rely on site location decisions. Locating renewable projects on degraded land instead of wilderness or higher biodiversity land has been proposed as an effective measure. It is consistent with the preference for avoidance by the "mitigation hierarchy."

Figure 40: Solar and Wind Projects' Impacts on Biodiversity Intactness by Capacity



Source: AIIB staff computation based on Newbold, et al. (2016), Wiki Solar Database (2023), Wind Power (2023), Global Energy Monitor (2023), ESA Landcover (2023) and NASA (2023)

Note: The figure reports estimated impacts of energy generation projects on BII, applying the difference-in-differences method and controlling for site-specific fixed effects; year fixed effects; and site-level temperatures, precipitations and proportions of the built-up area.

Placement in degraded areas, such as agricultural areas, can minimize land use changes and degradation associated with constructing and operating generation facilities. Additionally, the sites can co-locate close to existing support infrastructure such as roads and transmission facilities and further reduce biodiversity loss [Evans et al. (2023); Gasparatos et al. (2017); Sinha et al. (2018)].

This chapter empirically assesses the heterogeneity of renewables' impacts regarding land-cover and land-use characteristics. Each project site was classified into general wilderness, forest, grassland, agricultural and urban land by the dominant land-cover type within its 10-kilometer buffer area. The analysis was then conducted for each land-cover type. The results are telling. For both solar and wind projects, installations near agricultural land resulted in the least decline in biodiversity intactness. In contrast, installations close to general wilderness, forest or grassland registered the largest change in biodiversity intactness (Figure 41).

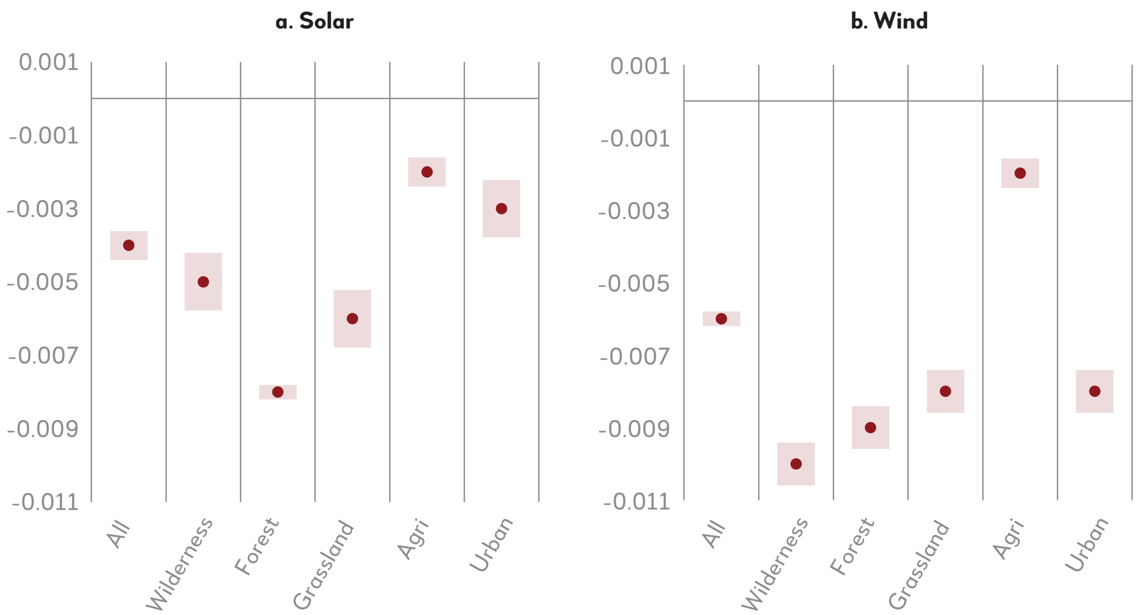
Interacting both scale and land-cover type choices may even hold a stronger potential for solar projects. The results are striking when further dividing the sample of solar installations located on agricultural land by capacity and applying the generalized synthetic control method. For small solar projects, the impact on biodiversity over time remained negative. For the large solar projects, biodiversity intactness improved significantly up to five years after construction and operation. The results are not driven by any trends prior to project installation (Figure 42).

The finding is consistent with studies that predict locating energy projects in low-quality agricultural areas might benefit energy yield, crop yield and nature conservation. Increasing pollinator activity and regrowth of native flora are the main channels (Box G).

However, it is also worth noting that the benefits can vary by the type of agricultural land. Biodiversity in land, including balks, may benefit little from installing solar farms. The presence of intermittent strips of wild vegetation in the form of balks may provide some degree of biodiversity resilience. On the other hand, biodiversity in irrigated agricultural land could benefit more from solar installation [Evans et al. (2023); Sinha et al. (2018); Montag et al. (2016); Peschel (2010)].

Maintenance and operation decisions are also crucial for conservation. It is not always possible to position renewables in degraded land or away

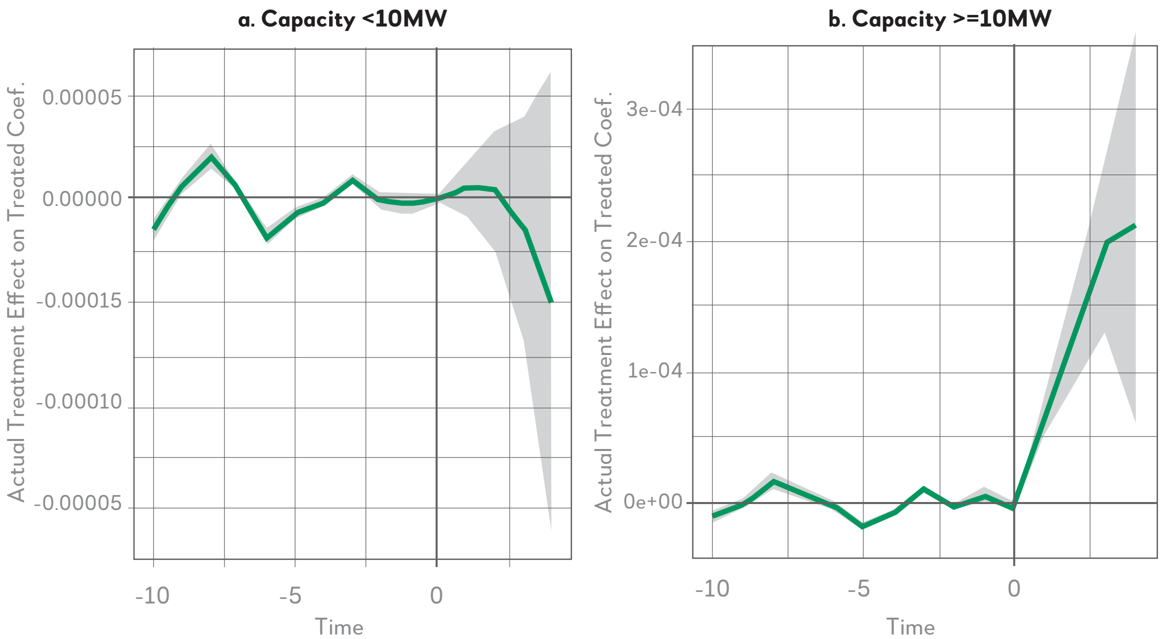
Figure 41: Solar and Wind Projects' Impacts on Biodiversity Intactness by Land-cover Type



Source: AIIB staff computation based on Newbold, et al. (2016), Wiki Solar Database (2023), Wind Power (2023), Global Energy Monitor (2023), ESA Landcover (2023) and NASA (2023)

Note: The figure reports estimated impacts of energy generation projects on BII, applying the difference-in-difference method and controlling for site-specific fixed effects; year fixed effects; and site-level temperatures, precipitations and proportions of the built-up area.

Figure 42: Agricultural-land Solar Projects' Impacts on Biodiversity Intactness by Capacity



Source: AIIB staff computation based on Newbold et al. (2016), Wiki Solar Database (2023), Wind Power (2023), Global Energy Monitor (2023), ESA Landcover (2023) and NASA (2023)

Note: The figure reports estimated impacts of agricultural-land solar projects on BII, applying the generalized synthetic control method and accounting for site-specific fixed effects; year fixed effects; and site-level temperatures, precipitations and proportions of the built-up area.

Box G: The Benefits of Agriculture Land Sites for Solar Farms

Biodiversity in the vicinity of solar and wind power sites benefits from being on previously degraded lands, such as urban areas and agricultural lands. Solar installations in agricultural land areas have attracted particular attention in the literature and in practice [Gasparatos et al. (2017)].

Locating solar plants in low-quality agriculture land use areas can synergize energy yield, crop yield and biodiversity. The channel through which these positive attributes can be achieved is mainly through increasing pollinator activity and regrowth of native plants or grasslands directly on the solar site. The partial shading layer that solar installations provide over previously degraded land can result in greater floral abundance and delayed bloom, favoring pollinators. Pollinators themselves have been valued at over half a trillion dollars globally to the agriculture sector each year [Evans et al. (2023); Sinha et al. (2018)].

In addition to relying purely on location, active management through seeding wildflowers, installing ponds, and bird boxes, and allowing for segments of grassland between panels has been linked to net positive biodiversity outcomes at solar site installations [BRE (2014); Montag et al. (2016); Peschel (2010)].

Source: Getty and Shutterstock

from wilderness areas because many high-yielding renewable energy locations are also in remote areas. In these cases, operation and maintenance measures can be taken to limit negative impacts. For wind power, reducing rotor speeds, shutting down turbines at high avian activity hours of the day and prioritizing smaller wind power installations over large turbines can be beneficial. For solar, limiting fencing around the site area and using environmentally friendly cleaning solutions can be helpful [Gasparatos et al. (2017)].

Finally, returning to the discussion on the dual challenges of nature degradation and climate change is necessary. Although GHG reduction and environmental conservation are often paired in the context of green transition, conservation concerns are not always considered. Instead, they are often planned separately from renewable energy objectives despite growing awareness of the negative feedback loops between renewable energy expansion and eco-system service provision [Hastik et al. (2015); Koppel et al. (2014)]. For example, Strantzali and Aravossis (2016) and Poggi et al. (2018) find that biodiversity considerations at renewable energy sites are rare. The studies also highlight how local legislation and economic interests often separate conservation objectives and renewable energy uptake.

State capacity is required to implement best practices for renewable expansion. This chapter also finds evidence in support of this idea. The analysis matched solar installations with the country-level Regulatory Indicators for Sustainable Energy (RISE) incentive indices compiled by the World Bank, which cover financial incentives and regulatory support for renewable electricity production, grid access and dispatch for renewables, EVs, and heating and cooling using renewable energy.[50]

The impact assessment of solar generation projects was replicated for country groups classified by RISE incentive scores and income levels. For higher-income countries, stronger renewable incentives were associated with less decline in biodiversity intactness. In contrast, stronger renewable incentives were associated with more decline in biodiversity in lower-income countries.[51] Fiscal and regulatory incentives for renewables are not necessarily inappropriate in the context of the dual challenges. However, central and local governments must have the will and capacity to safeguard biodiversity and ecosystem integrity in the subsequent expansion of renewables.

6.3 The Impact of Transport Infrastructure

6.3.1 The Biodiversity and Growth Trade-offs

Transport infrastructure can create large economic returns. Projects such as roads and railroads form the skeletal structure of economies by transporting individuals, goods and services across vast distances. Economic studies have quantified the impact of railroads on economic growth, both in historical and contemporary settings. There is also compelling evidence of the productive benefits of roads and highways [Banerjee et al. (2020); Duranton et al. (2020); Donaldson (2018); Storeygard (2016)].

Yet, such infrastructure projects span large swathes of territory and can have damaging environmental costs on their surroundings. Transport infrastructure can harm the environment and contribute to biodiversity losses directly and indirectly. Similar to other infrastructure, the most direct channel is habitat change due to the development of projects, clearing out green spaces for construction. The process eliminates or deteriorates natural habitats, diminishing the area and quality of living space for wildlife. In addition, roads, railways, canals and other linear transport infrastructure can split habitats into smaller, isolated patches or create barriers that prevent species from migrating across their natural habitats, limiting natural activity and gene flow.

Beyond physical construction, indirect environmental damage can occur from increased human activity. Chemical pollutants from vehicles, such as car exhausts, can harm various flora and fauna that occupy habitats close to infrastructure projects, affecting soil and air quality. There can also be increases in road-related mortality, "roadkill," as a form of human-wildlife conflict, affecting both large and small-scale species. Transport infrastructure also enables the entry of humans into previously intact areas, leading to deforestation, hunting, poaching, logging, mining and agriculture, with invasive species following suit. These deleterious effects of transport infrastructure can be especially damaging in highly biodiverse areas, where the sensitive ecological networks developed naturally through time can easily be distorted and have large net, knock-on effects for several fauna and flora [(Benítez-López et al. (2010); Nyhus (2016); Pratt and Lottermoser (2007); Laurance et al. (2009); UNEP (2022) ; Chen and Koprpwski (2016)].

It is also worth mentioning that construction of transport infrastructure like roads may have localized positive effects on nature depending on the local conditions and types of projects. For example, construction of roads may increase access to labor markets for the local population, decreasing the dependence on natural and forest products for livelihoods [Asher et al. (2020)]. The construction of transport projects can also reduce travel times and stop-and-go driving. This could also contribute to reduced emission and hence preserve biodiversity intactness globally compared to a scenario where demand for transport rose without infrastructure improvement.

50 https://www.worldbank.org/en/topic/energy/publication/rise---regulatory-indicators-for-sustainable-energy

51 The results are available upon request.

6.3.2 The Depletion of Forest versus the Acceleration of Urban

This chapter focuses on two major road projects in India and Indonesia and applies quasi-experimental approaches to quantify the impacts of transport infrastructure on India is one of the world's major pockets of biodiversity thanks to its vast expansion of land territory, diverse terrains and climate conditions, and extensive coastal lines. Located on the equator and as the world's largest archipelago country, Indonesia's rainforests are home to some of the highest levels of biodiversity in the world. Meanwhile, both countries have announced ambitious plans to develop their infrastructure in the coming decades, including roads, railways and other transportation projects. The biodiversity and growth trade-offs are acute in these two economic powerhouses. Deep diving into the experiences of their past projects will offer valuable lessons for future projects and other emerging and developing countries.

The Government of India launched its National Highways Development Project (NHDP) in 1999. Two major projects were announced: the Golden Quadrilateral Highway connecting the four major cities of Mumbai, Delhi, Chennai and Kolkata and thus consisting of four sections, and the North-South-East-West Highway Network, connecting the four endpoints of India. For the Golden Quadrilateral, the government principally sought to upgrade pre-existing roads and highways, such as extending road lanes and improving paving, instead of developing brand-new infrastructure. The upgrades began in 1999/2000 and were carried out in phases, with most road segments being finished by 2006. The total length reaches 5,846 kilometers, and most road segments are four or six lanes [Ghani et al. (2014); NHAI (n.d.)].

The Golden Quadrilateral has been shown to have profound positive economic impacts. Both formal and informal firms relocated as a result. Manufacturing output increased, and productivity grew for formal or more productive enterprises. Participation by women in the labor force improved subsequently as well [Asturias et al. (2019); Chatterjee et al. (2021); Ghani et al. (2014); World Bank (2018)]. However, more recent studies suggest that the project also led to more air pollution and forest cover decline [Asher et al. (2020); World Bank (2018)].

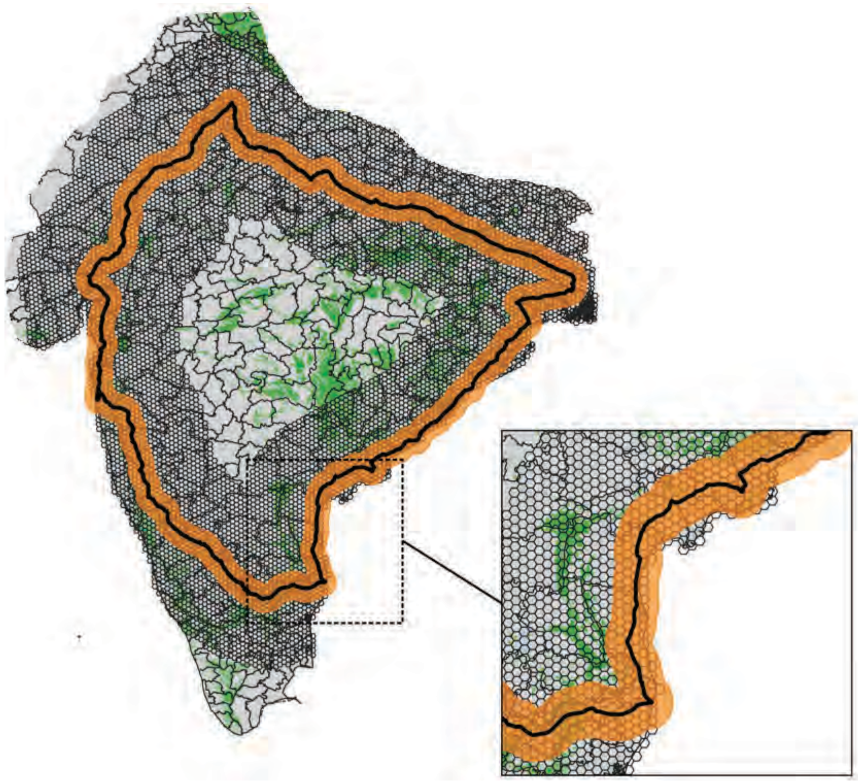
This chapter evaluates the impacts of the Golden Quadrilateral on biodiversity and land use. The road path of the Golden Quadrilateral was created by digitizing the road network of the entire country from commercial data source HERE and by identifying relevant road segments [Kompil et al. (2023); HERE Technologies (2021); NHAI (n.d.)]. Following Baragwanat et al. (2021), hexagonal units were formed as the core elements of analysis instead of administrative boundaries. Hexagons are the most circular-shaped polygons to form an evenly-spaced grid. Each hexagon is 250 square kilometers, with an edge length of about 10 kilometers (Figure 43).

Both the forest cover and urban settlement layers and the BII were overlayed with these hexagonal units to measure outcomes. The forest serves as a precious habitat for a multitude of fauna and flora. Forest cover is thus a proxy for the potential richness of endemic species. Urban settlement areas, on the other hand, can shed light on the extent of economic activities burgeoning along the road. Both layers are from the European Space Agency CCI Land Cover. The database provides consistent estimates of land covers at the global scale going as far back as the early 1990s, thus permitting the assessment in the years preceding the road construction [ESA (2023)].[52] BII serves as a direct measure of ecological richness, capturing the relative abundance of originally-present species and modeling site-level pressures, landscape-scale pressures and landscape history [Dasgupta (2021); Newbold et al. (2016); Scholes and Biggs (2005)].[53] For land cover layers, the analysis was conducted from 1992-2015; for BII, the analysis was between 2000 and 2015.

52 https://www.esa-landcover-cci.org/

53 The BII, calculated by the UK's Natural History Museum, is an index ranging from zero to one, measuring the proportion of species endemic to a given area relative to their natural, undisturbed levels. A value of one thus means a given area's species is the same as a perfectly intact original ecosystem. A value of zero suggests all biodiversity has been depleted due to human activities. The data used are the one square-kilometer raster files produced by the UN Biodiversity Lab. https://www.nhm.ac.uk/our-science/data/biodiversity-indicators/what-is-the-biodiversity-intactness-index.html https://map.unbiodiversitylab.org/earth

Figure 43: The Golden Quadrilateral and the Treated and Controlled Hexagonal Units



Source: AIIB staff computation based on Kompil, et al. (2023), HERE Technologies (2021); NHAI (n.d.) and ESA CCI Land Cover (2023)

Notes: The dark line shows the Golden Quadrilateral project, the hexagons highlighted in orange are ever-treated units and the other hexagons are never-treated units. These figures do not depict the entire map of India, but rather a snapshot of the geographical area that received the highway upgrade under the GQ/NS-EW project.

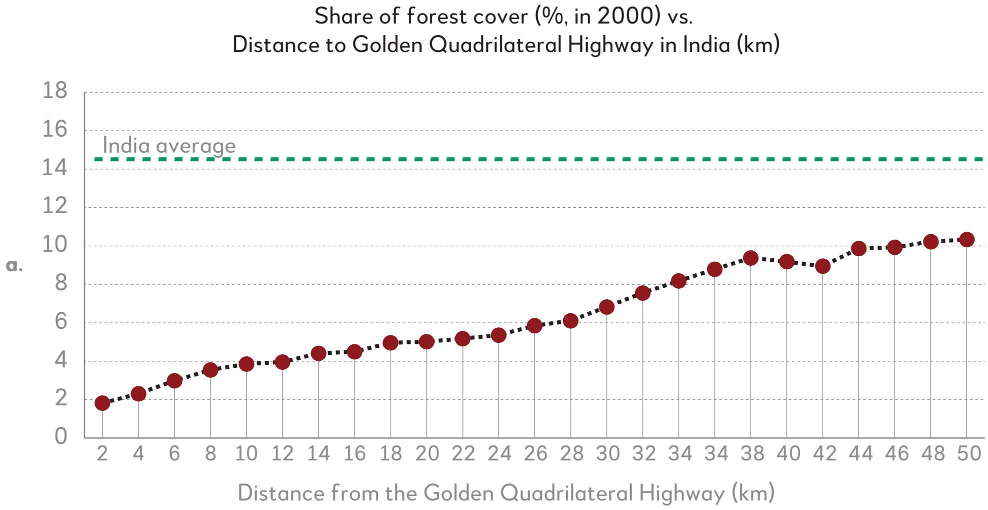
The figure does not represent the view of AIIB and its Board of Governors on the map of India. It illustrates the geographical areas that were included in the analysis.

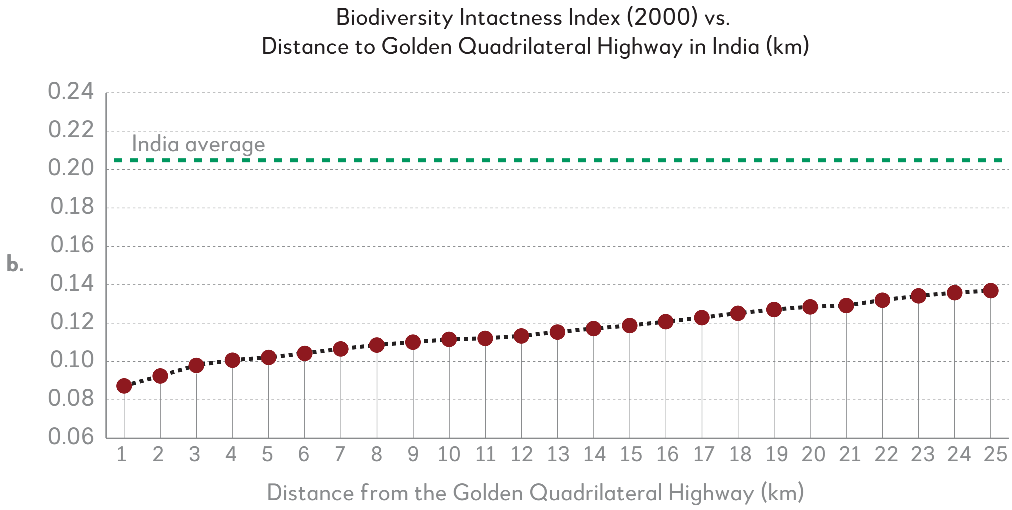
Distances to the highway and variations in the construction timelines of different segments were explored to conduct causal inferences. Both staggered difference-in-differences and event study approaches were applied. Existing literature suggests that the impact of a road on biodiversity concentrate within certain distances, for example, within the 1-kilometer buffer area for most birds and the 5-kilometer buffer area for most mammals. The effects fade further away [(Benítez-López et al. (2010); Laurance et al. (2009); UNEP (2022)].

