Death by a dozen cuts: Mitigation of biodiversity impacts from Development Corridors in Africa

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February 2026

Thesis submitted for the degree of

Doctor of Philosophy in Biodiversity Management

Death by a dozen cuts: Mitigation of biodiversity impacts from Development Corridors in Africa

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Acknowledgements

This thesis is mostly dedicated to my parents Dr Alberto Juffe Stein and Liliana Bignoli Seward who over the years have always encouraged me to get to the finish line with emotional and logistical support. Sempre avanti!

The research presented here was completed in a part time modality while working and sharing the raising of two kids. It would have been impossible to do this without the people who have been with me along the way. I thank Juan, Rocio and Valeria for that, but Aida is who has made this possible every day. ¡Mil gracias Aida!

The research formally started in June 2019 as part of the Development Corridors Partnership project (2018-2022). I am grateful to all DCP project researchers but especially to Professor Neil D. Burguess and Lisen Runsten for allowing this thesis and Jessica Thorn for a great collaboration in Chapter 3. Affectionate thanks to Jon Hobbs from whom I learned about impact assessment in practice and Tobias Nyumba who taught me about the fundamental role of social science in conservation. Sadly, nor Jon or Tobyas will see this thesis.

My PhD supervisors have also been incredibly supportive, and it is also because of them I did not quit in some hard moments. Thank you, Joe, Bob and Jake.

Finally, thank you to all my co-authors and collaborators over these years. Without collaboration, openness to listen and change, honest and respectful critical thinking, there is no science.

Author’s declaration

DJB wrote all the chapters, with editorial suggestions made by J.W.B. (primary PhD supervisor 2019-2022), R.J.S. (primary PhD supervisor 2022-2026) and J.E.B. (PhD supervisor 2022-2026). N.D.B. has been a strong collaborator throughout.

All Chapters except 1 and 6 were completed through collaborations with researchers outside of the supervisory team, as outlined below.

Chapter 2: Conceptualization, D.J.B. J.W.B, N.D.B.; Data Curation, D.J.B.; Formal Analysis, D.J.B; Writing – Original Draft, D.J.B; Writing – Review & Editing, all authors.

Chapter 3: Conceptualization, D.J.B., J.P.R.T., and R.A.M.; Data Curation, D.J.B., J.P.R.T., and B.M.; Formal Analysis, D.J.B. and J.P.R.T.; Writing – Original Draft, D.J.B. and J.P.R.T.; Review & Editing, all authors. This research was co-led by J.P.R.T and D.J.B. although the submission to the journal was led by J.P.R.T. and for this reason she is listed as first author.

Chapter 4: Conceptualization, D.J.B. J.W.B, R.J.S., and J.E.B.; Data Curation, D.J.B.; Formal Analysis, D.J.B; Writing – Original Draft, D.J.B; Writing – Review & Editing, all authors.

Chapter 5: Conceptualization, D.J.B., N.D.B. and A.W.; Original Draft, D.J.B., N.D.B. and A.W.; Review & Editing, all authors.

Abstract

Infrastructure development is fundamental for improving human well-being, but at the same time it can degrade natural habitats and ecological processes, leading to negative outcomes for biodiversity and people. In this thesis I study the tension between development and conservation, by examining a specific type of infrastructure development named Development Corridors. Development Corridors are national or transnational spatial development initiatives that include large infrastructure projects and associated industries, sometimes with accompanying policies, plans and programmes. I start by bringing some clarity to the development corridor terminology and then carry out a global review of biodiversity impact mitigation in development corridors. I