Therefore, hexagons less than 50 kilometers from the road were classified as treated units. Hexagons between 50 and 250 kilometers from the road were the never-treated units (Figure 43). A total of over 8,000 hexagonal units were included in the sample. The treated units were further divided into earlier treated or later treated, defined according to the construction timelines [Chatterjee et al. (2021)]. A series of fixed effects, including hexagon level, year-specific, state and year-specific, and road section and year-specific, were included in the analysis to account for other relevant factors.

The areas along the Golden Quadrilateral had low forest coverage and low biodiversity intactness before project construction (Figure 44). In areas less than 10 kilometers from the highway, the share of forest land cover was less than four percent, whereas the average was about 15 percent nationwide. In these areas, biodiversity intactness indices were also less than 0.1 in 2000, compared with the national average of 0.2. This is likely because the project mainly upgraded existing roads. Therefore, human activities had previously affected most areas in its proximity. Additionally, the higher quality road could induce more economic activities and accelerate nature degradation.

Figure 44: Forest Coverage and Biodiversity Intactness vs. Distance to the Golden Quadrilateral





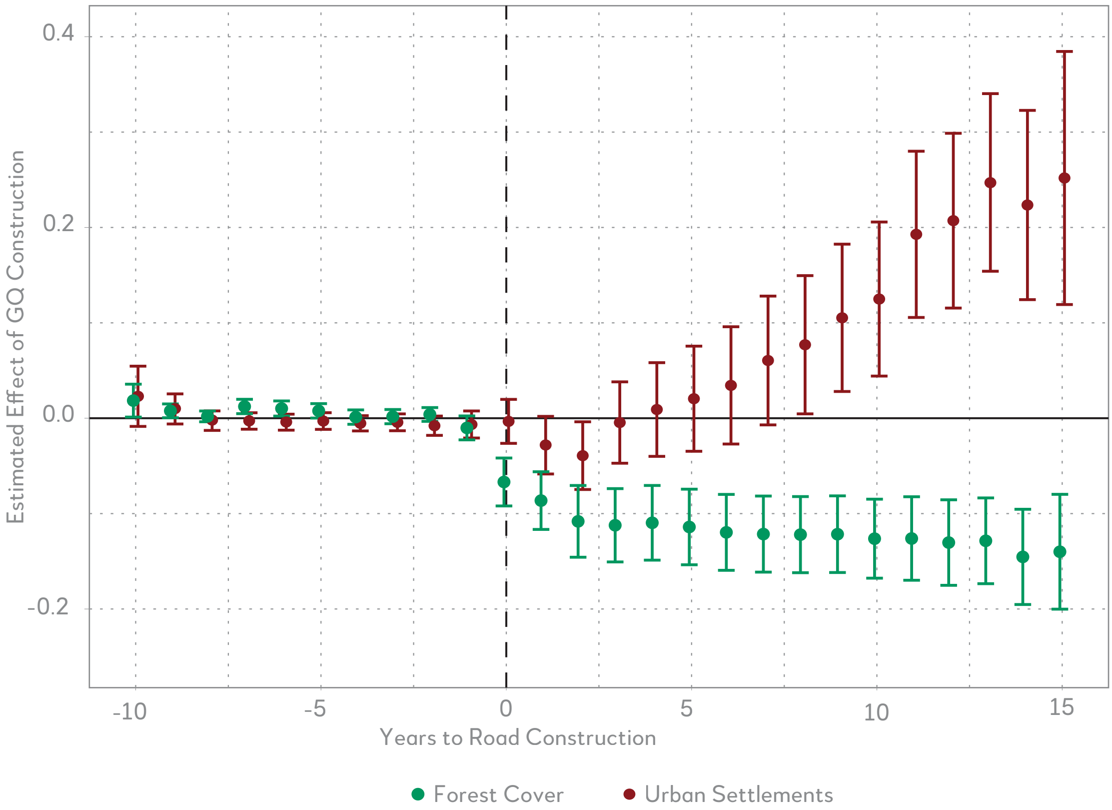
Source: AIIB staff computation based on Kompil, et al. (2023), HERE Technologies (2021), ESA CCI Land Cover (2023), and Newbold et al. (2016)

Indeed, the Golden Quadrilateral led to forest depletion while stimulating urban expansion (Figure 45). Before the construction, no declining trends in the forest in treated units relative to the controls existed. However, when construction began, forests in treated areas dropped sharply relative to those in the control areas. The effect persisted for over a decade, thus highlighting the long-term effects of deforestation from the project. Urban settlements expanded persistently in treated areas relative to control areas after the construction started, and the effect was not driven by any pre-trend. The impact on urban settlements became stronger over time, whereas the loss of forest cover from road construction was imminent.

Regarding the overall magnitude of the damage, the highway resulted in forest cover loss of 7.6 to 20 percent in treated areas relative to control areas (Table 8a). The results are robust to various specifications and samples. For example, when excluding never-treated areas and only comparing early-treated and later-treated areas, the impacts remain statistically significant, and the magnitudes of depletion are 7.6 to 9.5 percent.

The analysis also suggests that the Golden Quadrilateral resulted in biodiversity intactness decline, even though the empirical evidence is statistically weaker. When assessing impacts on biodiversity intactness, within-district

Figure 45: The Golden Quadrilateral's Impacts on Forest Cover and Urban Settlement Areas



Source: AIIB staff computation based on Kompil, et al. (2023), HERE Technologies (2021), ESA CCI Land Cover (2023) and Newbold et al. (2016)

between-hexagon variations are explored through district-level fixed effects to control for time-invariant district-level factors. Compared with relying on hexagon-level fixed effects, the empirical strategy is thus weaker by mixing over time and cross-sectional differences. With this limitation in mind, a strong negative association was found between the rollout of the highway and the biodiversity intactness in treated areas relative to control areas (Table 8b). The results are robust across different specifications and samples.

As mentioned in the previous section, the construction of transportation projects, such as the Golden Quadrilateral, reduced travel times and stop-and-go driving, which could contribute to reduced emission and hence preserve biodiversity intactness globally compared to a scenario where demand for transport rose without infrastructure improvement.

The Government of Indonesia inaugurated the Trans-Sumatra Toll Road project in 2013 as an ambitious infrastructure project to realize Sumatra's economic potential. The island is the country's second-largest in land area and population, contributing to one-fifth of national output. Designed to link the island from the north edge to the south toe, the toll road aims to improve road connectivity efficiency, safety and resilience. The development of the toll road is divided into four phases, with construction of the first phase commencing in 2015. Over 500 kilometers of road segments were fully operational in 2023 [(Antara (2023); Hutama Karya (2023); KPPIP (2023)].

Sumatra Island is extremely rich in fauna and flora. The alignment of the Trans-Sumatra Toll Road has been thoughtfully selected to avoid wildlife sanctuary areas. Some segments are designed to parallel the existing national road connecting these

Table 8: The Golden Quadrilateral's Impacts on Forest Cover and Biodiversity Intactness

	a. Dependent variable is ln(forest cover)					
	(1)	(2)	(3)	(4)	(5)	(6)
Golden Quadrilateral	-0.115***	-0.107***	-0.201***	-0.194***	-0.076*	-0.095**
	(0.035)	(0.033)	(0.060)	(0.058)	(0.041)	(0.036)
Hexagon FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	No	Yes	No	Yes	No	Yes
Section x Year FE	No	Yes	No	Yes	No	Yes
Dropping excess zeroes	No	No	Yes	Yes	No	No
Only treated districts	No	No	No	No	Yes	Yes
No. of hexagons	8048	8047	4342	4340	2031	2031
Observations	193,152	193,128	104,208	104,160	48,744	48,744

	b. Dependent variable is BII					
	(1)	(2)	(3)	(4)	(5)	(6)
Golden Quadrilateral	-0.037***	-0.036***	-0.042***	-0.043***	-0.038***	-0.039***
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	No	Yes	No	Yes	No	Yes
Section x Year FE	No	Yes	No	Yes	No	Yes
Dropping excess zeroes	No	No	Yes	Yes	No	No
Only treated districts	No	No	No	No	Yes	Yes
Observations	120,720	120,705	65,130	65,100	30,465	30,465

Source: AIIB staff computation based on Kompil, et al. (2023), HERE Technologies (2021), ESA CCI Land Cover (2023) and Newbold et al. (2016)

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors clustered by district in parentheses. GQ construction is a dummy variable for whether a hexagon is within a 50-kilometer distance from the road and whether the construction of the road segment had begun. Columns 3-4 drop observations where forest cover pixels are zero within a given hexagon throughout 1992-2015. Columns 5-6 drop those districts that are never treated. State x Year fixed effects capture time-varying characteristics across India's 28 federal states. Section x Year fixed effects capture time-varying characteristics across the four different sections of the project.

areas and will pass through primarily plantations and less environmentally sensitive lands [Hutama Karya (2023)]. Nevertheless, the island has already lost forests due to activities such as logging [Burgess et al. (2012)]. Road developments would require policy efforts to mitigate impact on nature.

This chapter evaluates the impacts of the operational segments of the Trans-Sumatra Toll Road on land cover and land use. It applied similar methods to collect data as in the case of the Golden Quadrilateral Highway. Road paths were created for operational segments by digitizing Indonesia's road network from commercial data HERE and identifying them based on official documents. For under-construction and planned segments, road paths were created by digitizing official planning maps [KPPIP (2023); Hutama Karya (2023)]. Sumatra was taken as the sample area, and hexagonal units (250 square kilometers) formed the

Figure 46: The Trans-Sumatra Toll Road and the Treated and Controlled Hexagonal Units

Source: AIIB Staff computation based on HERE Technologies (2022), KPPIP (2023), Hutama Karya (2023) and ESA CCI Land Cover (2023)

Note: The dark red lines represent the segments of the Trans-Sumatra Toll Road project that are operational or under construction, and the dark black lines represent the segments that are planned. The hexagons highlighted in orange are ever-treated units and the other hexagons are never-treated units.

The figure does not represent the view of AIIB and its Board of Governors on the map of Indonesia. It illustrates the geographical areas that were included in the analysis.

core units of analysis. The forest cover and urban settlement layers are used to measure outcomes at the hexagon level from 2000-2020 (Figure 46).

Both the forest cover and urban settlement layers are from the European Space Agency CCI Land Cover, which provides consistent estimates of land cover and land use from the early 1990s thereby allowing a robust comparison before and after the construction of the road segments. It is worth noting that the CCI Land Cover data is primarily based on satellite imagery. Its classification of forest cover may be different from Indonesian official definitions.

Causal inferences rely on the distances to the toll road and variations in the construction timelines of different segments. The staggered difference-in-difference approach is applied, similar to the Golden Quadrilateral analysis. Time variation in the project's rollout is defined at the constructed section level, with information from Hutama Karya (2023), the principal firm responsible for the construction.

Treated units are hexagons that fall within 50 kilometers of the road segments in operation or under construction. Never-treated units are hexagons located within 50 kilometers of the planned road segments or those more than 50 kilometers from the toll road (Figure 46). Road rollout is not random. A series of fixed effects, including hexagon or regency level, year specific, regency and year-specific, and province and year-specific, help capture other factors that could co-determine construction and forest loss.

Despite the project's early stages, there is preliminary evidence that the Trans-Sumatra Toll Road has had an impact on forests (Table 9). Through urbanization or other activities, there have been reductions in forest cover, with significant differences in land uses in units close to road segments in operation or under construction relative to the never-treated units after construction started. When focusing on changes at the hexagon level over time (i.e., using hexagon-fixed effects),

Table 9: The Trans-Sumatra Toll's Impacts on Forest Cover and Urban Settlement Areas

	a. Dependent variable is ln(forest cover)		
	(1)		
Trans-Sumatra	-0.084**	-0.068*	-0.071*
Construction	(0.035)	(0.036)	(0.040)
Regency FE	No	No	No
Hexagon FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Regency x Year FE	Yes	No	No
Province x Year FE	No	Yes	Yes
100 km bandwidth	No	No	Yes
Observations	44,058	44,289	35,217

	b. Dependent variable is ln(urban settlements area)		
	(1)	(2)	(3)
Trans-Sumatra	0.090	0.116***	0.097***
Construction	(0.079)	(0.025)	(0.026)
Regency FE	No	No	No
Hexagon FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Regency x Year FE	Yes	No	No
Province x Year FE	No	Yes	Yes
100km bandwidth	No	No	Yes
Observations	44,058	44,289	35,217

Source: AIIB Staff computation based on HERE Technologies (2022) and ESA CCI Land Cover (2023)

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors clustered by road section in parentheses. Data covers the period from 2000 to 2020. Trans-Sumatra construction is a dummy variable for whether a hexagon is within a 50-kilometer distance from the road and whether the construction of the road segment had begun. Columns 3 and 6 only use hexagons that are at most a 100-kilometer distance from the constructed or planned segments of the road. Regency x Year fixed effects capture time-varying characteristics across Sumatra's over 120 regencies. Province x Year fixed effects capture time-varying characteristics across Sumatra's 10 provinces.

the loss in forest cover ranged from 7.1 to 8.4 percent. On the other hand, urban settlement areas increased between 9.0 and 11.6 percent. When including variations between hexagons within the same regency (i.e., using regency fixed effects), urban expansions and reductions in forest cover were estimated to be even more significant (results are available upon request). Both results hold even when restricting the sample to hexagons within 100 kilometers of the toll road. In other words, when only comparing the areas close to the completed road segments with the areas close to the under-construction or planned segments, the findings remain the same.

Importantly, it is worth noting that the overall evidence of the Trans-Sumatra is weaker than that of the Golden Quadrilateral in terms of statistical significance. It could be partly because of the limited variation in construction time differences and because a substantial portion of the road segments remain unconstructed. Few "treated units" can lead to low statistical power to make precise inferences. For the Golden Quadrilateral, road construction (i.e., treatment) was more arbitrary given its near diamond-shaped connection of all major cities. The careful and selective planning of the Trans-Sumatra Toll road could yield greater potential for biases in the results even after including relevant fixed effects. This should be duly acknowledged. Indonesia requires improved connectivity, the Trans-Sumatra Toll Road will contribute to this and the economic return to this investment is expected to be sizeable. More research will be needed to ascertain the impact of infrastructure, to improve design and to mitigate. This is an opportunity for stakeholders (project developers, environmental experts, policy makers, financiers etc.) to work together to develop needed infrastructure while conserving nature.

The fact that major transport projects, have led to burgeoning economic activities but at the expense of forests and nature, may well be expected. However, these ecological effects are found to be causal even though the Golden Quadrilateral mainly upgraded existing roads, and the Trans-Sumatra avoided national parks and other officially biodiversity-sensitive areas. The findings align with recent studies on the impact of highways [Asher et al. (2020)].

In other words, they have followed the avoidance principle of the "mitigation hierarchy." The findings are also consistent with studies suggesting contemporary transport infrastructure's omnipresent features. For example, in the United States, roads cover only about one percent of the land but affect an estimated 20 percent of the country's landscape. In a German state, road development has left large unfragmented areas (over 100 square kilometers) to be about two percent of the overall land area. Globally, with an estimated 28 million kilometers of roads, only a few areas on earth are estimated to be genuinely unaffected by transport networks [KPPIP (2023); Hutama Karya (2023)].

6.3.3 The Potential of Ecological Connectivity for Nature Positive

To achieve net nature-positive outcomes, avoidance and ensuring environmentally sensitive setting of transport infrastructure remains the priority. Meanwhile, minimizing, restoration and offsetting measures are equally important for conservation in transport project development. Various tools have been proposed to minimize habitat fragmentation and reduce roadkill incidents. Wildlife crossings, fencing and special speed regimes are the most prominent local interventions. Road verges and other green infrastructure components are also important in landscape-scale biodiversity conservation interventions [Vasiliev (2022)].

Wildlife crossings or "ecological bridges" have been proposed as a potentially effective approach to minimize the ecological effects of roads and other linear transport infrastructure. They are structures built over or under infrastructure facilities to allow wild animals to cross safely. These specially designed crossings with accompanying fencing can potentially reduce negative impacts and generate positive impacts on nature through multiple channels. They can offer crucial wildlife connectivity between fragmented wildlife habitats and let animals access food, water and other resources. Allowing animals to move freely between habitats can enhance immigration, increasing genetic diversity and reducing inbreeding. Finally, providing new habitats and migration routes may improve adaptation and accommodation amid climate change.

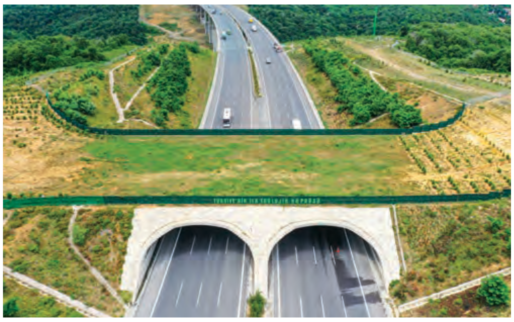
Many advanced economies and developing countries have built wildlife crossings along their major transport projects. Indonesia has also been constructing such ecological structures for megafauna along the construction of the Trans-Sumatra Toll Road. Türkiye is another case in point (Box H). Eleven major wildlife crossings have been built or planned for key sections of its highways. There are also more creative ways to construct bespoke animal crossings for distinct species. For example, among those fauna that rely heavily on trees for migration, such as arboreal mammals, canopies can be developed for safe migration above ground as an animal overpass [Nuwer (2020)].

These wildlife crossings are part of a broader effort to maintain ecological connectivity [IUCN (2023)]. Such crossings and other minimization and mitigation measures should be considered at the beginning of the planning stage and be carefully implemented. It is more cost-effective to build these structures during initial construction. Wildlife crossings could also be built as retrofitting or replacement structures when necessary. It is also worth noting that the effectiveness of these structures and other conservation measures for transport infrastructure require more empirical assessments. There are risks that they may exaggerate negative impacts on biodiversity.

Box H: The Wildlife Crossings Along Highways in Türkiye

Türkiye hosts 3,633-kilometer-long controlled-access highways that connect its major cities like Istanbul, Ankara, Izmir, Bursa and Adana. Almost half of these highways have been built in the last decade. To address some of the negative environmental impacts, several wildlife crossings, in the form of ecological bridges, have been planned and built. As of August 2023, there are 11 ecological bridges in Türkiye, of which nine have been built on the controlled access highways. By design, these ecological bridges connect major forests and other biodiversity-rich areas. The Garipce Bridge on the Kuzey Marmara Highway, the Soma Bridge on the Istanbul-Izmir Highway and the Zeytinler Bridge on the İzmir-Çeşme Highway are cases in point. Their impacts on nature conservation will be felt over time.

Figure H1: Garipce Bridge–Kuzey Marmara Highway



Map data ©2023 Google

Figure H2: Soma Bridge–Istanbul-Izmir Highway

Map data ©2023 Google

Figure H3: Zeytinler Bridge–İzmir-Çeşme Highway

Map data ©2023 Google

Source: Anadolu Agency and Google Maps

CHAPTER 7

CITIES AND URBAN BIODIVERSITY

Highlights

- City growth and urban biodiversity have moved in the opposite direction in the past few decades. This poses a dilemma as developing economies continue to urbanize. Nevertheless, cities also offer unique opportunities for conservation.
- Cities can grow via horizontal expansion, infill development and vertical layering. Vertical growth can be more effective at limiting harm to nature, while sprawling cities are more damaging. The use of gaps left between structures (infill development) needs to reduce interrupting vegetation dynamics, especially in brownfield landscapes. Informal settlements could have worse environmental consequences than planned horizontal expansion.
- Increasing the total size of green spaces over time can mitigate biodiversity loss due to urban expansion, especially for small and medium-sized cities. Large and small green spaces play essential roles in maintaining the overall richness of species in cities through different channels.
- Increases in mining or manufacturing industries correlate with declines in biodiversity intactness. On the other hand, increases in services are correlated with improvements in biodiversity intactness. These preliminary results point to an important area for future research and policy attention.
- Targeted city development programs have become one popular way to support city growth. Three flagship city development programs with conservation objectives were implemented in China, India and Indonesia. An evaluation comparing cities in the programs with those not in the programs found that these programs led to a reduced rate of biodiversity loss. Local government capacity remains important to turn cities into real opportunities for conservation.

"Whenever and wherever societies have flourished and prospered rather than stagnated and decayed, creative and workable cities have been at the core of the phenomenon" [Jacobs (1992)]. Cities bring together firms and households, amplifying the possibilities for innovation and prosperity. Cities absorb migrants, fulfilling the promise of mobility and inclusion. There is clear consensus in the development literature on the importance of cities. A growing number of dynamic cities have emerged in the past few decades, driving economic growth and lifting millions of people out of poverty [Black and Henderson (1999); Duranton (2015); Glaeser (2011); UN DESA (2013)].

Global urban areas grew by 20 percent from 2000 to 2015, surpassing half a million square kilometers, with much of the expansion in developing countries. Shrinking cities have also emerged but remain few in these countries. According to the United Nations, the proportion of the global population residing in cities has risen from 40 percent in 1980 to 56 percent in 2020, whereas that in developing countries has increased from 30 percent to 51 percent. This trend is expected to continue, with the urban population reaching 70 percent globally and 66 percent in developing countries by 2050. Urban areas will expand accordingly, if not more rapidly. Some have even argued that the planet has moved into a new urban era [Chen et al. (2020); Simkins et al. (2023); UN DESA (2018)].

City growth depends on ecosystem services linked to biodiversity and nature. Ecosystems outside of cities are essential for provisioning services, e.g., food and fresh water. Ecosystems in cities are vital in offering regulating services. For example, green spaces and waters regulate local temperature and mitigate urban heat islands effect. Urban vegetation improves air quality through carbon sequestration, improves water quality, reduces surface run-off and minimizes the risk of extreme weather events [Elmqvist et al. (2013); Gómez-Baggethun et al. (2012)].

City growth, however, profoundly impacts nature. At the city scale, the process encroaches on green spaces, destroys native habitats and fragments remaining natural habitats. It modifies natural disturbance regimes and introduces non-native species by increasing the rate of introduction events and creating disturbed habitats. It degrades and alters ecosystem processes. At the regional scale, cities shape land use patterns and affect ecosystems beyond urban areas through food and resource demand, pollution and climate change [McDonald et al. (2013); Simkins et al. (2023); McDonald et al. (2019)].

Nevertheless, cities also offer unique opportunities for conservation. Nature leaves no voidance, and cities are not landscapes deprived of plants and animals. In contrast, many cities reveal a great variety of habitats and species—urban biodiversity—especially in temperate cities. More broadly, cities help reduce the human footprint on the environment by making it possible to lower the unit costs of energy, infrastructure and public services. The hypothetical development path of depleting cities is neither plausible nor desirable [McDonald et al. (2013); McDonnell and Hahs (2008); McKinney (2002); Müller (2002)].

Building on the literature, this chapter focuses on urban biodiversity, on which cities' impacts are more direct. While the indirect ecological impacts of cities at broader spatial scales are far-reaching, minimizing urban biodiversity loss and managing it properly will be a cornerstone for any conservation solution. Regarding city features, the chapter starts with urban forms that have been a focus of both urban ecology and urban planning literature. It then assesses the relationship between economic activities and urban biodiversity, trying to bridge the gap between urban economics and urban ecology studies. Mindful of the critical role of urban governance, the chapter evaluates three flagship city development programs implemented in the last decade by three major Asian countries—China, India and Indonesia—quantifying their effectiveness and discussing lessons learned toward balancing city growth and urban biodiversity through targeted city-level programs.

7.1 City Characteristics and Urban Biodiversity

7.1.1 The Dichotomy Between City Growth and Urban Biodiversity

The concept of urban areas varies considerably across countries and over time [Duranton (2021)]. As a working definition, this chapter views cities as the proximity between people, the contiguity between markets, the agglomeration of modern economic activities, and the concentration of buildings and supportive infrastructure. For analysis at the global scale on city growth and urban form, a threshold approach based on population density, market contiguity and built-up areas is adopted because of cross-country comparability and data availability. The data is from the GHS Urban Centre Database and covers cities across all countries [(Dijkstra et al. (2021); Florczyk et al. (2019)]. For country-specific analysis, administrative urban areas defined by the corresponding country authorities (China and Indonesia) or administrative city locations with buffer areas (India) are used to leverage richer administrative information on economic activities and development programs.

The idea of urban biodiversity is intuitive, but how to measure it accurately remains a research agenda itself. Following the urban ecology literature, this chapter sees urban biodiversity as the richness and abundance of living organisms and habitats found in and on the edge of urban areas, spanning from the rural fringe to the urban core. For measurement, this chapter uses the Biodiversity Intactness Index (BII) and the Biodiversity Habitat Index (BHI) in the corresponding urban areas defined above as proxies. BII reports the relative abundance of originally-present species and models site-level pressures, landscape-scale pressures and landscape history [Dasgupta (2021); Newbold et al. (2016)].[54] BHI estimates change in the proportion of biological diversity retained within a specified spatial unit as a function of habitat loss, degradation and fragmentation across that unit.[55] They correlate with and complement each other.

At the city level, urban areas and urban biodiversity have moved in the opposite direction over the past few decades. Across the 14,500-plus cities defined by the GHS Urban Centre Database, biodiversity intactness experienced a more pronounced decline in cities that saw greater expansion between 2001 and 2015 (Figure 47).

To capture the heterogeneity, cities are further divided into three size categories based on their estimated population in 2015: large cities with at least 1,000,000 inhabitants, medium cities with a population of 200,000 to less than a million, and small cities with 50,000 to 199,000 people.

The relationship is persistent across city size categories. This may not be a surprise because of how the BII is computed. However, for smaller cities, biodiversity losses were more severe on average but less correlated with city growth. And there are outlier cases across all city size categories as well. Therefore, it is useful to understand what factors could have mitigated the detrimental impacts of city growth.

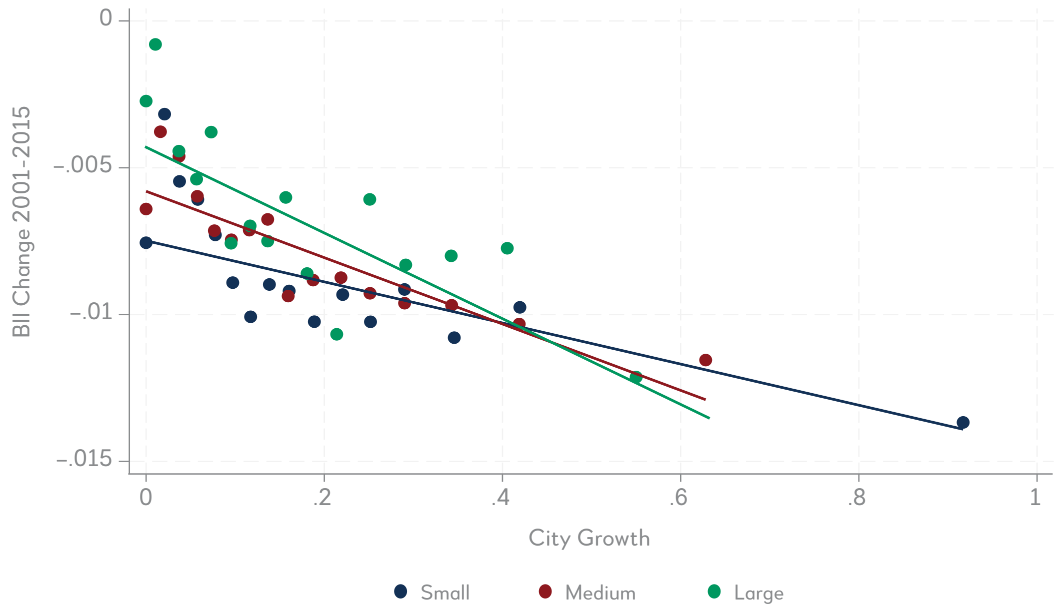
7.1.2 The Importance of Green Spaces

The urban ecology literature considers promoting green spaces as vital to restoring and preserving urban biodiversity. Biodiversity and green spaces are closely intertwined as the latter has been found to promote biodiversity through diverse channels [Guillen-Cruz et al. (2021); Jenerette et al. (2011); Yuan et al. (2021)]. Remnant vegetation is generally more valuable than agricultural landscapes. At the same time, novel habitats that have emerged with cities, from ornamental landscapes (including formal parks and private gardens) to urban-industrial landscapes (such as road verges, derelict sites and wastelands) also contribute to urban biodiversity, including preservation and conservation of native species.

54 The BII, calculated by the UK's Natural History Museum, is an index ranging from zero to one, measuring the proportion of species endemic to a given area relative to their natural, undisturbed levels. A value of one thus means a given area's species is the same as a perfectly intact original ecosystem, whereas a value of zero suggests all biodiversity has been depleted due to human activities. https://www.nhm.ac.uk/our-science/data/biodiversity-indicators/what-is-the-biodiversity-intactness-index.html

55 https://publications.csiro.au/rpr/download?pid=csiro:EP157133&dsid=DS4

Figure 47: City Growth and Change of City-level Biodiversity Intactness



Source: AIIB staff computation based on Newbold et al. (2016) and GHS Urban Centre Database [Florczyk et al. (2019)]

Note: Figure presents binned scattered plots and fitted linear trend lines by city size category.

There is also an active debate on the effectiveness of urban green spaces regarding patch size and patch configuration. For example, for plant species richness, larger remnant patches in urban areas contain more native species than smaller ones. On the other hand, smaller patches can contain more unique species and thus benefit overall urban biodiversity. Small patches and backyard habitats can also connect sites or networks for species that migrate among habitats and through urban areas. The discussion resembles the land-sparing versus the land-sharing debate of croplands' environmental impacts in rural areas [Florgård (2007); Goderoid and Koedam (2003); Lin and Fuller (2013)].

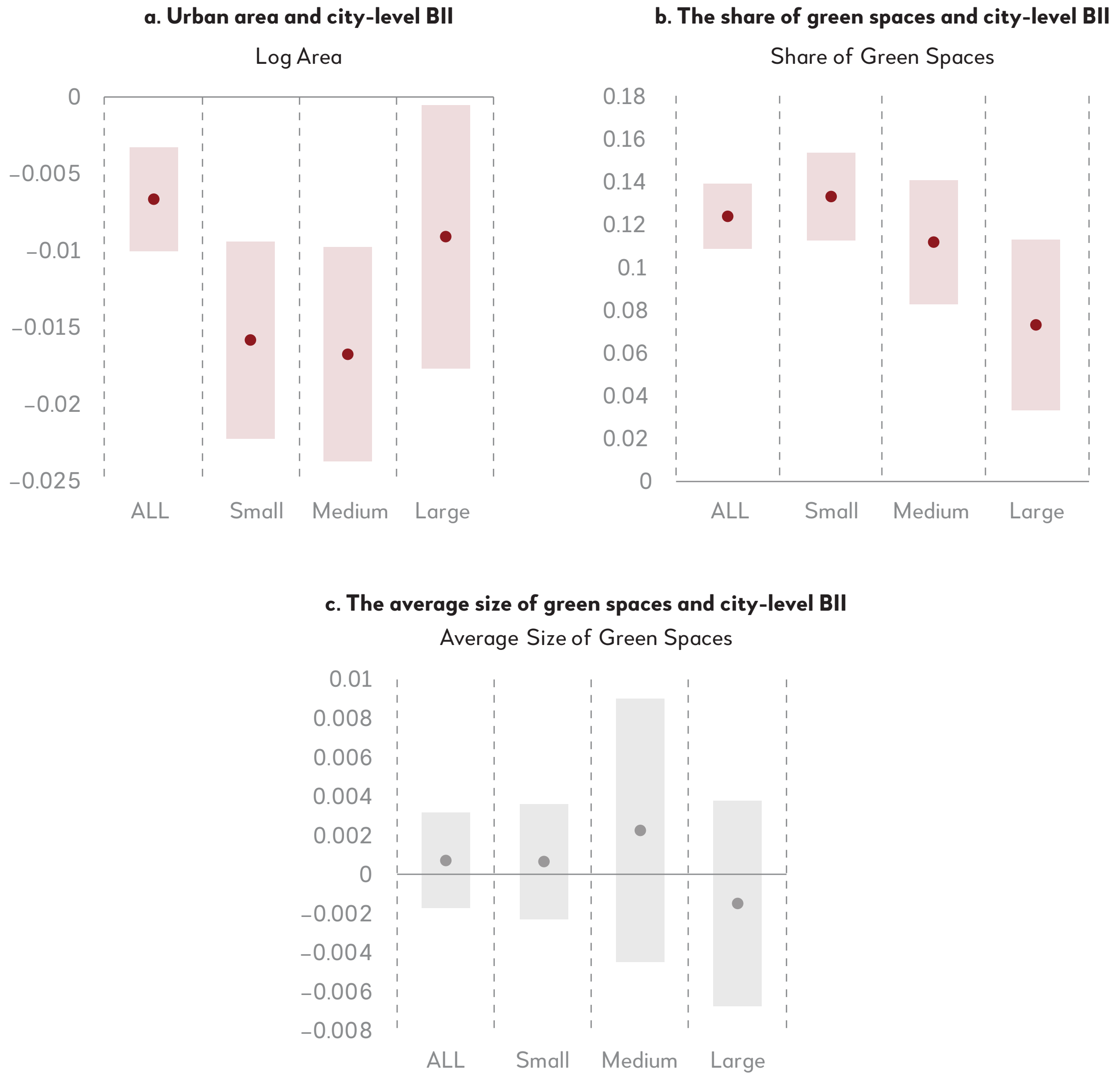
This chapter empirically assesses the impacts of green spaces in preserving urban biodiversity. It looks at both the share of green spaces in a city between 2001 and 2015 and their average size and quantifies how they are related to the city's biodiversity intactness. City and year-fixed effects, a city's compactness, population density, temperature and precipitation, and national income are included to account for other relevant factors.[56]

Indeed, more green spaces in cities are related to greater biodiversity, especially for small and medium-sized cities. Urban expansion persistently led to biodiversity loss regardless of city size (Figure 48a). Meanwhile, increasing the total size of green spaces over time can mitigate biodiversity loss. The impacts are statistically more significant for small and medium-sized cities than for large cities (Figure 48b). The finding is reassuring in that promoting green spaces would be an effective strategy for most cities. And, more refined strategies are needed for large cities, leveraging both remnant and emergent habitats.

Whether larger or smaller patches of green spaces are more effective, there is no clear evidence (Figure 48c). The results are in line with the literature. Both large and small green spaces play essential roles in maintaining the overall richness of city species. They influence species through different channels. The relationship between the average size of green spaces and urban biodiversity is not linear.

[56] The data on precipitation, temperature, and country income classification are from the Global Human Settlement Urban Center Database.

Figure 48: Green Spaces and Urban Biodiversity



Source: AIIB staff computation based on Newbold et al. (2016), GHS Urban Centre Database Florczyk et al. (2019) and ESA (2017)

Note: Figures a, b and c report the estimated effects on city-level BII of city area (in logarithmic form), the percentage share of green spaces and the average size of green spaces (in logarithmic form), respectively. The analysis controls for city-fixed effects, year-fixed effects, the Polsby-Popper index, population density, temperature and precipitation, and national income.

7.1.3 The Ambiguity of City Compactness

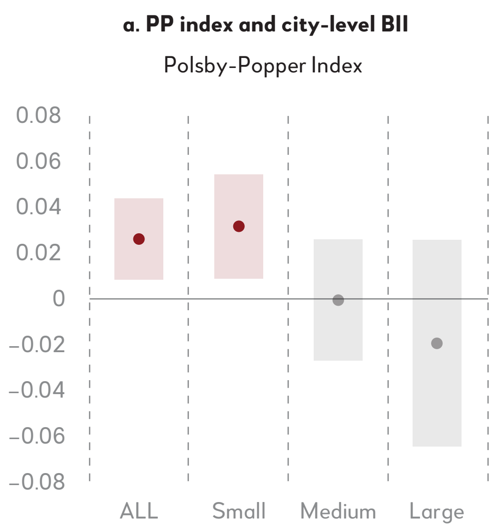
Urban planners consider building compact cities an effective way to balance a city's growth and environmental footprint. Recent urban economics studies have also provided supportive evidence. Cities can grow in three different ways: horizontal expansion, infill development and vertical layering. Horizontal expansion often ends up as low-density sprawl. Infill development creates built-up areas in the gaps left between existing structures. Vertical layering establishes taller buildings, replacing existing structures and adding floor spaces [Lall et al. (2021)]. Compact cities grow through infill development as well as vertical layering. A more compact form is correlated with decreased land use, higher population density, greater economic output, and lower emissions of CO_2 and PM2.5. The evidence is strongest for cities with taller buildings than otherwise.

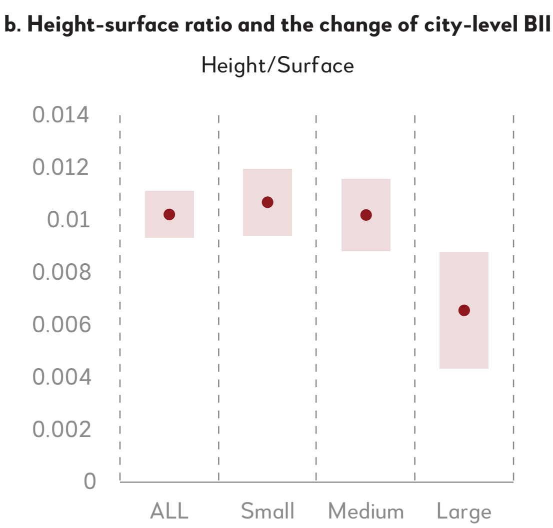
The chapter uses the Polsby-Popper (PP) index and height-surface ratio as proxies of infill development and vertical layering, respectively. The PP index measures how close the form of an area is to a circle by calculating the ratio of the area of a city to the area of a circle whose circumference is equal to the city's perimeter. The index relies on built-up area information available for both 2001 and 2015. The analysis thus resembles the above for green spaces, leveraging the two-year panel data. The height-surface ratio is the ratio of the average building height of a city to its area. The underlying data on building height are only available for 2015.[57] Therefore, the analysis quantifies how the change of city-level BII between 2001 and 2015 correlates with height-surface ratio, accounting for the changes of other relevant factors, including the area of the city, the share and average size of green spaces, population density, temperature and precipitation, and national income.

Compactness achieved through infill development seems to have limited effects on conservation, but vertical layering could be the most effective. Increases in the PP index only weakly correlated with increases in city-level BII and the correlation is held for small cities only (Figure 49a). On the other hand, cities with higher height-surface ratios experienced lower biodiversity loss in 2000-2015. The correlation is significant across all city-size categories (Figure 49b). Both assessments are not causal inferences; as more data becomes available, future research is needed to shed more light on this question.

With this caveat in mind, the impacts of infilling versus sprawling are more ambiguous than previously thought after accounting for the overall size of urban areas and that of green spaces. The result aligns with the urban ecology studies showing that brownfield landscapes, such as wastelands and vacant lots, can be species-rich by containing native and non-native species. New evidence also suggests wastelands have supported many rare plant and insect species. Some emergent urban landscapes have become refugia for an increasing number of animals, especially as nonurban areas are heavily modified by agriculture and other human uses. Despite not encroaching natural habitats in peri-urban areas, infill development may interrupt vegetation dynamics

Figure 49: City Compactness and Urban Biodiversity





Source: AIIB staff computation based on Newbold et al. (2016), GHS Urban Centre Database [Florczyk et al. (2019)] and ESA (2017)

Note: Figure a reports the estimated effects on city-level BII of the Polsby-Popper index, controlling for city-fixed effects, year-fixed effects, the city area, the percentage share of green spaces, and the average size of green spaces, population density, temperature and precipitation, and national income. Figure b plots the estimated line correlation between the change of city-level BII and height-surface ratio, controlling for the changes in the city area, the percentage share of green spaces, the average size of green spaces, population density, temperature and precipitation, and national income.

[57] Downloaded from https://ghsl.jrc.ec.europa.eu/download.php?ds=builtH

in these brownfield landscapes and reduce the likelihood of species development [Kattwinkel et al. (2011); Kowarik and von der Lippe (2018)].

In addition, slums and informal settlements are common in developing countries. A quarter of the world's urban population (over one billion) is estimated to live in these settlements. Housings are of low density and poor structures with limited durability. Access to drinking water and other utilities is limited. Solid waste and wastewater treatment systems are inadequate or non-existent. Habitat degradation is severe due to modification, irregular disturbing events and pollution. While providing accommodations for those experiencing poverty, infilling without planning and via informal construction could have brought worse environmental consequences than planned horizontal expansion. Upgrading slums through planning and vertical layering would be economically and environmentally win-win strategies. However, implementing it has been challenging due to credit and land market frictions and limited local government capacity [Henderson (2020); Rastandeh and Jarchow (2020)].

7.1.4 The Implications of Economic Specialization

Spatial transformation and economic structure transformation are integrated development processes. Urban economics literature has paid particular attention to the sectoral and functional specialization of cities. For example, in advanced economies, industry production is shown to relocate to smaller specialized cities, taking advantage of lower land and labor costs, whereas innovation activities and business services dominate large and diversified cities. In developing countries, manufacturing sectors are found to agglomerate in major coastal urban locations to exploit low transportation costs and scale economies [Becker and Henderson (2000); Duranton and Puga (2005); Henderson (2020)].

Despite its economic importance, the implications of specialization have received little attention in urban ecology literature. Several ecology studies have assessed the relationship between land ownership and urban biodiversity at fine local scales. Only a handful have considered how the concentration of certain economic activities will impact nature.

As a step toward filling this knowledge gap, this chapter studies the relationship between sectoral activities and regional biodiversity in Indonesia. The analysis evaluates how the importance of mining, manufacturing and services sectors correlate with regency-level biodiversity intactness.[58] The sample includes administratively urban regencies. Sectoral importance is measured as sectoral share in regency output of the previous year. Using regency-level data from 2010-2015, the analysis also controls for regency-fixed effects, year-fixed effects, and regency-level population density, per capita income, and precipitation and temperature of the previous year.[59]

Increases in mining or manufacturing industries in the economic mix correlate with declines in biodiversity intactness at the regency level (Figure 50). Increases in services, on the other hand, are positively correlated with improvements in biodiversity intactness. The results are statistically significant, but admittedly, this is not a causal inference. Reverse causalities are legitimate concerns.[60]

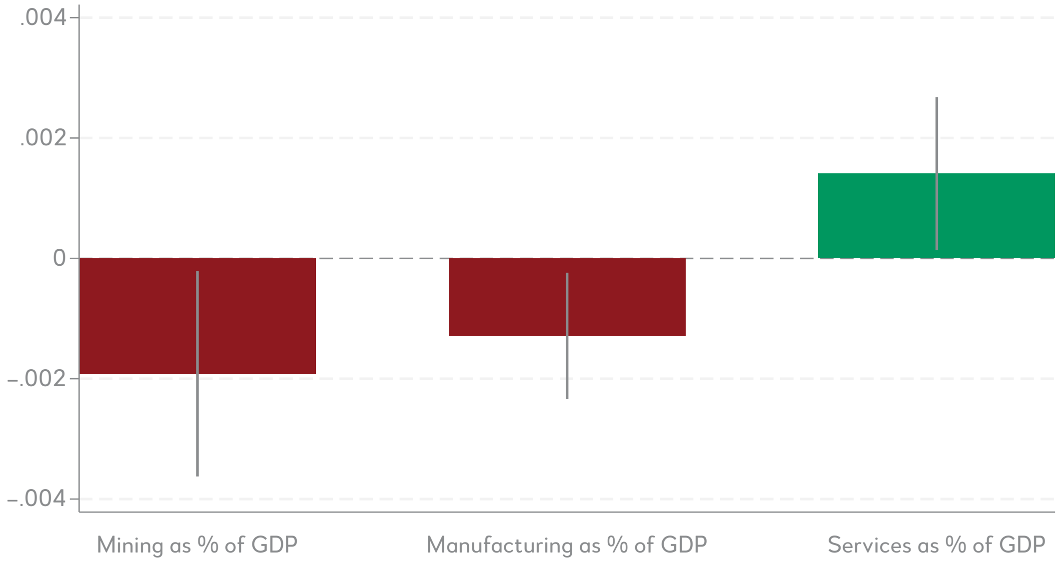
With these limitations in mind, these preliminary results are intuitive. The finding aligns with limited existing urban ecology studies. For example, the manufacturing and construction industries contribute to biodiversity decline in Shanghai, China [Singh and Kennedy (2018)]. The results could be due to multiple channels. Land use change is the primary channel through which city

58 Agriculture, forestry and fishery sectors are the omitted category.

59 The data on temperature and precipitation are from GLDAS Noah Land Surface Model L4 monthly V2. [Beaudoing et al. (2020)] and GPM IMERG Final Precipitation L3 1-day V06 1 [Huffman et al. (2019)]. The data on socioeconomic outcomes are from the Indonesia Database for Policy and Research compiled by the World Bank. https://databank.worldbank.org/source/indonesia-database-for-policy-and-economic-research

60 Remote or peri-urban locations—where connectivity is improving, densification is occurring and natural habitats are rapidly modifying—are likely to attract manufacturing production. On the contrary, urban cores of large cities, where structures are saturated and habitats change slowly, tend to draw high value-added services. Accounting for time-invariant characteristics with regency-fixed effects and selected time-varying factors mitigates but does not fully address these concerns.

Figure 50: Sectoral Economic Activities and City-level Biodiversity Intactness



Source: AIIB staff computation based on Newbold et al. (2016) and World Bank (2023).

Note: Figure reports the estimated effects on regency-level BII of the share of different sectoral economic activities in the regency economic mix, controlling for regency-fixed effects, year-fixed effects, regency-level population density, output per capita income, and precipitation and temperature of the previous year.

growth destroys and isolates habitats and reduces biodiversity. Mining and manufacturing industries are substantially more land-intensive than services. In developing countries, these industries are also sources of air, water and soil pollutants, another key channel of nature degradation. Another indirect channel is related to differences in the education and income composition of households and gaps in their willingness to pay for amenities, such as green spaces, blue skies and clear water.

Again, this chapter takes a first stab at this question with stylized facts of one country case. More work is needed to address technical concerns. More importantly, it is imperative to set up a framework by merging urban economics and urban ecology and to gain deeper insights into how urban economic activities and land, housing and labor markets are related to urban biodiversity.

7.2 City Development Programs and Urban Biodiversity

The role cities play in economic transformation has prompted policymakers in the developing world to focus more on urban governance. Empowering local urban governments with autonomy, resources and accountability are considered best practices. It is conducive to integrating top-down and bottom-up approaches and bringing in various stakeholders.

However, in these countries, political economy concerns often hinder autonomy at the local level. Fiscal capacity and implementation capability vary considerably across local jurisdictions. Accountability of local governments to local constituencies and stakeholders is further diminished by fragmented local institutional structure and overlapping ambiguous mandates.

To address these challenges, city development programs targeting selected jurisdictions with defined objectives have become one popular way to support city growth in the past decade. Some of these programs cover green spaces and other environmental considerations in their objectives. However, their impacts on urban biodiversity have yet to be systematically evaluated. This chapter does so by studying three country flagship programs: the Green Cities Development Program of Indonesia from 2011-2014, the Smart Cities Program of China from 2013-2015 and the most recent Smart Cities Mission of India from 2016-2018.

7.2.1 The Impact of Indonesia's Green Cities Development Program (2011-2014)

Indonesia's Green Cities Development program was launched in 2011 by the Directorate General of Spatial Planning in the Ministry of Public Works. The program was primarily anchored to the specific mandate in Law 26/2007 on Spatial Planning, which obligates local spatial plans to provide green open space to at least 30 percent of a city's total area. The program was carried out in phases over time. As many as 60 local governments participated in the program in 2011, 16 joined in 2012, 36 in 2013 and 30 in 2014 [Directorate General of Spatial Planning (2013)].

The program required participating cities to improve upon eight aspects relevant to a green city: environment-friendly urban planning and design, availability of green open spaces, efficient energy consumption, effective water management, 3Rs (reduce, reuse, and recycle) in waste management, energy-saving buildings, sustainable transportation system and green community.

The Directorate General of Spatial Planning program assessment found that green open spaces increased by 162.6 hectares during 2011-2016 in the participating regencies [Directorate General of Human Settlements (2017)]. An independent study of the program in Semarang City also suggested that participating in the program increased green spaces in urban areas [Ekaputra and Sudarwani (2013)].

This chapter evaluates the Green Cities Development Program's impacts on regency-level biodiversity intactness using a causal inference. Both staggered difference-in-differences and event study approaches are used. It compares the regency-level biodiversity intactness indices of the 142 participating places with those of the 196 remaining places for the periods before and after program participation. It also explores variations in the timeline of program participation by dividing participating regencies into earlier treated and later treated. Using regency-level panel data over 2001-2015, the analysis controls for regency-fixed effects, year-fixed effects, regency-level population density, per capita income, and share of primary and industry activities in regency output.

Participating regencies registered lower biodiversity intactness levels in 2001 compared to other places. There were also heterogeneities among participating places. Regencies that joined the program in 2011 witnessed the lowest average BII in 2001 (0.15), followed by regencies that joined in 2012 and 2014 (about 0.28-0.29). Regencies that participated in 2013 registered the highest BII (0.36) and were much closer to the average value of non-participating places (0.43). Biodiversity intactness levels have been falling regardless of program participation.

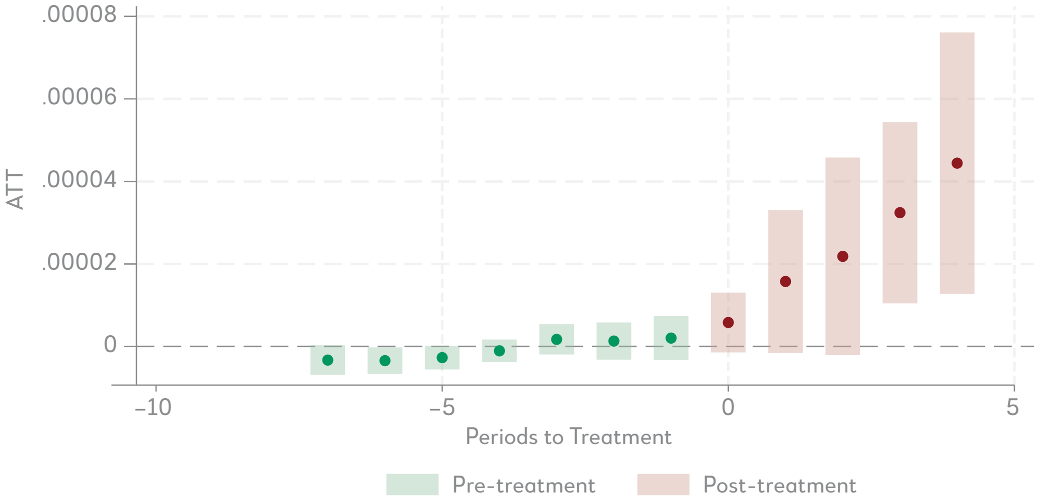
However, the Green Cities Development Program contributed to conservation by slowing biodiversity loss. Regencies in the program experienced a slower decline in biodiversity intactness after joining relative to non-participating places. Before the program, there were no apparent trends of biodiversity change in the treated areas relative to the control places. However, biodiversity intactness started to fall slower in participating regencies three to four years into the program (Figure 51a). The impact of the program on biodiversity took some time to realize. As a result, only regencies that participated in 2011 and 2012 witnessed a statistically significant reduction in the trend of biodiversity deterioration (Figure 51b). Another salient observation is that the magnitude of the impact was small despite the statistical significance. Overall, by 2015, the Green Cities Development program only had marginal impacts on urban biodiversity and only for those regencies participating in 2011 and 2012.

7.2.2 The Impact of China's Smart Cities Program (2013-2015)

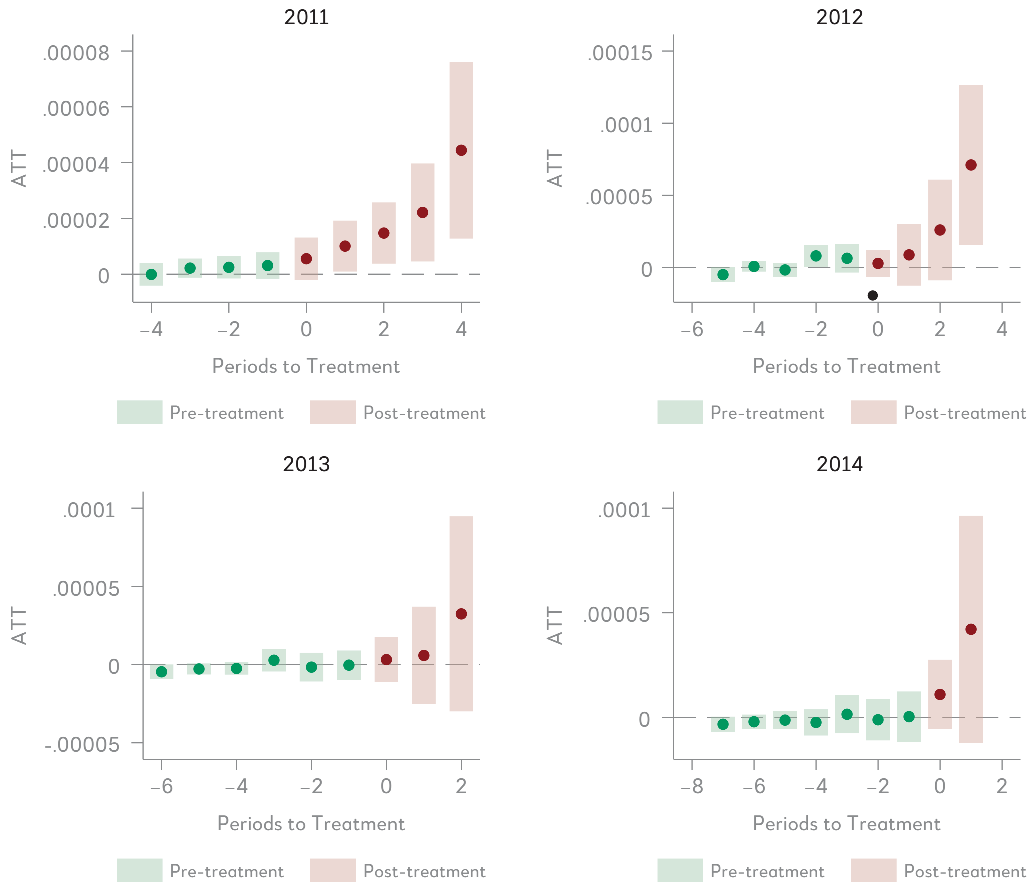
China's Smart Cities program was launched in November 2012 by the Ministry of Housing and Urban-Rural Development. The program was initiated in January 2013, August 2013 and April 2015 in 90, 103 and 84 localities, respectively. These localities cover prefecture-level cities, districts, counties and towns. The comprehensive program covers smart infrastructure, smart urban planning, smart governance and public services, and smart industry and economy to support growth and sustainability.

Figure 51: Indonesia's Green Cities Development Program's Impact on Urban Biodiversity

a. All participating regencies



b. By years of participation



Source: AIIB staff computation based on Newbold et al. (2016) and World Bank (2023)

Notes: In figures a and b, the dots represent the point estimates of the differences in BII between the cities that participated in the city program and those that did not in the corresponding year relative to the year when the program was implemented. The bars indicate the 95 percent confidence interval of the estimates. In figure b, the groups are classified by the years when cities participated in the program.

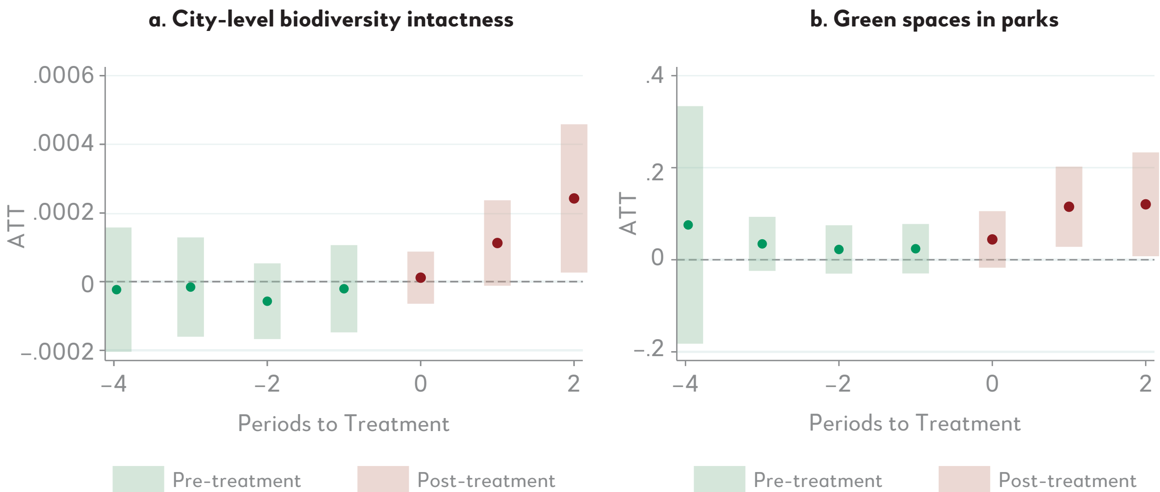
ATT refers to Average Treatment Effect on the Treated.

The program encompassed biodiversity-related components, though it did not explicitly list biodiversity conservation as its objective. Some critical components are green gardens, green buildings, energy-saving buildings, drainage systems, water-saving applications, waste disposal, smart transportation and logistics, smart energy, smart environmental protection, smart land use, innovation, the transformation of traditional industries, and the development of high-technology sectors and modern service sectors.

Existing studies of the Smart Cities program have found it to be effective in expanding green spaces, reducing environmental pollution, inducing green innovation, improving energy efficiency, promoting clean energy development and mitigating carbon emissions [Filiou et al. (2023); Shu et al. (2023); Yu and Zhang (2019)]. Land use changes, pollution and climate change are the primary sources of biodiversity loss in urban areas. The program could have affected biodiversity by improving city performance on these drivers.

This chapter directly assesses the effects of China's Smart Cities program on biodiversity. To ensure comparability, the analysis focuses on the performances of 72 prefecture-level cities that participated in 2013 and that of 118 non-participating prefecture-level cities. The study period is between 2007 and 2015. Other types of localities and the prefecture-level cities that participated in 2015 were excluded from the sample. Both standard difference-in-difference analysis and an event study are conducted to estimate the difference in Biodiversity Intactness Index between participating cities and non-participating ones before and after the program's implementation. Other factors considered in the analysis include city-fixed effects, year-fixed effects, province-year fixed effects, city-level population density, per capita income, share of agriculture in city output, share of industries, fiscal capacity (measured as the ratio between revenues and expenditures), and spending on education and science & technology.[61]

Figure 52: China's Smart Cities Program's Impacts on Urban Biodiversity



Source: AIIB staff computation based on Newbold et al. (2016) and National Bureau of Statistics of China (2008-2016)

Notes: In figures a and b, the dots represent the point estimates of the differences in BII and in size of green spaces in parks, respectively, between the cities participated in the city program and those did not in the corresponding year relative to the year when the program was implemented. The bars indicate the 95 percent confidence interval of the estimates.

ATT refers to Average Treatment Effect on the Treated.

[61] The data are from Newbold et al. (2016) and National Bureau of Statistics of China (2008-2016).

The Smart Cities program led to an increase in BII relative to the non-participating ones. Since average BII declined during the sample period, the program helped slow the deteriorating trend of biodiversity in China. Similar to the case of Indonesia's city program, the difference was not due to trends prior to program implementation (Figure 52a). On one hand, the impact was almost immediate: city-level biodiversity intactness improved in participating places one year after the program started. This differs from the Indonesian case. On the other hand, the impact was also marginal.[62]

China's Smart Cities program also expanded green spaces in parks (Figure 52b). Meanwhile, the analysis suggests that the program's effect on the overall size of green spaces was limited. This may be because the area of green space in parks allows for more accurate measuring. It could also be because public parks are an easier way to increase city green space.

7.2.3 The Impact of India's Smart Cities Mission (2016-2018)

The Ministry of Housing and Urban Affairs launched India's Smart Cities Mission to develop core infrastructure, a clean and sustainable environment, and quality of life through smart solutions. Its key features include mixed land use, housing and inclusiveness, walkable localities, preserving and developing open spaces, public transport, governance, accountability and transparency, and efficient use of resources.[63]

The program selected 100 cities using a two-stage selection procedure. In the first stage, the states and union territories shortlisted cities based on a scoring criterion that covered existing service levels, institutional systems, self-financing ability and past track record on reforms. In the second stage, the nominated cities submitted a proposal to the central government, which included the development model, the extent of infrastructure services and smart solutions, and a revenue model, among others. The selection was done in four rounds between January 2016 and January 2018. Most cities (90) were selected between January 2016 and June 2017.

To evaluate the performance of India's Smart Cities Mission, this chapter compares the 100 participating cities with 24 cities not inducted into the program before and after program implementation. The 24 cities were chosen based on their inclusion in the National Institute of Urban Area (NIUA)'s assessment of a city's readiness index [NIUA (2021)]. Information on green cover was obtained annually for the period 2010-2020, while data on Biodiversity Habitat Index (BHI) were collected at an interval of five years. On average, participating cities are more populated and bigger in urban areas than non-participating cities.

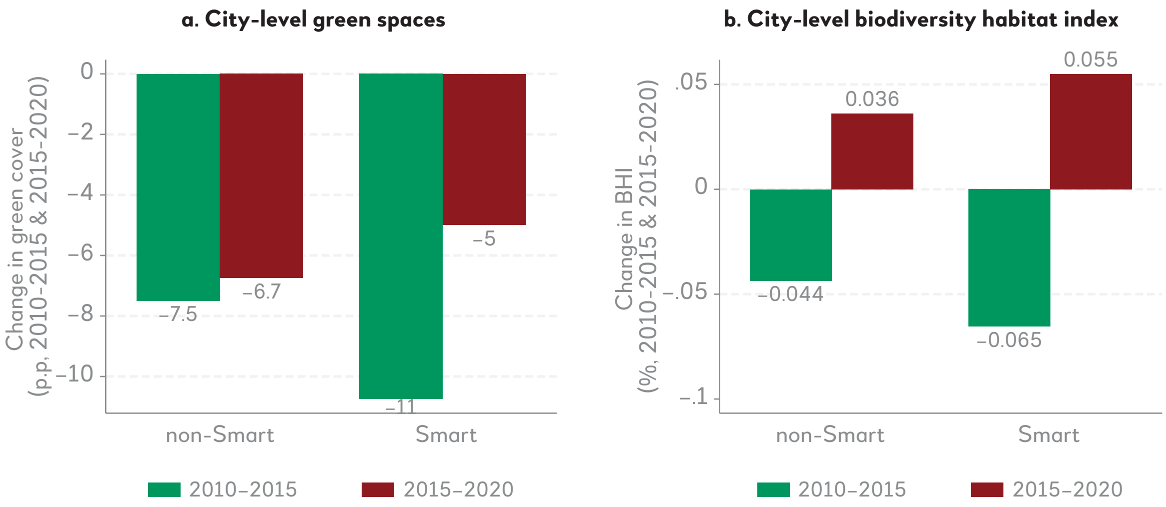
The Smart Cities Mission was associated with slower declines in green spaces and sharper rebounds in the biodiversity measured by the BHI. The green spaces across both groups of cities have witnessed a secular decline over the last two decades. Although the declining trend slowed down for both groups of cities after program implementation, the slowdown was more prominent for the participating cities (Figure 53a). A comparable trend is observed in the case of BHI. Before the program, both groups of cities witnessed a decline in the biodiversity measured by BHI. After the program's introduction, biodiversity recovered in both groups of cities, but the recovery was more pronounced in participating cities (Figure 53b).

To establish the causality of the above impacts, this chapter uses a difference-in-difference method and evaluates whether the program affected the green spaces and BHI in participating cities after the program was implemented relative to other comparable cities. The sample was slightly reduced to 95 smart cities and 22 non-smart cities due to data availability. Both standard 2x2 difference-in-differences and event study specifications were implemented. Leveraging the panel structure of the data, the analysis controls for city-level time-invariant factors, macro factors affecting all cities, and state-level trends.

[62] The results are robust to applying the instrumental variable. The instrumental variable (IV) strategy is adopted to address the potential selection issue of the smart cities. The city-level historical conditions of posts and telecommunications in the 1980s interacted with the time trend and is used as the IV. On one hand, cities with good existing digital infrastructure may become the pilots of the smart cities program. The IV meets the relevance condition. On the other hand, the historical conditions of digital infrastructure are unlikely to directly affect biodiversity today. The IV also meets the exclusion restriction.

[63] https://smartcities.gov.in

Figure 53: India's Smart Cities Mission and Urban Biodiversity



Source: AIIB staff computation based on CSIRO (2023) and ESA (2023)

The analysis further establishes the exogeneity of the program by exploring whether initial environmental factors influenced program participation. The share of green spaces in total urban areas (as of 2015), the growth of green spaces (2010-2015), the BHI (as of 2015) and distance to protected areas did not have any impact on the selection of cities in the program. This exogeneity of the program to the outcome variables suggests there was no systematic selection of cities into the program that may bias our results.

The Smart Cities Mission led to an increase in urban biodiversity. Before introducing the program, no different trends in biodiversity loss were observed in participating cities relative to other cities. However, five years after program implementation, biodiversity, measured by BHI, saw an increase in participating cities compared to other cities (Figure 54). The impact is statistically significant. Due to data limitations, assessing whether the effect is immediate is impossible. At the same time, the magnitude of the impact is small, which is in line with the findings in the China and Indonesia city programs.

India's Smart Cities Mission also positively impacted the growth of green spaces in participating cities (Table 27 in Appendix 4). Since there had been a secular decline of green spaces over the last two decades, the program was more effective at slowing down green space depletion than otherwise. Further analysis also suggests that city population and population density did not influence the impacts on BHI and green spaces.[64]

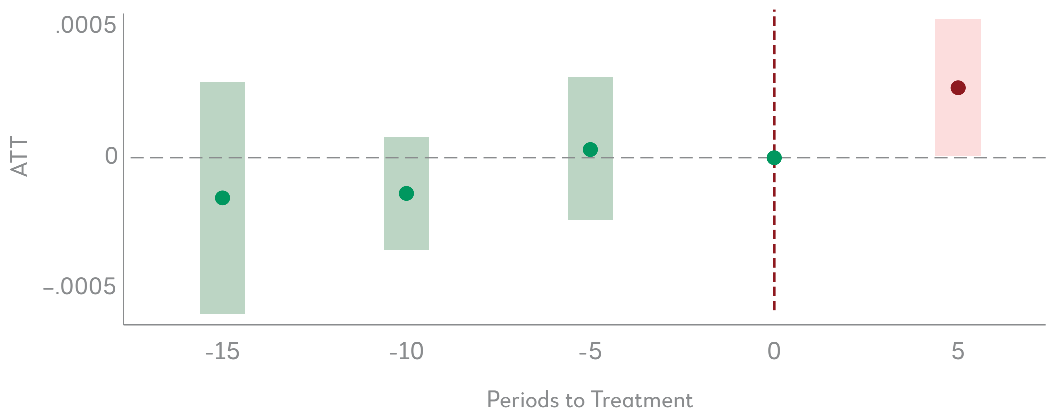
7.2.4 The Potential and Challenges of City Development Programs

All three city development programs have led to slowdowns in biodiversity loss in respective cities. Meanwhile, the impacts were small in all cases. This chapter further explores which factors may have contributed to the programs' effectiveness and limitations.

Based on a comparison between China's Smart Cities program and other parallel city programs, the program scope seems to matter. Two city programs were introduced over the same period as the Smart Cities program in selected Chinese cities, namely the Low-Carbon Cities program and the National Civilized Cities program. The former was found to reduce carbon emissions, and the latter was conducive to pollution reduction [Hou et al. (2023); Liu et al. (2023)].

64 The results are available upon request.

Figure 54: India's Smart Cities Mission's Impacts on Urban Biodiversity



Source: AIIB staff computation based on CSIRO (2023) and ESA (2023)

Notes: The dots represent the point estimates of the differences in BHI between the cities participating in the city program and those that did not in the corresponding year relative to the year when the program was implemented. The bars indicate the 95 percent confidence interval of the estimates.

ATT refers to Average Treatment Effect on the Treated.

However, when including all three city programs in the analysis and assessing the urban biodiversity of the respective participating cities, the effect of the Smart Cities program remains positive and significant, while the other two city programs have little impact.

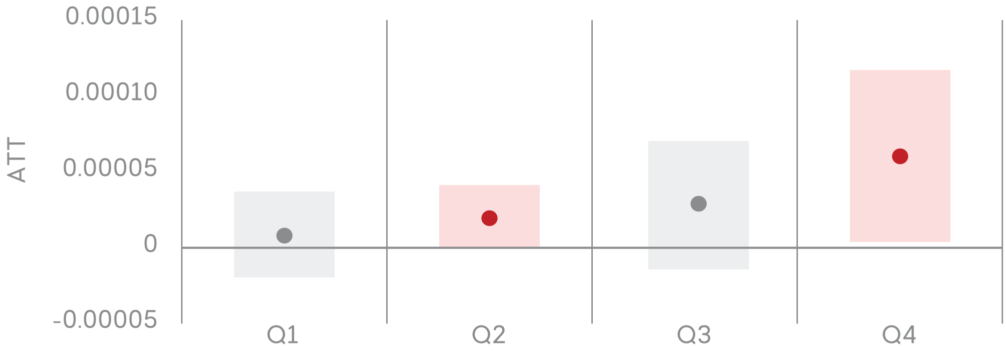
This might be because these other programs are less comprehensive and radical than the Smart Cities program, which extensively applied digital technologies and fundamentally transformed how cities monitor outcomes and coordinate across sectors. It suggests that comprehensive, systematic and digitally enabled city programs could be more effective in biodiversity conservation.

A deeper exploration of all programs suggests strong local governments are an essential pre-condition, particularly concerning technical, coordination, implementation and fiscal capacity. In the case of Indonesia's Green Cities Development program, regencies were divided into quartiles based on their governance capacity, which is proxied by the number of times financial reports were rated as normal based on accounting principles over 2005-2015. The impact on urban biodiversity was more pronounced in regencies with higher capacity (Figure 55). Existing independent studies also highlighted that institutional and technical constraints hindered participating cities' progress regarding waste and water management and energy-saving buildings [Ekaputra and Sudarwani (2013)]. In the case of China's Smart Cities program, the effects on green spaces in parks were more significant in prefecture-level cities with more robust fiscal capacity, measured by the ratio between revenues and expenditures.

In the case of India's Smart Cities Mission, higher institutional and technical capacity led to a more robust governance mechanism toward biodiversity conservation. Under NIUA's Climate Smart Cities Assessment Framework, cities are scored on five composite indicators, one of which is urban planning, green cover and biodiversity. Under this indicator, the relevant subcomponents include (a) rejuvenation and conservation of water bodies and open areas and (b) urban biodiversity.

While the former is based on the current extent and status of water bodies and open areas, the latter is based on the extent to which the city acts to protect, conserve and manage urban biodiversity. Overall, Indian cities in the sample perform poorly on the urban biodiversity subcomponent, with 46 percent of cities showing a lack of progress. Cities under the Smart Cities Mission perform better, with the average urban biodiversity score nearly twice that of other cities (Figure 56).

Figure 55: Indonesia's City Governance Capacity and Urban Biodiversity

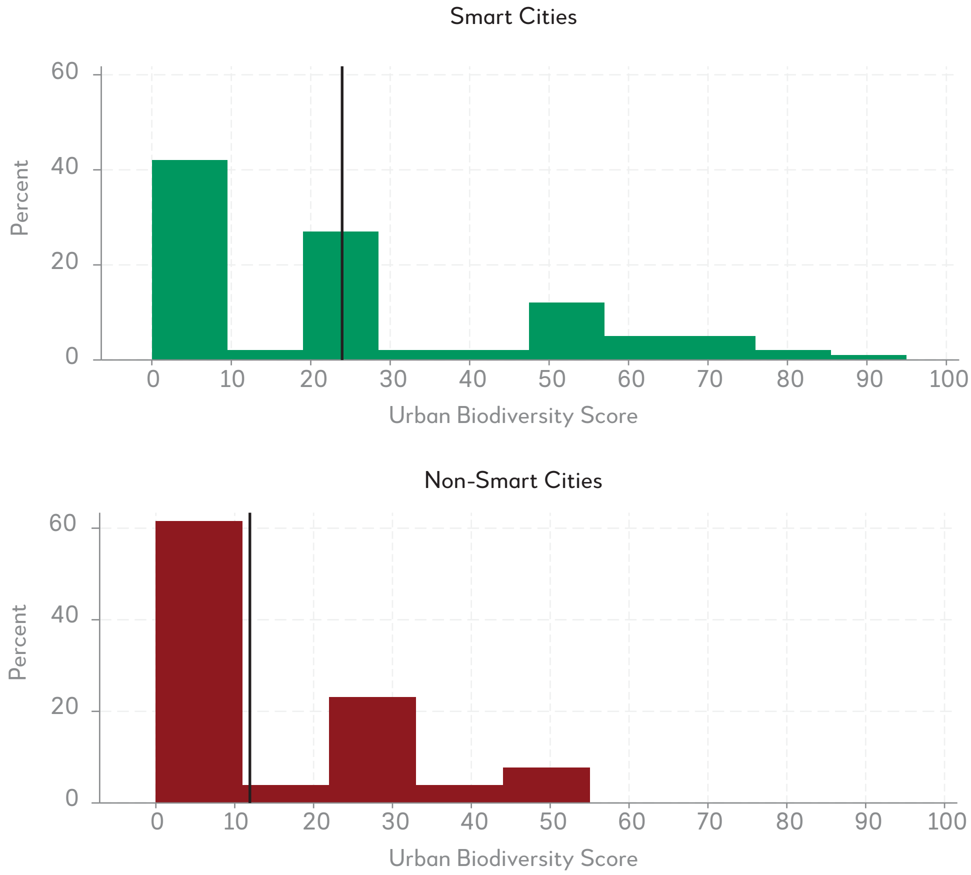


Source: AIIB staff computation based on Newbold et al. (2016), Indonesia Database for Policy and Research, and World Bank (2023)

Notes: Dots report the estimates of the differences in BII between the regencies that participated in the city program and those that did not before and after the program was implemented over 2001 and 2015. The bars indicate the 95 percent confidence interval of the estimates. The quartiles of regencies were classified by the number of times regency financial reports were rated as normal based on accounting principles over 2005-2015.

ATT refers to Average Treatment Effect on the Treated.

Figure 56: Urban Biodiversity Scores Across Indian Cities



Source: AIIB staff computation based on NIUA (2021)

Note: The black vertical line denotes the mean of the urban biodiversity score.

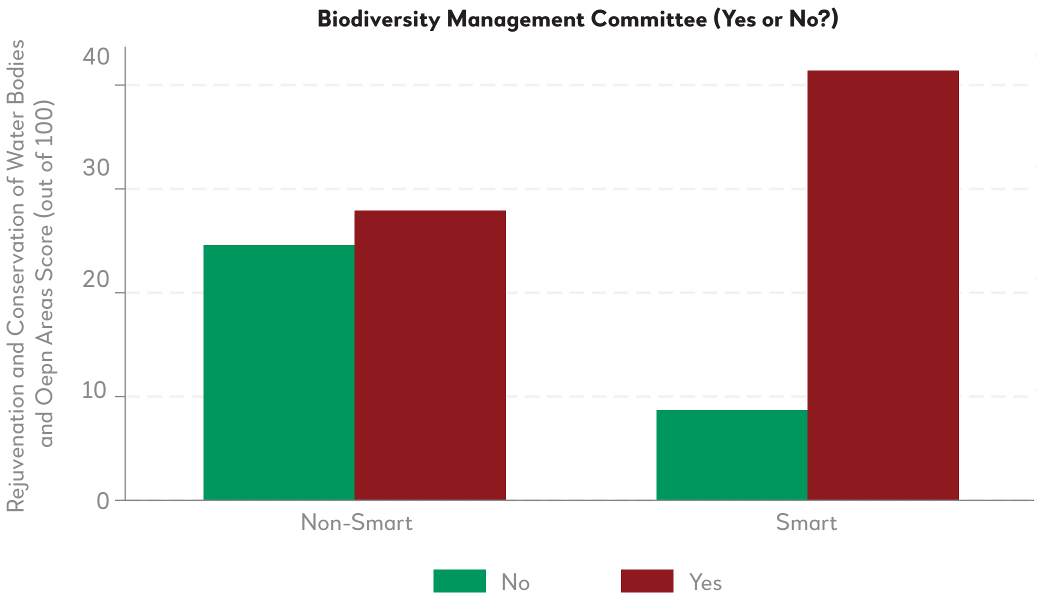
One subcomponent under urban biodiversity records the establishment of biodiversity management committees, which are tasked with promoting conservation, sustainable use and documentation of biological diversity. Across both participating and other cities, those with a committee had higher scores on rejuvenation and conservation of water bodies and open areas. However, the difference was starker among the participating cities, indicating a relatively higher efficacy of such committees on the rejuvenation scores of the smart cities. In addition, participating cities with such committees allocated more resources toward ecosystems and open spaces.

Finally, text analysis of India's city-level planning documents and review of budgetary allocation suggest a misalignment between planning and resource allocation. The inconsistency could have reduced the Smart Cities Mission's effectiveness. This chapter performs a text analysis of the proposals submitted by cities for their biddings for the city program, searching for key words related to nature and biodiversity. More frequent occurrences of these key words relative to the total number of words in the documents were considered more favorable for nature conservation. No systematic correlation existed between the planning and the budgetary allocation (Figure 58).

The majority of the cities are bunched in the lower-right quadrant, implying that these cities incorporated nature into their planning documents but lacked commensurate budgetary allocation. In contrast, a handful of cities in the upper-left quadrant did not favor nature in their planning documents but budgeted a significant amount on ecosystems and open spaces. These cities may not have the necessary framework to implement policies for conservation even though they budgeted for it.

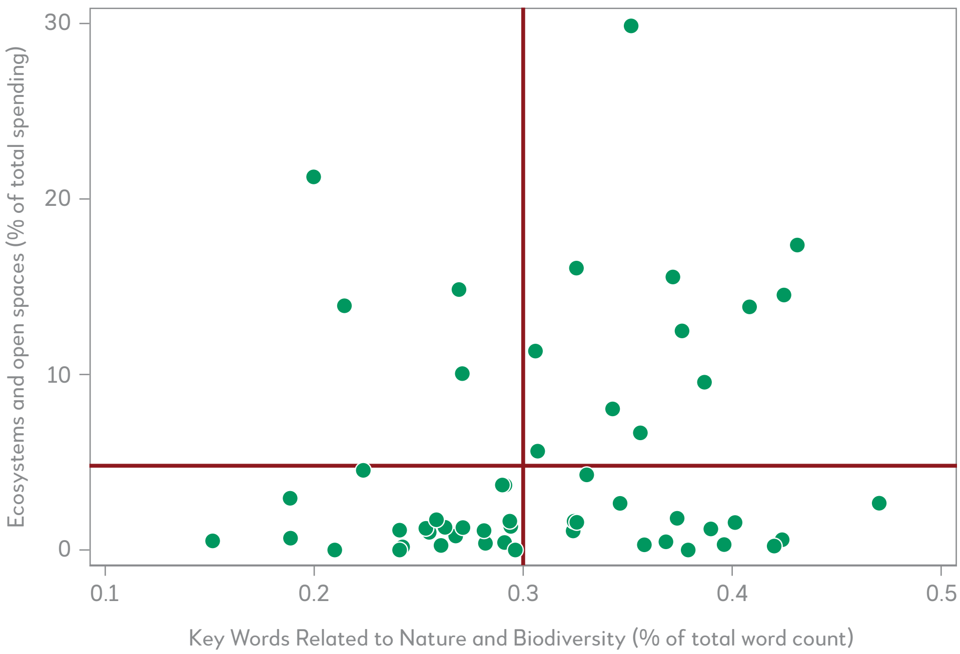
Overall, our analysis indicates that higher institutional, technical and fiscal capacity of the local government is associated with a slower pace of biodiversity loss. Thus, better planning, assessment and improved community-based conservation work would have a positive bearing on nature in general.

Figure 57: India's City-level Biodiversity Management Committee and Urban Biodiversity



Source: AIIB staff computation based on NIUA (2021)

Figure 58: India's City-level Planning and Resource Allocation for Urban Biodiversity



Source: AIIB staff computation based on information from Smart Cities Mission website, accessed in June 2023.

CHAPTER 8

FIRMS, MARKETS AND NATURE —A NEED FOR BETTER DATA AND INCENTIVES

Highlights

- Firms significantly impact nature, especially those in the utilities, material and infrastructure sectors, and those operating in locations with high biodiversity.
- Event studies show a negative impact on firms' market valuations when negative environmental, social and governance related (ESG) issues or nature impacts are disclosed. This highlights how disclosures and markets can provide strong incentives to encourage responsible firm behaviors.
- Data on how firms impact nature is incomplete. More effort is required to track the impact on nature to highlight risks and design mitigation efforts. More market tools are needed to incentivize firms toward positive action.

In previous chapters, the report touches not only on the economic contribution of nature and biodiversity but also on the negative impact of different economic sectors. This chapter zooms deeper into the interactions between firms and nature.

8.1 Firms Have Large Impact on Nature but Data and Actions Remain Inadequate

As firms are the key economic actors in the production processes, it is essential that firms become key stakeholders in the protection of natural ecosystems. Nevertheless, as reported by S&P Global, biodiversity continues to be a blind spot for many companies, especially those outside Europe [Rueedi and Whieldon (2022)]. In the Asia Pacific, only a quarter of the sampled top 600 listed companies analyzed the impact of their operations on nature, and none analyzed the wider impact of their value chains [Centre for Governance and Sustainability (2022)]. Furthermore, related disclosures and commitments to nature are limited to listed companies. Clearly, this is inadequate, considering that Asia and EMDEs are home to a large source of nature and biodiversity and also see fast development that will have an impact (as seen in previous chapters).

Using data from primarily advanced economies, this chapter provides two sets of analyses to add to existing knowledge. First, the chapter tracks the impact on nature by different firm sub-groups. Second, the chapter provides some early evidence that market investors do pay some attention. Negative news on ESG and nature seems to result in a sustained negative impact on share prices, highlighting how the market can provide the necessary incentives (and discipline) for companies to be more responsible toward nature. Finally, the chapter also discusses the lack of data and how this would need to be improved, and also briefly summarizes the various policy options for firms.

8.2 How Firms in Different Sectors Impact Nature

The firm-level analysis in this section utilizes Moody's dataset, which contains ESG data of publicly listed firms making the necessary disclosures under the European Union's Sustainable Finance Disclosure Regulation (SFDR). Within the set of disclosures lies the Principal Adverse Impact 7 (PAI7) indicator, with a coverage of 9,847 companies globally, with 3,806 in North America, 2,907 in Asia Pacific, and 2,510 in Europe and Central Asia. Data coverage is good for constituents in the global indices, especially the S&P 500 and the MSCI World Series (see Appendix 5). The PAI7 ratio of the reported company i is given as

The PAI7 of each firm i is calculated by Moody's, utilizing the asset location of each firm, including subsidiaries. Note that the locations of the assets are layered with spatial data of biodiversity indicators in order to derive any potential harm. It is also important to note that the above measure does not imply a causal action that harms nature but flags the company's operations in areas with high risk to nature.

Globally, 1.7 percent of the investment operates in areas of high risk. Infra sectors have higher exposure to biodiversity risk than non-infra counterparts in every subregion (Figure 59). The top three sectors with the biggest exposures are gas-based electricity generation, forest products and oil-related services, with more than six percent of investment in or near biodiversity-sensitive areas (Figure 60). Furthermore, state-owned enterprises (SOEs) in waste-related utilities and building materials have a higher PAI7 ratio, while non-SOEs in the non-infra sector, energy and oil-related services are relatively higher (Figure 61). This speaks of the importance of improving disclosures and governance.

$$PAI7_i = \frac{\sum_0^k Investment\ in\ investee\ k\ with\ facilities\ in\ sensitive\ areas\ and\ adverse\ impact}{\sum_0^k Total\ investment\ in\ investee\ k}$$

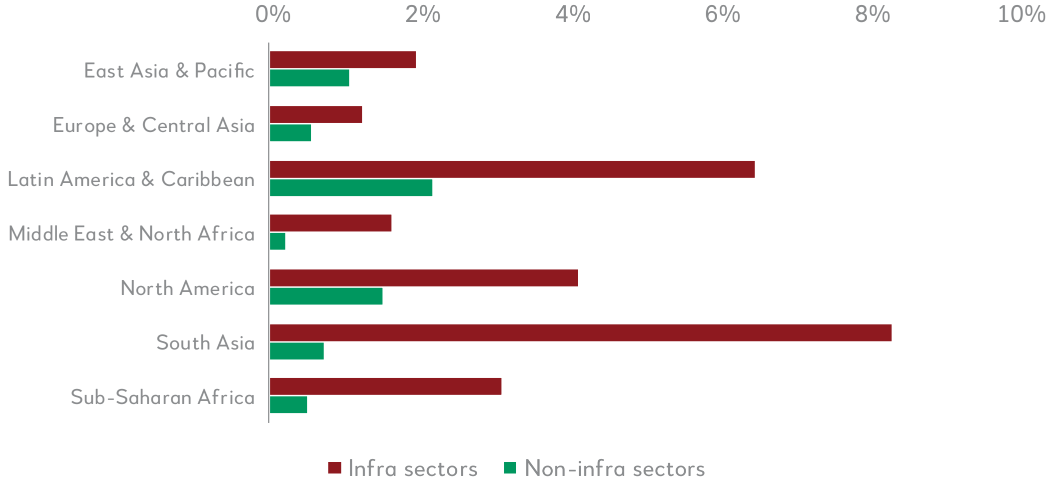
This ratio broadly measures the portion of investment in each company group that potentially harms nature. The numerator sums up the investment from investee companies with assets in nature-sensitive areas, while the denominator summarizes the total investments from the reported company i to investee companies k. For the investee to be considered potentially harmful and included in the numerator, it must meet two criteria:

- It is associated with an industry that is known to have a high impact on the natural environment in the residing country [Lenzen et al. (2013)].
- Assets of the investee k are in or within a five-kilometer zone, areas with high biodiversity significance [Mokany et al. (2020)] experiencing disturbances [Curtis et al. (2018)].

Further analysis shows that PAI7 is positively correlated with PAI3, which measures the GHG intensity of investee companies. Higher PAI7 implies more investment and assets in biodiversity-important areas. Such investments could lead to deforestation and reduce carbon storage capacity [Soto-Navarro et al. (2020); Wudu et al. (2023)]. In contrast, carbon emissions contribute to climate change, which risks species extinction and ecosystem resilience [IPCC (2023)]. Protecting and restoring forests could hit two targets in one go with a proper pairing [Anderson-Teixeira (2018)].

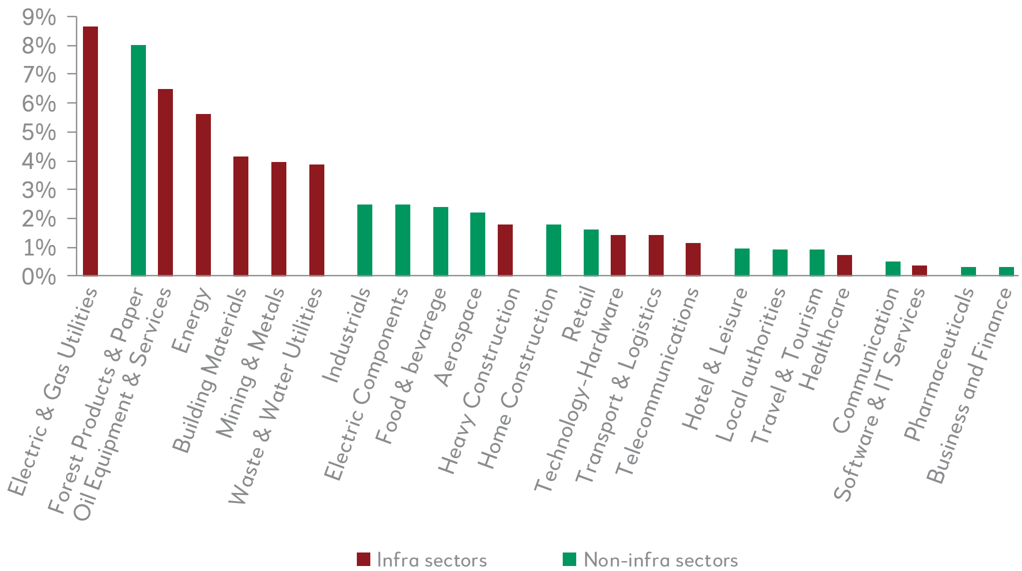
The sectoral analysis found that building materials, transport, oil-related services and gas-based power generation are the infra sectors to watch out for impacts on biodiversity and climate (Figure 62).

Figure 59: Average PAI7 by Regions



Source: Moody's SFDR dataset with AIIB staff's calculation

Figure 60: Average PAI7 by Sectors



Source: Moody's SFDR dataset with AIIB staff's calculation

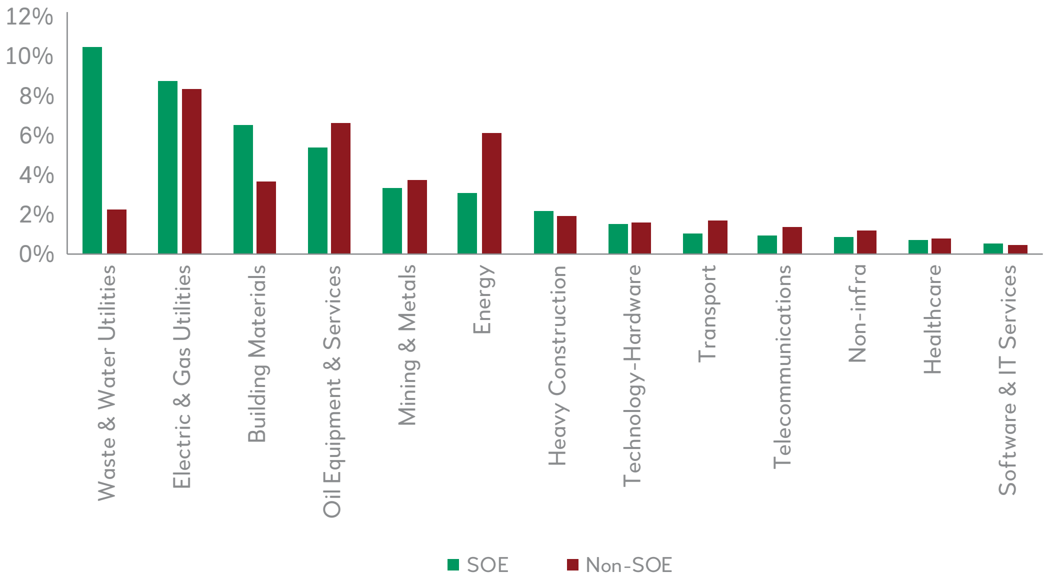
The PAI7 of some non-infra sectors, such as industrials, business and finance, retail, and food, also positively correlated with PAI3.[65] There are two immediate takeaways. Firstly, these sectors could be impacting both nature and biodiversity and contributing to climate change. Secondly, transforming the business models and reforming governance in these firms is needed to meet the twin goals of mitigating climate change and protecting nature.

8.3 Do Markets Act as a Constraint?

Firms are often hit by controversies or damaging disclosures. The key question is whether such events affect their stock prices. How markets react to negative disclosures can be a powerful constraint, which can then incentivize them toward responsible behavior. Disclosures can be broadly categorized into environmental, social and governance issues.

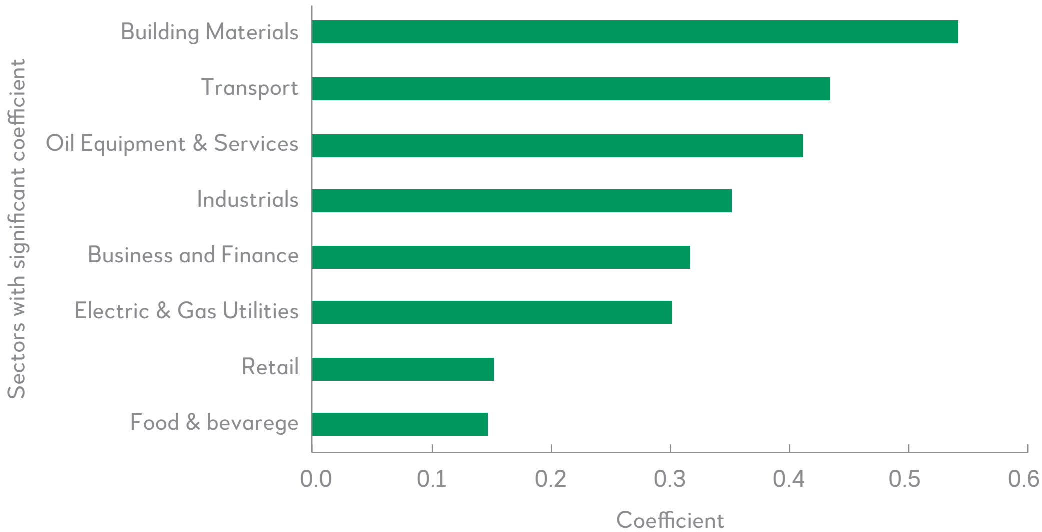
65 Some sectors display economic significance but not statistical significance, ranked by the coefficients, which are travel and tourism, software IT, aerospace, pharmaceuticals, hotel, communication, telecom, hardware IT and heavy construction.

Figure 61: Average PAI7 by Entity Types



Source: Moody's SFDR and ORBIS dataset with AIIB staff's calculation

Figure 62: Sector Correlation between PAI7 Biodiversity and PAI3 GHG Emissions Intensity



Source: Moody's SFDR dataset with AIIB Staffs' calculation.

Note: Both PAI3 and PAI7 are expressed in the log. The coefficient is interpreted as a percentage increase in PAI7 positively correlating with a percentage change in PAI3. The coefficients of the listed sectors are statistically significant with at least a 90 percent confidence interval.

However, the magnitude of the reaction depends on how well the market can price in the risk from the controversy. This section takes a cursory look at the impact of ESG-related controversies on company stock prices and sheds some light on whether and how markets react to nature-related controversies.

The impact of news or controversies on stock prices is well-studied in the literature. Studies on climate-related risk shed light on how markets react when firms disclose or face climate risks or controversies. Faccini et al. (2023) find that the US market can only price US climate policy changes, while news about natural disasters is not priced in. Huynh and Xia (2020) use corporate bond yields and suggest that bonds with higher climate-change news risk earn lower future returns. Few studies focus on the consequences of nature-related controversies. Cherief et al. (2022) show that corporate bond spreads widen when companies face acute biodiversity events.

This analysis uses Moody's Controversial Activities Screening database, which documents ESG-related controversies from over 4,000 firms. Controversies are categorized into "minor," "significant," "high," and "critical" by severity (Figure 63). The database also allows us to categorize controversies into themes, e.g., nature-related controversies (see examples in Table 10).

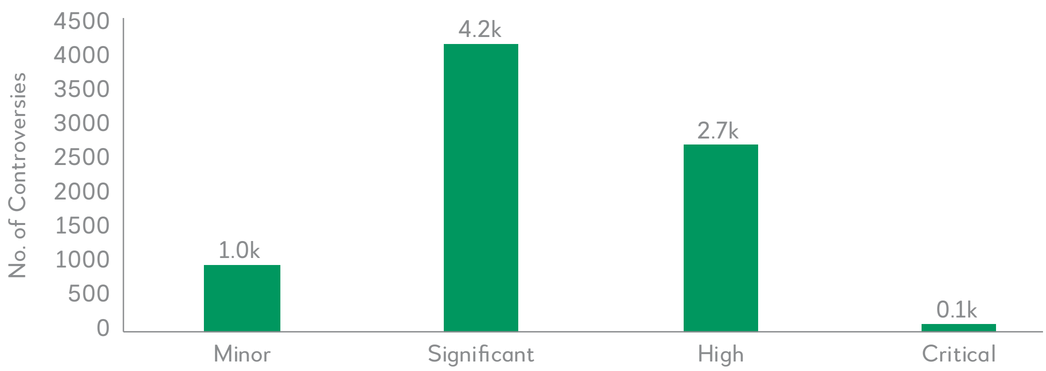
For this analysis, we compare stock prices of firms hit by a "critical" controversy vis-à-vis firms that are not hit by a critical controversy.[66] We limit the controversies to those that occurred in 2015 and onward. Only "initial stages" of controversies are kept; i.e., if there are multiple after-events of the initial controversies, only the initial controversies are kept. This allows us to separate the effects arising from the subsequent events.

We look at the impact of the event on the stock prices by restricting the time period to t-6 days to t+6 days with t representing the day of the event. This restricted time period allows us to see how the stock prices for the controversy-hit companies move close to the event date, compared to those that are unaffected. Since we limit the scope of

Table 10: Examples of Events in Moody's Database

Year	Controversy Title	Severity
2020	DuPont targeted by a lawsuit over drinking water contamination in Michigan	High
2019	Google fined by EU over abusive practices in online advertising	Critical
2018	Xerox responsible for fraudulent Medicaid payments	Significant
2017	Nokia sued over breach of contract by a Kenyan firm	Minor

Figure 63: Distribution of Controversies by Severities, 2010-2013



Source: AIIB staff calculations based on Moody's controversial activities database

66 In this study, we are comparing firms that are hit by critical controversies and firms that are not. Ideally, the comparison should be done between firms that are hit by controversies and those that are never hit, essentially all listed firms. However, our data set contains firms hit by controversies during the period. But controversies do not hit the firms at the same time. If a critical controversy hits a firm, it is unlikely in the data that another firm gets hit by a controversy on the same day. We are also restricting the sample to a 14-day window and ensure that no other controversy hits another firm within that window. Essentially, when a controversy hits a firm, all other firms (regardless of whether they get hit or get hit by a controversy later or earlier than the 14-day window) can serve as the control group.

study to "critical" controversies only, the relatively small number of events (53) under this category allows us to obtain the unique 13-day intervals of controversies, with no overlapping period between the different 13-day window.

The table and charts below report the magnitude of the impact of the controversy following the event date for affected firms relative to other firms after controlling for company-fixed effects and date-fixed effects. Firms that are hit by ESG-related controversies suffer on average a 4-percentage point hit to their stock returns (yearly return) during the six days post the event (Table 11). Figure 64 shows the time evolution of the effect. The hit on stock price persists until six days post controversy.

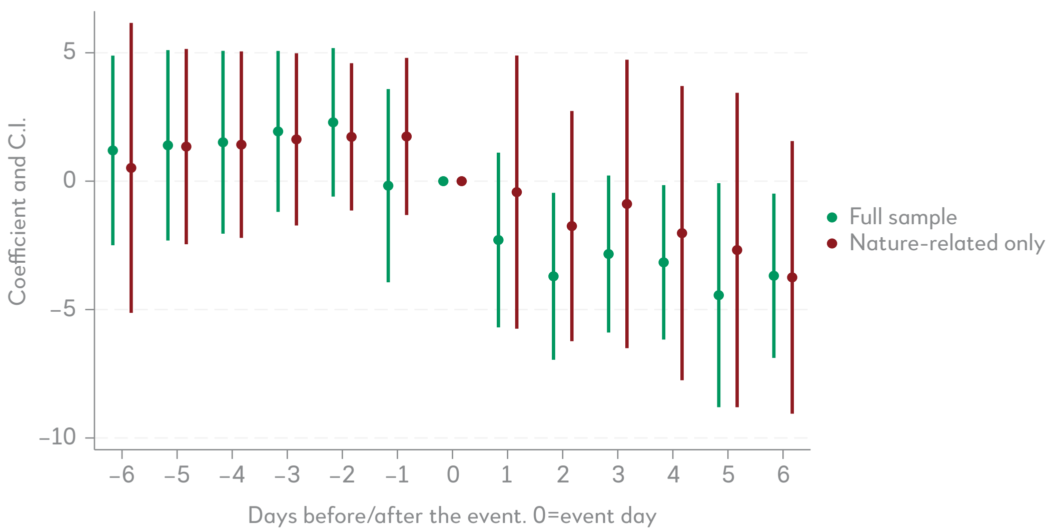
Table 11: Impact of Controversies on Stock Prices

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Full Sample	E-Related only	S-Related only	G-Related only	Nature-related only
Controversy*Post	**-4.062*** **	**-6.611*** **	**-3.910** **	**-5.564*** **	**-1.334**
	(1.569)	**(2.535)**	**(1.705)**	**(1.963)**	**(3.202)**
Constant	-7.377***	-4.263***	-8.104***	-6.582***	-3.587***
	(0.00527)	(0.00697)	(0.00565)	(0.00624)	(0.00606)
Observations	464,307	150,715	370,235	324,848	97,652
R-squared	0.217	0.254	0.230	0.222	0.322
Company FE	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes

Source: AIIB staff calculations based on Moody's controversial activities database and Refinitiv financial data

Notes: Controversy takes a value of 1 for a firm that gets hit by a controversy. Post takes value of 1 for the 6 days after the controversy hits. The specification includes firm and day fixed effects. Standard errors (in parentheses) are clustered at the firm level. The number of firms included in all specifications is 889 *** p<0.01, ** p<0.05, * p<0.1

Figure 64: Event Studies of Stock Prices Following Negative ESG and Nature Disclosures



Source: AIIB staff calculations based on Moody's controversial activities database and Refinitiv financial data

Among the ESG-related controversies, environment-related controversies have the largest "controversy effect," followed by governance-related and social-related controversies. Within environment-related controversies, however, nature-related controversies do not seem to have a significant negative impact on stock prices. Many factors could drive such a result. For example, the average intensity of nature-related controversies may be lower than other environmental controversies. Second, there could be information asymmetry in the financial market for nature-related risks. Lastly, the market cannot price nature-related risks due to the lack of frameworks, disclosure requirements and financial instruments.

The obvious question is, does controversy have a longer-term impact on firms? More generally, do firms with higher ESG risks perform worse? To assess the long-term impact of stock prices, we compare the yearly average stock price one year after the controversies happened versus one year before the controversy. For the firms hit by critical controversies, the average stock price was four percentage points lower in the year following the controversy (Figure 65).

This result is not meant to be interpreted as causal since stock prices are affected by many factors. Nevertheless, it provides preliminary evidence that corroborates with studies that have found that nature-related risks can lead to financial risks through the feedback loop—reduction in ecosystem services leads to production reduction, translating into a deterioration of financial position. Meanwhile, some production processes adversely impact the ecosystem through overexploitation [OECD (2019); von Toor et al. (2020)].

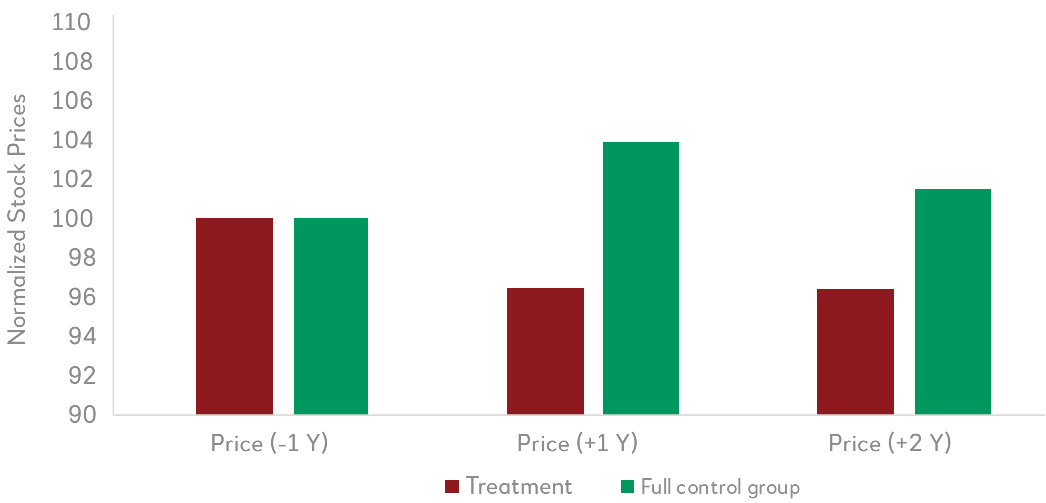
8.4 Strengthening Data Collection and Incentives

For firms to account for the well-being of nature, a set of enabling conditions is required.

8.4.1 Harmonizing Disclosure Standards

First, there needs to be high-quality data that measure and disclose firms' impact on nature. The SFDR is a start, but it covers listed companies only. Thankfully, there are increasingly high-quality geospatial data on nature and biodiversity. As this report demonstrates, it is possible to map firms or projects to nature to get an approximate impact on nature, even for smaller firms. Availability of such information and impact estimation is essential for improving regulator enforcement, possibly laying out a pricing mechanism (e.g., nature-related taxes) to nudge firm behavior toward nature-positive outcomes.

Figure 65: Stock Price One Year Before and One Year After Disclosure



Source: AIIB staff calculations based on Moody's controversial activities database and Refinitiv financial data

Note: The above chart normalizes the yearly average one year before controversies to 100. The red bars indicate the stock price performance of those with critical or significant negative disclosures. The green bars indicate those with minor negative disclosures.

However, disclosure of information depends on the institutions that can lay out the standards and procedures consistent across geographies. A number of institutions exist and have been set up recently to address nature and biodiversity-related financial disclosures. These institutions can be classified into three groups:

- Non-governmental organizations (NGOs) promoting biodiversity-related disclosure standards for corporations (e.g., Climate Disclosure Standards Board (CDSB), established in 2007)
- Intergovernmental efforts facilitating coordination among government institutions (e.g., The Task Force on Climate-related Financial Disclosure (TCFD), The Task Force on Nature-related Financial Disclosures (TNFD) and the Network of Central Banks and Supervisors for Greening the Financial System (NGFS)
- Private-sector organizations establishing global standards for corporate disclosure (e.g., ISSB).

To truly maximize their impact, these institutions must coordinate and align their policies related to disclosure. By coming together and harmonizing their frameworks, they can effectively push corporations to integrate biodiversity considerations into financial decision-making. These frameworks and disclosure standards would also help formalize the different pricing mechanisms, a handful of which are operational now in the market.

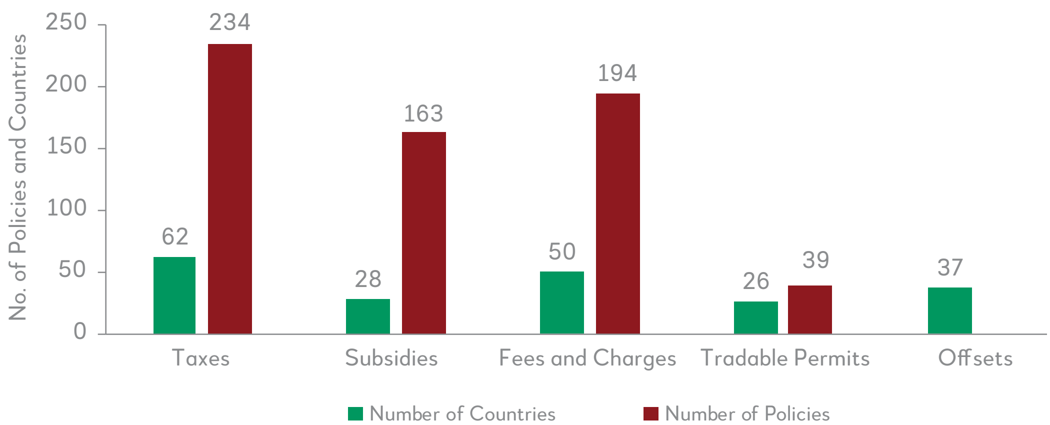
8.4.2 Pricing Mechanisms

Negative disclosures affecting stock prices negatively can serve as a "deterrent," but it is not sufficient. Assessing the value of nature and biodiversity is a daunting task, given their intrinsic worth, non-market characteristics and intricate interconnections [Nature (2019)]. Different instruments have been developed, falling into two main categories. The first category is biodiversity-relevant taxes, fees and charges, and tradable permits; the second is payments for ecosystem services, subsidies and offsets. These mechanisms aim to provide financial incentives and support for activities that promote biodiversity conservation and sustainable practices.

Biodiversity-relevant taxes and subsidies

Pigouvian taxes can be imposed on polluters using resources or chemicals that harm nature. Examples of activities subject to taxation include using pesticides and fertilizers and extracting forest products. According to the OECD Policy Instruments for the Environment (PINE) database, these taxes generated an average annual revenue of USD7.7 billion between 2017 and 2019. Currently, 62 countries have implemented biodiversity-relevant taxes, totaling 234 such taxes globally (Figure 66).

Figure 66: Distribution of Policies and Countries Enacting Biodiversity-related Measures



Source: OECD PINE Database 2021 for taxes, subsidies, fees and charges, and tradable permits. Bull and Strange (2018) for Biodiversity-relevant offsets.

Subsidies are also widely employed by countries worldwide. The PINE database reveals the existence of 163 biodiversity-motivated subsidies across 28 countries. These subsidies aim to incentivize and support activities that contribute to biodiversity conservation. They provide financial assistance to individuals, businesses or organizations engaged in practices that benefit biodiversity.

Biodiversity-relevant fees and charges

Unlike taxes, fees and charges provide the payer with a direct benefit or service corresponding to the amount paid to the government. Common examples of such fees and charges include admission costs for entry into national parks and fees levied for hunting animals. By directly linking the payment to the use or enjoyment of specific natural resources or services, these fees and charges incentivize sustainable practices while generating revenue to support conservation efforts. The OECD PINE database reports that as of 2021, 194 instruments are in place across 50 countries that have implemented biodiversity-relevant fees and charges.

Biodiversity-relevant tradable permits

Biodiversity-relevant tradable permits, or cap-and-trade programs, enforce limitations on utilizing natural resources within a country. These limitations are divided into individual permits that users can trade among themselves. The allocation of permits can involve providing them at no cost to existing resource users or conducting auctions to determine their distribution. Through the auctioning of permits, financial resources can be generated and specifically allocated to biodiversity-focused initiatives. Tradable permits offer the advantage of being tradable in a market among users.

Transferable quotas for fisheries, tradable development rights and tradable hunting rights are examples of biodiversity-relevant tradable permits. As per the OECD's PINE database, 26 countries have implemented tradable permit systems, resulting in 39 schemes as of 2021. Establishing a market for these permits enables the generation of funds dedicated to biodiversity-related efforts.

For instance, in Canada's Alberta province, a minimum of 60 percent of the funds generated through hunting permit auctions is directed toward projects aimed at benefiting the Rocky Mountain bighorn sheep population. Tradable permits contribute to the sustainable utilization of resources while simultaneously providing financial support for conservation initiatives.

Payment for ecosystem services

Payment for ecosystem services operates on a beneficiary-pays approach, wherein payments are contingent upon voluntary pro-environmental actions. For instance, governments may compensate forest owners for refraining from deforestation on their land. Jayachandran (2013) examines the effectiveness of this approach and discovered that the credit constraints faced by landowners influenced its success. In Uganda, a study of 1,245 private subsistence forest owners across 136 villages in 2010 revealed that those with higher credit constraints are less likely to participate in payment for ecosystem services compared to their non-credit-constrained counterparts. This finding indicates that biodiversity-preserving policies must be complemented by other measures that support the well-being of people to achieve their intended objectives.

Offsets

Biodiversity offsets involve compensatory actions taken by agents that have caused negative impacts on the environment. Across 37 countries, approximately 13,000 offset projects have been identified, generating an estimated revenue of around USD6 billion to USD9 billion per year [Bull and Strange (2018)]. The idea is to provide compensation by implementing conservation measures or restoring ecosystems elsewhere to offset the ecological harm caused by the original activity (aligning with the principle of polluter payment).

Biodiversity offsets have been controversial, with experts raising ethical concerns. Tupala et al. (2022) highlight that biodiversity offsets often fail to adequately consider the needs of local communities. Similarly, Karlsson et al. (2021) argue that offsetting violates the intrinsic value of nature, as losses in biodiversity cannot be fully compensated for by human interventions. They also emphasize that knowledge is insufficient to make appropriate offsets and that offsetting may hinder the development of positive attitudes and behaviors toward nature.

8.4.3 Regulations and Enforcements

There needs to be effective local regulations and enforcement. Unlike greenhouse gas emissions with the same global externality, wherever their emission source, nature and biodiversity are "hyper-local." Nature and biodiversity are differentiated everywhere, with complex linkages. Setting a single price (unlike a single carbon price) will be more difficult. This also implies that regulations need to account for local factors and will have to be differentiated, which would only be possible with proper data and research. Enforcements could also take the form of standards and labeling specific to nature outcomes. Such non-price policy lever can help to make informed choices by producers and consumers.

Overall, there is a need to develop a broader international market for nature financing. In Chapter 3, the report further discusses the development of macro-financial type instruments, such as debt for nature swaps, nature linked bonds etc., that can catalyze more financing toward nature and biodiversity.

CHAPTER 9

TOWARD SOLUTIONS

Investing in nature-positive projects, nature-based solutions and nature as infrastructure requires significant accumulation and sharing of knowledge, policy intervention, financial resources and coordination among stakeholders. Most of all, finance must support and be aligned with nature-positive outcomes consistent with national development priorities and the Kunming-Montreal framework. Systematic planning and implementation in three key areas are needed:

- Developing data and associated frameworks, along with analytic capabilities, that are needed to understand dependencies, risks, impacts and opportunities.
- Implementing policies and regulatory frameworks to ensure consistency in dealing with nature across different investment options, sectors and landscapes.
- Developing nature-sensitive financial instruments that can be deployed in aligning investments with nature-positive development outcomes.

This report's final chapter summarizes some key ideas while acknowledging that much work lies ahead.

9.1 Data and Technology as Enabling Conditions

Nature-related data provides the foundations for understanding the state of nature. At one level, data guides actions and operations to conserve nature. At another, it underpins the proper functioning of any nature-related instruments and, ultimately, markets. Data is also vital to managing risks and mobilizing investment flows. Data and digital technology innovations range from on-the-ground environmental DNA testing to satellite tracking.[67]

Data infrastructure enables the collection, processing, sharing and analysis of data embedded in the stock of natural capital. A solid infrastructure foundation is indispensable since it provides the critical measurements of inputs needed for designing effective products and services—and generates meaningful and actionable evidence-based insights for its users, be they government policymakers or private sector decision-makers. The data also underpins the financial instruments and markets. Sound nature conservation and sustainable development policies require significant investment in data and enabling technology. Thus, it is the starting point of embedding nature into infrastructure. Fortunately, the recent wave of

[67] See (https://www.usgs.gov/special-topics/water-science-school/science/environmental-dna-edna). Environmental DNA originates from cellular material shed by organisms (via skin, excrement, etc.) into aquatic or terrestrial environments that can be sampled and monitored using new molecular methods. Such methodology is important for the early detection of invasive species as well as the detection of rare and cryptic species.

innovation around data management and analytics has created significant opportunities. Much of this report could not have been written without the availability of such data.

- **Geographic information systems (GIS) and remote sensing** technologies provide capabilities for mapping and monitoring natural resources. For instance, geospatial imagery and ground-sourced data can combine to create powerful tools to track deforestation rates or assess the health of marine ecosystem.
- **Biodiversity indices** convert raw or processed data into time-series indicators that quantify the variety and abundance of species within specific ecosystems. These indices form part of environmental databases on which policymakers, researchers and conservationists rely to assess ecosystem health and guide conservation initiatives.

Increasingly, artificial intelligence and machine learning tools can be used to process and analyze data, especially large and unstructured data, to forecast environmental trends, thereby supporting decision-making processes [UNEP (2022)]. The BII, used many times in this report, is also a great example of the mix of both ground-up data and satellite images aided by artificial intelligence to provide granular, spatial estimates of the state of ecosystem intactness. Increasingly, the challenge is less about generating more data and more about making such data consistent, useable, timely, accessible, affordable and—equally importantly—paired with relevant economic data for decision-making.

- **Big data management and analytics** are a suite of products, including application processing interfaces (APIs), robotic process automation (RPA), and real-time dynamic dashboards that can accommodate high volume, variation and frequency data, such as geospatial imagery and remote sensing information. By establishing a robust end-to-end processing pipeline that minimizes the scope for human error or manipulation, these solutions can improve the reliability and timeliness of the underlying data, thereby ensuring a more effective and user-friendly monitoring of nature.
- **Data-sharing platforms** enable the seamless exchange of information between governmental agencies, non-governmental bodies and the private sector to foster collaborative efforts. By combining data sets, individual contributors can generate richer insights than would otherwise be possible [Moore (2022)]. For instance, geospatial imagery can be overlaid with analytical layers from various sources (e.g., geological surveys, infrastructure maps, financial access points, etc.) that can identify critical vulnerabilities and opportunities for nature-based solutions. In Chapter 4 of this report, BII is overlaid with project-level or other human settlement data to identify risks and propose mitigants.
- **Indicator registries** are data-sharing platforms containing processed data, rather than the raw inputs, that are captured, transformed and reported in a harmonized fashion. Users are given a single source of truth about a given nature-based key performance indicator (KPI), which greatly facilitates the development of standardized products, services and policies.
- **Blockchain technology**, an immutable ledger or database that can be shared across a distributed network of users to ensure transparency and traceability in transactions, can be deployed to natural resources to track the origin of products, reduce illegal activities and provide confidence in the integrity of the underlying data [Radocchia (2018)].

Clear, widely accepted and practical standards are needed to ensure the meaning and useability of data and associated analytics.

- **Natural capital accounting** allows nature's value to be integrated into national accounts, policymaking and project evaluation. The CWON dataset is one notable effort, and there are ongoing efforts to improve the coverage and quality of the data. Adopting natural capital accounting enhances decision-making by uncovering the intrinsic worth of natural capital [The White House (2023)]. It also facilitates comparisons between countries regarding the state of nature. Ultimately, these accounting standards empower policymakers with an understanding of national capital formation and encourage the preservation of natural infrastructure, for sustainable development [System of Environmental Economic Accounting (2021)].

Multilateral development banks are well placed to support the build-out of these enabling foundations, although many market-based opportunities may not need public support.

9.2 Policies and Regulations

Market innovation is essential in aligning financing with nature-positive outcomes. Policies and regulations, supported by statutory and voluntary standards, are needed to ensure that such developments are suitably incentivized and scaled. Sovereign signatories to the Convention on Biological Diversity are committed to developing National Biodiversity Strategies and Action Plans focusing on mainstreaming biodiversity conservation into policy decision-making and across all sectors of the national economy [Convention on Biological Diversity (2023)]. This commitment is an important starting point, but leaves open the question of framing methodology and content.

- **Disclosures are needed**, much like climate-related risks. As highlighted in Chapter 8, disclosures by firms remain inadequate. There is an urgent need to ensure that markets price nature risk into business and investment decisions. The Task Force on Nature-Related Financial Disclosures (TNFD) released its final recommendations on 18 September 2023, and take-up will depend in part on measures adopted by national policymakers and regulators, notably basic statutory disclosure requirements. Such measures would be aligned with the longer-term adoption of the global baseline being developed by the International Sustainability Standards Board. This report also highlights the power of disclosures and market discipline.
- **Monetary policy and financial regulations**—the purview of central banks and financial supervisors—have embraced the principle of engagement in "green" matters, exemplified by the Network of Central Banks and Supervisors on Greening the Financial System (NGFS) [NGFS (2023)]. Although initially focused exclusively on climate and specifically carbon-related risks, the NGFS has extended its scope to embrace the need to consider the implications of biodiversity-related risks for those governing the financial system. A second generation of nature-related financial stability analyses is underway, and much is being done to build out associated metrics, models and scenarios.
- **Pricing instruments** will be an important part of the regulatory toolkit, as they are for many other aspects of economics. These would include taxes for damages, fees or tradable permits for extraction, etc. The key difference is that pricing instruments for nature would likely be locally focused, compared to GHG emissions.
- **Green budgeting frameworks** govern spending and ensure that it is in line to acknowledge nature as an essential infrastructure. It involves examining how budgets are allocated across different sectors to ensure that they contribute to maintaining and enhancing our natural assets. This approach is especially valuable in preventing investments in infrastructure like roads and buildings from undermining the value and effectiveness of natural infrastructure such as forests and wetlands. As per the OECD's framework, implementing a green budgeting framework should be based on a country's existing public financial management, considering both its strengths and limitations in the budgeting process [OECD (2021)].
- **Regulatory frameworks for nature markets**—strong and effective regulatory systems are crucial to support trustworthy nature markets [Taskforce on Nature Markets (2023)]. These markets deal with financial instruments such as biodiversity credits or offsets, which encourage the preservation and restoration of nature. Regulations are key in establishing credibility by following scientifically backed standards, verification processes, and reliable systems for issuing and trading credits. Regulations that strike a balance between scale, accountability and inclusivity have the potential to drive nature markets. This would help direct resources toward conservation objectives while upholding their integrity.

These solutions address challenges like lack of coordination, insufficient financing and limited adoption of sustainability practices. They enable and build on each other, creating a cohesive and synergistic approach.

9.3 Financial Instruments and Markets

Financial instruments serve as the building blocks for mobilizing capital toward nature-positive initiatives. Nature is increasingly recognized as a source of financial risk associated with a dependency on the underlying economic asset, notably water and other productive nature assets, such as soil for food production to mangroves and reefs for coastal protection. In the first instance, such risks are factored into many investment decisions through emerging standards such as the disclosure recommendations of the TNFD and integration into risk assessments and prudential regulation by central banks and financial authorities. They also create opportunities for a growing pool of investors oriented toward ESG objectives. Beyond this, various nature-specific (sometimes integrated with climate considerations) financial instruments exist, especially in debt markets.

- **Use-of-proceeds (UoP) bonds**, including green and blue bonds, link the proceeds of a bond issuance to pre-selected projects or activities. The color of the bonds broadly corresponds to the sector or ecosystem being targeted—green bonds for terrestrial conservation projects, energy transition and circular economy investments; and blue bonds [The Nature Conservancy (2023)] for marine and aquatic conservation efforts.[68]
- **Sustainability-linked bonds (SLBs) and sustainability-linked loans (SLLs),** unlike UoP bonds, do not stipulate how borrowed funds are to be allocated but instead define sustainability targets with KPIs that can encompass nature and biodiversity conservation commitment alongside other ESG objectives. An embedded incentive mechanism, with coupon interest rate steps-up/steps-down if the issuer under-/overachieves its targets at set observation dates, is designed to induce actions without prescribing how to undertake them [Kulenkampff et al. (2023)]. It also signals to the market the issuer's commitment to the targets. The flexibility to use the proceeds for repaying outstanding debt obligations makes them an effective instrument in the liability management toolkit [Climate Bond Initiative (2021)].
- **Debt-for-nature swaps (DNS)** are financing structures that convert existing outstanding debt into UoP bonds (although SLBs are also possible) with more concessional terms (e.g., lower interest rates, longer tenors) and some degree of debt reduction in exchange for commitments to environmental conservation [Owen (2022)]. The outstanding bonds are typically bought at a discount, which can be quite steep in the case of distressed sovereigns, thereby lowering the debt burden. In recent DNS transactions, MDBs and DFIs provided credit enhancement on the UoP bonds to reduce the cost of financing, while a third-party conservation organization was mandated to set up an endowment to oversee the allocation of conservation funding. While they offer a unique approach to tackling high debt and environmental degradation, their effectiveness is often subject to high transaction costs and limited overall debt relief. Nonetheless, they remain a tool of interest for countries grappling with debt and environmental challenges.
- **Wildlife conservation bonds**, which are also named after the specific species of animals that they seek to protect (e.g., 'Rhino Bonds,' 'Tiger Bonds,' or 'Jaguar Bonds'), are outcome-based financing instruments that replace coupon payments with commitments to transfer funds to protect the animal in question. At maturity, investors receive the principal plus a 'success payment'—a capitalized coupon payout tied to the growth of the species population during the bond's life.[69] These instruments have generally come to market with support from MDBs and DFIs.

As can be seen from the above examples, MDBs play a catalytic role. At the minimum, this has taken the form of technical assistance, such as the

68 There are natural concerns about whether such color label bonds result in additional financing or merely constitute repackaging of government expenditures into a color label. Setting sufficiently tough targets with high standards, disclosures and consistency can ameliorate some concerns.

69 For example, the inaugural "Rhino Bond," issued by the World Bank's International Bank for Reconstruction & Development (IBRD) in 2022, raised USD150 million of sustainable development financing. The five-year bond embeds a conservation success payout clause to noteholders contingent on verifiable growth in Rhino populations. The investors forego coupon payments in exchange for the IBRD contributing a series of "conservation investment payments," totaling around USD10 million, to assist rhino conservation initiatives and improve the net rhino growth rate in two selected sites.

Inter-American Development Bank's (IDB) collaboration with the Government of Uruguay to issue its sustainability-linked bond [Inter-American Development Bank (2022)]. In other instances, the support has been more extensive, including credit enhancement in the cases of the debt-for-nature swaps in Belize, Ecuador and Gabon.

Credit enhancements are critical to mobilizing capital for conservation. By de-risking transactions and improving the credit ratings of the underlying instrument or projects, they can attract private-sector investors who might otherwise eschew investments in nature. MDBs and DFIs are key providers of credit enhancement due to their favorable terms and high credit standing, which can provide significant "uplift" to the covered instrument. Credit enhancement can take several forms—guarantees, political risk insurance, first-loss funds and anchor investors, etc. MDBs, in particular, could be seen as less susceptible to expropriation.

Nature credit markets: Financial instruments can form the basis for entirely new markets as well as new asset classes, and this is already the case for nature-linked instruments in the form of various forms of nature credit markets.

- **Carbon markets** are increasingly linked to nature by virtue of its capacity to store carbon. Over two-thirds of carbon credits traded in voluntary carbon markets—a nascent market that saw about USD2 billion traded in 2022—and were involved in nature-linked carbon sequestration. A far smaller proportion of credits are nature-linked in the much larger compliance markets, valued in aggregate at about USD850 million in the same year. Moreover, the next generation of carbon offset certification schemes will include an optional analysis of biodiversity-related analytics, including the impacts of efforts to store more carbon in nature assets.
- **Biodiversity credit markets** are of growing interest and attention, although there is still a negligible level of trading. Unlike for carbon, there may be many types of biodiversity credits and different types of markets, including offsetting and insetting, with and without secondary trading, linked to policy drivers or entirely voluntary [NatureFinance (2023)].[70] This is consistent with the more localized characteristics of nature. A global initiative was launched in Paris in June 2023 to develop principles, norms and standards governing this new generation of credit markets, with strong involvement of policy and market actors, scientists and other experts, along with Indigenous Peoples and local communities, which together steward more than 80 percent of the world's remaining biodiversity [NatureFinance (2023)].

A summary of stakeholders and action areas is provided below.

Table 12: Summary of Stakeholder Action Areas

Stakeholders	Solutions	Actions
Policymakers	Natural Capital Accounting	Integrate natural capital into national economic planning.
	Data Infrastructure	Establish centralized data repositories for nature-positive initiatives.
	Macroeconomic Modeling	Incorporate natural capital into economic models.
	Green Budget	Implement green budgeting practices.
	Nature Markets Regulations	Develop frameworks for biodiversity and carbon markets.
	Debt Instruments	Facilitate green financing mechanisms.

continued on next page

70 Insetting focuses on doing more good (as opposed to less bad) within one's value chain.

Table 12 *continued*

Stakeholders	Solutions	Actions
Central Banks	Monetary Policy Incentives	Adjust monetary policy tools to encourage nature-positive financing.
	Disclosure Regulations	Mandate reporting on nature-related risks.
Private Sector	Technology for Monitoring	Utilize technology for environmental monitoring.
	Nature-Related Risk Disclosure	Report nature-related risks according to standards.
	Sustainability Instruments	Issue or invest in sustainability-linked bonds.
	Nature Markets Participation	Engage in carbon and biodiversity markets.
	Nature Credit Markets	Issue and trade carbon and biodiversity credits; adhere to industry standards.
Financial Institutions	Nature Risk Integration	Incorporate nature-related risks in lending and investment decisions.
	Sustainability-Linked Instruments	Offer sustainability-linked loans and bonds.
	Credit Enhancements	Provide guarantees and first-loss funds for nature projects.
	Nature Credit Markets	Issue and trade carbon and biodiversity credits; set market standards.
Credit Rating Agencies	Nature-Related Risk Assessment	Incorporate nature-related considerations into risks assessments.
Multilateral Development Banks	Natural Capital Accounting	Develop and promote accounting standards.
	Nature-Sensitive Instruments	Structure sustainability bonds, debt swaps and nature credits.
	Policy and Framework Support	Provide regulatory, standard and budgeting expertise to governments.

APPENDICES

Appendix 1: Data and Estimations for Chapter 2

The CWON dataset provides comprehensive data on a range of man-made capital, human capital and natural capital. This research also draws on the IMF capital stock dataset, which contains a detailed series on gross fixed capital formation (GFCF). This research further separates renewable natural capital into two subsets—cultivated capital (timber, cropland, fisheries, pastureland) and ecosystem capital (mangrove, non-timber forest, protected areas).

Table 13: Summary of CWON Variables

CWON Variable	Remarks	Time Period
Variables in CWON Dataset		
Total wealth	Sum of produced capital, natural capital, human capital, and net foreign assets	1995-2018
Produced capital	Value of machinery, buildings, equipment, and residential and nonresidential urban land	1995-2018
Natural capital	Value of non-renewable natural resources and renewable natural resources	1995-2018
Renewable natural capital	Sum of values of renewable natural resources (forests, mangroves, fisheries, protected areas, cropland, and pastureland)	1995-2018
Forest – timber	Value of timber forest, based on present value of output	1995-2018
Forest – non-timber	Value of non-timber forest, based on present value of ecosystem services	1995-2018
Mangroves	Value of mangroves, based on present value of flood protection benefits	1995-2018
Fisheries	Value of fisheries, based on present value of output	1995-2018
Protected areas	Value of protected areas, estimated as the lower of returns to cropland and pastureland	1995-2018
Cropland	Value of cropland, based on present value of output	1995-2018
Pastureland	Value of pastureland, based on present value of output	1995-2018
Non-renewable natural capital	Sum of values of nonrenewable natural resources (oil, gas, coal and minerals)	1995-2018
Oil	Present value of oil stock	1995-2018
Gas	Present value of natural gas stock	1995-2018
Coal	Present value of coal stock	1995-2018
Minerals	Present value of minerals stock	1995-2018

Source: World Bank

Table 14: Other Variables

Variable	Remarks	Time Period
Human capital (H)	Human capital index incorporating education level and return to education. Data source: Penn World Table (PWT)	1995-2019
Employment (L)	Number of persons engaged in employment. Data source: Penn World Table (PWT)	1995-2019
Effective human capital (HL)	Calculated as human capital multiplied by employment by authors	1995-2019
GFCF stock	Calculated as the sum of general government investment and private investment GFCF by authors. Data source: IMF	1995-2018
Infrastructure stock	Calculated as the sum of general government investment (GFCF) and PPP capital stock by authors. Data source: IMF	1995-2018
Population	Data source: United Nations Population Division	1995-2019
Land area	Land area in square kilometers. Data source: FAO	1995-2019
Voice and accountability	Estimate. Data source: World Bank	1996/8, 2000, 2002-2019
Political stability	Estimate. Data source: World Bank	1996/8, 2000, 2002-2019
Government effectiveness	Estimate. Data source: World Bank	1996/8, 2000, 2002-2019
Regulatory quality	Estimate. Data source: World Bank	1996/8, 2000, 2002-2019
Rule of law	Estimate. Data source: World Bank	1996/8, 2000, 2002-2019
Control of corruption	Estimate. Data source: World Bank	1996/8, 2000, 2002-2019

Source: PWT, IMF, UN Population, FAO, World Bank

Accounting for Biodiversity

While CWON provides a good starting point for data on natural capital, it does not include data on biodiversity. To plug this gap, the research turns to the BII. This was first started for South Africa [Scholes and Biggs (2005)] and is now extended to global coverage [Newbold et al. (2016)]. It relies on a mix of high-level satellite pictures, field data, and algorithms to create a 0 to 1 score for each granular, spatially differentiated area. It is "an estimate of the percentage of the original number of species that remain and their abundance, despite human pressures." A score closer to 1 will mean greater biodiversity intactness. Coverage has been extended globally; it is now a key indicator tracked and maintained by the Natural History Museum in the UK and used in many research and reports.

The key advantage of BII is that it contains a mixture of granular data, which can then be aggregated at the country level. BII also accounts for both biodiversity and biomass but with more emphasis on the former. The slight disadvantage is that this index prizes intactness over relative biodiversity abundance or biomass. For example, a desert may be considered more pristine and achieve a high score but may not necessarily have the biomass of flora and fauna compared to a less pristine forest with a lower intactness score. It may thus be difficult to compare regions with very different climates and natural environments. Finally, the latest BII data is only up to 2014, thereby reducing the number of data points whenever this series is used.

Table 15: BII Scores of Economies (2014)

Antigua and Barbuda	1.000	Botswana	0.825	Lithuania	0.672
Egypt	1.000	Iceland	0.819	Mozambique	0.670
Jordan	1.000	Ethiopia	0.815	Turkmenistan	0.668
Kuwait	1.000	Croatia	0.813	Albania	0.665
UAE	1.000	Bolivia	0.805	Paraguay	0.664
Qatar	1.000	Myanmar	0.803	Sri Lanka	0.659
Oman	1.000	Slovenia	0.802	Greece	0.657
Bahrain	1.000	Ecuador	0.801	Thailand	0.655
Iraq	1.000	Chad	0.791	Costa Rica	0.654
Cyprus	1.000	Malaysia	0.785	Italy	0.652
Suriname	0.993	Tanzania	0.784	Comoros	0.652
Cabo Verde	0.990	Tajikistan	0.779	Belgium	0.646
Turks and Caicos Islands	0.979	Panama	0.771	Switzerland	0.643
Saint Kitts and Nevis	0.975	Türkiye	0.770	China	0.634
Algeria	0.967	Namibia	0.770	Nicaragua	0.633
Finland	0.960	Nepal	0.768	Montenegro	0.631
Norway	0.952	Portugal	0.767	Guinea-Bissau	0.629
Central African Republic	0.949	Belarus	0.766	Eswatini	0.627
Sweden	0.949	Georgia	0.766	Kazakhstan	0.625
Curaçao	0.946	Hong Kong, China	0.765	France	0.622
Guyana	0.940	Angola	0.763	Dominican Republic	0.618
D.R. of the Congo	0.940	Brazil	0.762	Czech Republic	0.615
The Bahamas	0.940	Yemen	0.753	Guatemala	0.615
Grenada	0.939	Congo	0.748	Philippines	0.615
Brunei Darussalam	0.938	Morocco	0.748	Romania	0.610
Barbados	0.935	Liberia	0.745	South Africa	0.609
Israel	0.931	Mexico	0.741	India	0.606
Trinidad and Tobago	0.913	Kyrgyzstan	0.737	Netherlands	0.605
Equatorial Guinea	0.912	Djibouti	0.733	New Zealand	0.603
Belize	0.908	Austria	0.724	Hungary	0.600
Canada	0.908	Cambodia	0.722	Serbia	0.597
Dominica	0.905	Poland	0.721	Syria	0.594
Peru	0.902	Honduras	0.721	Ukraine	0.581

continued on next page

Table 15 *continued*

Iran	0.898	Colombia	0.720	Madagascar	0.575
Lao PDR	0.896	Bulgaria	0.719	Guinea	0.575
Zambia	0.887	Indonesia	0.719	Togo	0.572
Japan	0.885	Kenya	0.712	Ghana	0.571
Mauritania	0.883	Argentina	0.711	Uganda	0.567
Russia	0.882	Azerbaijan	0.711	Lesotho	0.565
Chile	0.880	Armenia	0.706	Côte d'Ivoire	0.561
Benin	0.877	Sudan	0.701	Lebanon	0.539
Estonia	0.874	Viet Nam	0.697	Sierra Leone	0.534
Mali	0.869	Jamaica	0.697	Luxembourg	0.531
Pakistan	0.868	Bosnia and Herzegovina	0.696	Moldova	0.508
Venezuela	0.863	Australia	0.696	Mauritius	0.507
Zimbabwe	0.862	Uzbekistan	0.695	Rwanda	0.506
São Tomé and Príncipe	0.859	Tunisia	0.693	Mongolia	0.489
Latvia	0.859	Saudi Arabia	0.690	Nigeria	0.474
Burkina Faso	0.856	Spain	0.690	Burundi	0.462
Cameroon	0.855	United States	0.688	Haiti	0.461
Republic of Korea	0.848	North Macedonia	0.687	Denmark	0.449
Niger	0.842	Malta	0.685	United Kingdom	0.423
Gabon	0.840	Germany	0.685	Ireland	0.406
Fiji	0.839	Gambia	0.684	Bangladesh	0.374
Bhutan	0.836	Malawi	0.679	El Salvador	0.371
Senegal	0.829	Slovakia	0.678	Singapore	0.345
				Uruguay	0.332

Source: UNDP and Natural History Museum, UK

Environment Performance Index

The EPI dataset from the Yale Center for Environment Law and Policy uses 40 performance indicators to rank countries on their efforts "to protect environmental health, enhance ecosystem vitality, and mitigate climate change" [Wolf et al. (2022)].

The key advantage of this dataset is that with the richer set of 40 indicators, it is, in principle, possible to further unpack the qualitative aspects of nature's health (e.g., nitrogen management, fisheries health, pollution, waste management so on). Unfortunately, this dataset is highly unbalanced.[71]

[71] Some variables have data collated annually, some once every few years and some only once in the entire dataset.

Table 16: Summary of Select EPI Indicators Used as Additional Instruments in R10

Variable	Time Period
Recycling rate (REC)	2000, 2005, 2010, 2015
Unsafe sanitation (USD)	1995-2019
Nitrogen oxide (NOE)	2002-2019
Methane growth (CHA)	1999-2019
CO_2 from land cover (LCB)	2010-2017
PM2.5 exposure (PMD)	1995-2019
Tree cover loss (TCL)	2006-2019
Household solid fuel use (HAD)	1995-2019
Sulphur dioxide exposure (SOE)	2002-2019

Source: Environment Performance Index by Yale Center of Environmental Law and Policy

Growth Accounting Regressions

The research begins with a familiar growth decomposition:

Equation 1

$$Y = K^{\alpha} N^{\beta} (QHL)^{1-\alpha-\beta}$$

where K and N are infrastructure and non-infrastructure capital stocks, respectively, L is labor, H is human capital (HL being effective labor), and Q the augmenting total factor productivity. This becomes:

Equation 2

$$y = k^{\alpha} n^{\beta} Q^{1-\alpha-\beta}$$

where y, k, ny, k, n are expressed in effective labor. Incorporating natural capital, this becomes

Equation 3

$$y = \left(\prod p_i^{\theta_i}\right) k^{\alpha} n^{\beta} Q^{1-\alpha-\beta-\sum \theta_i}$$

where P_i are the categories of natural capital stocks (again in effective labor) and θ_i the respective elasticities, which in growth terms becomes:

Equation 4

$$\gamma_y = \sum \theta_i p_i + \alpha\gamma_k + \beta\gamma_n + (1 - \alpha - \beta - \sum \theta_i)\gamma_Q$$

The above formulation can be represented straightforwardly as a log-differenced regression (e.g., γ_k is represented by $\ln k_t - \ln k_{t-1}$ and so on). Time-invariant variables are also purged, just as it would be under fixed-effect regressions. Growth regressions (as opposed to levels) are also more robust against spuriousness caused by trends.

Panel Regressions

R1 is a traditional growth regression without natural capital. R2 expands on this and includes non-renewable and renewable natural capital as per Equation 4. R3 further disaggregates renewable capital into cultivated capital and ecosystem capital. R4 replaces ecosystem capital with the biodiversity adjusted one. R5 is similar to R4 but has ecosystem capital and BII as separate variables instead. All regressions are carried out with year dummies, and with clustered standard errors by each economy.

Table 17: Regressions of Output and Capital Stocks

	R1	R2	R3	R4	R5
Infrastructure stock, log difference	0.174***	0.189***	0.177***	0.200***	0.200***
	[0.046]	[0.050]	[0.050]	[0.049]	[0.049]
Other GFCF stock, log difference	0.137***	0.131***	0.129***	0.104**	0.104**
	[0.038]	[0.041]	[0.041]	[0.052]	[0.052]
Non-renewable natural capital, log difference		-0.004**	-0.004**	-0.004**	-0.004**
		[0.002]	[0.002]	[0.002]	[0.002]
Cultivated natural capital, log difference			-0.002	-0.000	-0.000
			[0.011]	[0.011]	[0.011]
Ecosystem natural capital, log difference			0.063**		0.101**
			[0.025]		[0.039]
Renewable natural capital, log difference		0.029*			
		[0.015]			
Ecosystem natural capital BII adjusted, log difference				0.102***	
				[0.037]	
BII, log difference					0.124
					[0.143]
Constant	0.026***	0.026***	0.026***	0.014***	0.014***
	[0.002]	[0.002]	[0.002]	[0.003]	[0.003]
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2,854	2,476	2,476	1,521	1,521
R-squared	0.151	0.162	0.165	0.197	0.197
Number of groups	125	115	115	113	113
R-squared overall	0.176	0.188	0.192	0.213	0.212
F-statistics	19.54	19.83	20.54	19.27	18.21
p-value	0	0	0	0	0

Errors are clustered by economy and reported in brackets

*** p<0.01, ** p<0.05, * p<0.1

System Generalized Method of Moments (GMM)

To address endogeneity concerns, a set of regressions using the Arellano-Bond (AB) estimator is implemented, where past values of regressors are used as instruments. The results are presented in regressions R5 to R8, mirroring R1 to R4, respectively. These regressions make use only of system instruments, i.e., lagged values. In regression R10, a set of EPI indicators is included as an additional instrument. The assumption here is that these environmental indicators correlate and provide information on biodiversity but do not affect per capita incomes directly.

Table 18: Regressions of Output and Capital Stocks (Arellano-Bond)

	R6	R7	R8	R9	R10
Infrastructure stock, log difference	0.135**	0.220***	0.202***	0.241***	0.218***
	[0.060]	[0.045]	[0.045]	[0.052]	[0.044]
Other GFCF stock, log difference	0.149**	0.175***	0.172***	0.145**	0.143***
	[0.065]	[0.052]	[0.048]	[0.061]	[0.055]
Non-renewable natural capital, log difference		-0.007***	-0.006***	-0.005**	-0.003*
		[0.002]	[0.002]	[0.002]	[0.002]
Renewable natural capital, log difference		0.049			
		[0.033]			
Cultivated natural capital, log difference			0.006	-0.006	0.001
			[0.017]	[0.018]	[0.015]
Ecosystem natural capital, log difference			0.088**		
			[0.040]		
Ecosystem natural capital BII adjusted, log difference				0.083**	0.117***
				[0.035]	[0.039]
Constant	-0.021***	0.011**	-0.020***	0.021***	0.021***
	[0.008]	[0.005]	[0.005]	[0.005]	[0.006]
Instruments	Lagged variables	Lagged variables	Lagged variables	Lagged variables	Lagged variables, land area, and EPI
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2,854	2,476	2,476	1,521	1,521
Number of groups	125	115	115	113	113
Wald statistics	738.7	863.9	1090	757	776.7
P-value	0	0	0	0	0

Errors are clustered by economy and reported in brackets

*** p<0.01, ** p<0.05, * p<0.1

Pseudo Poisson Maximum Likelihood (PPML)

Following Santos Silva and Tenreyro (2006), the research checks for the robustness of constant elasticity log linear estimates. This is highly relevant in the context of this chapter as there are likely sources of heteroskedasticity. For example, the impact of natural and ecosystem capital could be larger for economies with higher shares of primary sectors. Data on natural capital are also relatively new and subject to various methodological uncertainties.

A key constraint with PPML is that it only deals with non-negative dependent variables. In a growth regression context, this is a particular constraint as growth can be negative in some years. One can thus express growth as a ratio—with a ratio above and below 1 implying positive growth and contraction otherwise. Using *t* as the time subscript, growth can be written as:

Equation 5

$$\frac{y_t}{y_{t-1}} = \left[\prod\left(\frac{p_{it}}{p_{it-1}}\right)^{\theta_i}\right]\left(\frac{k_t}{k_{t-1}}\right)^{\alpha}\left(\frac{n_t}{n_{t-1}}\right)^{\beta}\left(\frac{Q_t}{Q_{t-1}}\right)^{1-\alpha-\beta-\sum\theta_i}$$

With this, negative value variables are avoided on the LHS, and the RHS variables can be implemented in the PPML estimation as log-differenced terms (e.g., $\frac{k_t}{k_{t-1}}$ on the RHS can be represented by $\ln k_t - \ln k_{t-1}$ and so on), just as the regressors in previous sections. Time-invariant omitted variables would also not have any impact on the regression, similar to fixed-effect panels.

In Table 20 below, the regressions for fixed effect R4, AB estimator in R5, and PPML estimator in R14 are reproduce with World Bank's governance indicators added as controls. The elasticity estimates for ecosystem capital remain positive and significant at around 0.12.

Table 19: Regressions of Output and Capital Stocks (PPML)

	R11	R12	R13	R14	R15
Infrastructure stock, log difference	0.173***	0.196***	0.175***	0.199***	0.195***
	[0.045]	[0.048]	[0.049]	[0.050]	[0.044]
Other GFCF stock, log difference	0.137***	0.134***	0.128***	0.101*	0.116**
	[0.039]	[0.042]	[0.041]	[0.054]	[0.050]
Non-renewable natural capital, log difference		-0.004**	-0.004**	-0.005**	-0.004**
		[0.002]	[0.002]	[0.002]	[0.002]
Cultivated natural capital, log difference			-0.002	0.001	-0.002
			[0.011]	[0.010]	[0.010]
Ecosystem natural capital, log difference			0.066***		0.103***
			[0.025]		[0.039]
Renewable natural capital, log difference		0.001			
		[0.014]			
Ecosystem natural capital BII adjusted, log difference				0.105***	
				[0.040]	
BII, log difference					-0.095
					[0.075]

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Table 19 *continued*

	R11	R12	R13	R14	R15
Year-fixed effects	Yes	Yes	Yes	Yes	Yes
Observations	2,854	2,475	2,475	1,521	1,626
Number of groups	125	114	114	113	113
Chi-square	459.2	540.8	575.3	349.3	402.8
P-value	0	0	0	0	0

Errors are clustered by economy and reported in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table 20: R4, R9 and R14 with World Bank Governance Indicators Added as Controls

	R4 (alternate)	R9 (alternate)	R14 (alternate)
Infrastructure stock, log difference	0.170***	0.185***	0.174***
	[0.054]	[0.057]	[0.053]
Other GFCF stock, log difference	0.111*	0.145**	0.104*
	[0.059]	[0.059]	[0.062]
Non-renewable natural capital, log difference	-0.004**	-0.003	-0.004**
	[0.002]	[0.002]	[0.002]
Cultivated capital stock, log difference	0.002	0.011	0.004
	[0.010]	[0.016]	[0.009]
Voice and accountability	0.014	0.003	0.008
	[0.016]	[0.004]	[0.016]
Political stability	0.012***	0.003	0.011***
	[0.005]	[0.003]	[0.004]
Government effectiveness	-0.011	0.001	-0.014
	[0.011]	[0.008]	[0.013]
Regulatory quality	0.001	0.006	0.000
	[0.010]	[0.009]	[0.010]
Rule of law	0.004	-0.002	0.005
	[0.013]	[0.009]	[0.012]
Control of corruption	0.012	-0.012*	0.015
	[0.011]	[0.007]	[0.012]

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Table 20 *continued*

	R4 (alternate)	R9 (alternate)	R14 (alternate)
Ecosystem natural capital BII adjusted, log difference	0.124***	0.120***	0.125***
	[0.039]	[0.037]	[0.040]
Constant	0.017***	0.020***	
	[0.003]	[0.006]	
Observations	1,390	1,390	1,390
R-squared	0.197		
Number of groupid	111	111	111
R-Square Overall	0.0560		
F-statistics	17.36		
Wald Statistics		989.9	
chi-square			422.3
p-value	0	0	0

Robust standard errors in brackets

*** p<0.01, ** p<0.05, * p<0.1

Table 21: BII Correlation with Economy Characteristics and EPI Indicators

Land area, in logs	1.687***	PM 2.5 exposure	-0.002*
	[0.111]		[0.002]
Per capita GDP in PPP, in logs	-0.471**	Tree cover loss	0.002***
	[0.240]		[0.000]
Population, in logs	-0.420**	Household solid fuel use	0.011***
	[0.197]		[0.002]
Recycling rate	0.022***	Sulphur dioxide exposure	0.008***
	[0.002]		[0.003]
Unsafe sanitation	-0.009***	Constant	-21.510***
	[0.003]		[1.360]
Nitrogen oxide exposure	-0.008***		
	[0.003]	Year-fixed effects	Yes
Methane growth rate	-0.001**	Economy-fixed effects	Yes
	[0.000]	Observations	690
Carbon dioxide from land cover	0.001**	Chi-square	610,546
	[0.000]	P-value	0

Errors are clustered by economy and reported in brackets

*** p<0.01, ** p<0.05, * p<0.1

Appendix 2: Data and Estimations for Chapter 4

To estimate the extensive and intensive margins of mangroves on tidal flood disasters, the analysis extensively exploited disaster data collected from the Indonesia National Agency for Disaster Relief, which provides data on damage for each disaster type at the regency level in detail starting in 2008. Information on mangrove coverage in a five-kilometer buffer area from coastlines at the regency level is calculated through geospatial analysis by overlaying mangrove data from Global Mangrove Watch and land boundaries from HUMDATA provided by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). Based on mangrove coverage and tidal-flood disaster, the coastal regencies are characterized into four categories as followed:

Table 22: Number of Coastal Regencies Based on Mangrove Coverage and Tidal Flood Disasters

	Tidal Flood Risk	
	Yes	No
Mangrove	138	127
No Mangrove	36	35

Regencies are characterized as facing tidal flood risk if they experienced tidal flood disaster at least once from 2008 to 2022. On the other hand, they are marked as having mangrove cover if mangrove cover was present through the entirety of 2008 to 2022. When analyzing the extensive margin of mangroves, the analysis includes all regencies with mangroves, with and without tidal flood risk. The correlation between mangrove coverage and tidal flood occurrence is estimated through Equation 6 using Panel logit regression.

Equation 6

$$P(Flood_{it} = 1) = \alpha_i + \delta_t + Mangrove_{it} + CV_{it} + \varepsilon_{it}$$

Where:

$Flood_{it}$ takes 1 if a flood occurs in regency i at year t.

α_i is a regency-fixed effect.

δ_t is a year-fixed effect.

$Mangrove_{it}$ is the mangrove coverage within a 5-km distance from the coastline.

CV_{it} is control variables, i.e., sea level, coastal population, GDP, agriculture activity and literacy level.

On the other hand, when analyzing the intensive margin of mangroves, the analysis includes all regencies exposed to tidal flood risk, with and without mangrove coverage. The correlation between mangrove coverage and tidal flood damage is estimated through Equation 7 using Panel LS regression.

Equation 7

$$Impact_{it} = \alpha_i + \delta_t + Mangrove_{it} + Flood_{it} + Mangrove_{it} * Flood_{it} + CV_{it} + \varepsilon_{it}$$

Where:

$Impact_{it}$ is tidal flood impact in regency i at year t.

α_i is a regency-fixed effect.

δ_t is a year-fixed effect.

$Mangrove_{it}$ is the mangrove coverage within a 5-km distance from the coastline.

$Flood_{it}$ takes 1 if a flood occurs in regency i at year t.

CV_{it} is control variables, i.e., sea level, coastal population, GDP, agriculture activity, and literacy level.

Appendix 3: Data and Estimations for Chapter 5

Table 23: Extract of the Condition Account for Ecosystem Type (Water)

SEEA Ecosystem Condition Typology Class		Variable Descriptor	Measurement Unit	Year	Variable Values	Reference Level Values		Indicator Values (0–1)
						Lower level	Upper level	Opening
(1)	(2)	(3)	(4)			(7)	(8)	(9)
Abiotic Characteristics	Physical state	Annual rainfall infiltration supplementary volume	m^3	Unknown	16,520,000	Unknown	Unknown	Unknown
		River water lateral supply and irrigation leakage supply	m^3	Unknown	50,490,000	Unknown	Unknown	Unknown
		Underground water supply	m^3	Unknown	67,020,000	Unknown	Unknown	Unknown
		Groundwater dynamic reserve	m^3/day	Unknown	80,000	Unknown	Unknown	Unknown
	Chemical state	Groundwater pH	Dimensionless	Unknown	7.5-7.9	5.5	9	0.57 - 0.69
		Groundwater calcification degree	g/L	Unknown	0.4	Unknown	Unknown	Unknown
		Groundwater total hardness	German degree	Unknown	3.5-9.9	Unknown	Unknown	Unknown
		Water quality reaching the standard in the Taoer River Baliba section	%	2021	100	100	0	0.00
		pH	Index	Unknown	0.13	1	0	0.87
		Ammonia nitrogen (NH3-N)	Index	Unknown	0.08	1	0	0.92
		Total phosphorus (P)	Index	Unknown	<0.02	1	0	0.98
		CODcr	Index	Unknown	0.35	1	0	0.65
		Suspended solids	Index	Unknown	<0.12	1	0	0.88
		BOD5	Index	Unknown	0.38	1	0	0.62
		Permanganate index	Index	Unknown	0.15	1	0	0.85
		Petroleum	Index	Unknown	0.40	1	0	0.60

Source: AIIB Staff Computation based on Arcadis' NCV Model.

Table 24: Physical Ecosystem Service Flows Account

Ecosystem Type	Year	Crop Provisioning			Meat Provisioning		Milk Provisioning	Tourism*	Water Provisioning	Wetland Extent
		Corn	Rice	Beans	Pork	Mutton				
		ton	ton	ton	ton	ton	ton	number of tourists	m^3	ha
Forest	Unknown									
Water	Unknown							719,040	212,000	
Cropland	2021	66,185	25,941	309						
Urban	Unknown							719,040		
Grasslands	2021				1,096	1,823	30,562	719,040		
Sparse Vegetation	Unknown									
Shrubland	Unknown							719,040		
Wetland	1992									224
	2002									219
	2012									205
	2018							719,040		135
Total	Latest Available Year	66,185	25,941	309	1,096	1,823	30,562	3,595,200	212,000	
Users										
Agriculture	2021	66,185	25,941	309	1,096	1,823	30,562			
Forestry										
Fisheries										
Energy & Water Supply	Unknown								212,000	
Government & Households	Unknown							395.2		

Source: AIIB Staff Computation based on Arcadis' NCV Model.

Table 25: Monetary Ecosystem Service Valuation Account

Ecosystem type	Year	Crop Provisioning			Meat Provisioning		Milk Provisioning	Tourism*	Water Provisioning	Air Filtration Services	Global Climate Regulation Services	Local (micro and meso) Climate Regulation Services	Peak Flow Mitigation Services. River Food Mitigation Services	Retention and Breakdown of Nutrients	Soil Quality Regulation Services	Storm Mitigation Services
		Corn	Rice	Beans	Pork	Mutton										
		US$/ton			US$/ton		US$/ ton	US$/ tourist	US$/ m3	US$/ ha	US$/ ha	US$/ ha	US$/ ha	US$/ ha	US$/ha	US$/ha
Forest	Unknown															
Water	Unknown							111.2	12.6							
Cropland	1992	84.5	120.00													
	2002	146.2	140.90													
	2006			613.3												
	2012	383.4	456.2	1,286.4												
	2018	398.0	474.8	755.4												
	2020	419.4	413.6	702.8												
	2021	431.5	422.0	711.3												
Urban	Unknown							111.2								
Grasslands	1992				645.6	998.40	143.3									
	2002				1,078.9	1,786.90										
	2004						541.3									
	2012				3,349.0	7,296.8	606.7									
	2018				1,951.7	4,121.1	499.6									
	2021				6,177.4	18,337.1	665.2	111.2								
Sparse Vegetation	Unknown															
Shrubland	Unknown							111.2								
Wetlands	2012									117.9	469.0	770.8	4,379.9	161.3	4,009.9	798.9
	2018							111.2		133.1	529.1	869.6	4,941.5	181.9	4,524.1	901.2

Source: AIIB Staff Computation based on Arcadis' NCV Model.

Table 26: Scenario Analysis Outputs

Sustainability Category (1-4)	Sustainability Category Description
4 (Sustainable Scenario)	Significant improvements to wetland and river ecosystem extent and condition; implemented nature-based solutions to deal with water management; risk of flooding and storm surges mitigated to the greatest extent possible through a combination of grey and green infrastructure; strict, enforced laws; concentrations of all water quality variables fall within the target range of the relevant pollutant standards; all residual flows appropriately minimized and managed, and risk to local communities, wildlife and flora is minimal; ongoing maintenance schedule in place; significantly improved provisioning of ecosystem services; remediation of any polluted areas underway; human health risks mitigated; compliant with SDG6 and SDG15.
3 (Project Scenario)	Improvements to wetland and river ecosystem extent and condition; implemented some nature-based solutions to deal with water management; risk of flooding and storm surges mitigated to some degree through a combination of grey and green infrastructure; enforced laws; concentrations of most water quality variables fall within the target range of the relevant pollutant standards; most residual flows appropriately minimized and managed so risk to local communities, wildlife and flora is minimal; ongoing maintenance schedule in place; improved provisioning of ecosystem services; remediation of some polluted areas underway; human health risks mostly mitigated; compliant with SDG6 and SDG15.
2 (BAU Scenario/Baseline)	Relatively stable wetland and river ecosystem extent and condition; minimal use of nature-based solutions to deal with water management; risk of flooding and storm surges mitigated to some degree, primarily via grey infrastructure; few and/or rarely enforced laws; concentrations of some water quality variables fall within the target range of the relevant pollutant standards; some residual flows appropriately minimized and managed so risk to local communities, wildlife and flora is material; ad-hoc maintenance occurs; relatively stable provisioning of ecosystem services; some human health risks mitigated; not compliant with SDG6 and SDG15.
1 (Unsustainable Scenario)	Declining wetland and river ecosystem extent and condition; no use of nature-based solutions to deal with water management; risk of flooding and storm surges mitigated to a small extent via grey infrastructure; few and/or rarely enforced laws; concentrations of many water quality variables fall outside the target range of the relevant pollutant standards; few residual flows appropriately minimized and managed, resulting in material risk to local communities, wildlife and flora; ad-hoc maintenance occurs; declining provisioning of ecosystem services; human health risks not mitigated; not compliant with SDG6 and SDG15.

Source: AIIB Staff Computation based on Arcadis' NCV Model.

Appendix 4: Data and Estimations for Chapter 7

Table 27: Impacts of India's Smart Cities on Green Space Growth

	Impact on Green Cover Growth			
	(1)	(2)	(3)	(3)
Smart*Post	**1.26***	1.30+	0.79	1.09
	(0.62)	(0.67)	(0.75)	(0.68)
Smart*Post*Population		**-0.00**		
Smart*Post*Population Density		**(0.00)**	**(0.00)**	
Smart*Post*Biodiversity Committee			**(0.00)**	**0.28**
				(0.48)
Constant	-2.18*** (0.26)	-2.19*** (0.26)	-2.16*** (0.26)	-2.18*** (0.26)
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
StateXYear trend	Yes	Yes	Yes	Yes
N	1,169	1,169	1,169	1,169
Cities	117	117	117	117
r2	0.43	0.43	0.44	0.43

Source: AIIB staff computation based on ESA (2023)

Note: Standard errors are clustered at the city level. Post*Treatment denotes the interaction dummy for city under the SCP post 2015

+ $p < 0.10$, *$p < 0.05$

Appendix 5: Data and Estimations for Chapter 8

Table 28: Coverage of Global Indices

Major Indices	SFDR PAI7 Coverage	
	Number of Compositions	Percentage of Coverage (%)
FTSE All Share	378	64
FTSE 350	268	77
MSCI WORLD	1,465	98
STOXX 1800	1,757	98
US RUSSELL 3000	2,449	83
Canada S&P TSX	208	88
SBF 120	117	98
SP US 500	498	10
STOXX 600 AP	588	98
STOXX 600 NAM	586	98
MSCI EM	995	84
BB EM	1,534	59
BB HY	491	90
Barclays Global Aggregate Index	19,780	81
EURO Aggregate	3,285	97
JPM CEMBI Broad Diversified Composite	1,834	86
MSCI EMU	229	99
MSCI EUR ex EMU	194	99
MSCI Pacific	376	99
SPI	192	91
Australia ASX 300	251	84
New Zealand NZX 50	43	86
Topix 1000	865	87

Source: Moody's

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ASIAN INFRASTRUCTURE FINANCE 2023
NATURE AS INFRASTRUCTURE

The Asian Infrastructure Finance 2023 report examines how nature as infrastructure can be a transformative concept for development. Developing economies need to invest significantly in infrastructure to close the infrastructure gap. Both advanced and developing economies will have to invest in infrastructure as part of the net zero transition. Yet the degradation of nature and biodiversity over the past decades now pose an existential risk as much as climate change. The degradation of nature must be reversed quickly together with climate change. Infrastructure development has to be part of the solution, through leveraging nature as infrastructure, nature-based solutions and mitigation efforts. There is a need to understand the value of nature, and the report discusses both macro and project-level valuation tools. The report provides detailed examples where nature can provide infrastructure-like services, and where investments into nature should be incorporated. The report recognizes that traditional infrastructure will always be needed, and proposes solutions to design and locate these better. Finally, the report highlights the need to channel more financial flows to nature and to low income economies, and how MDBs can play a catalytic role to achieve this.

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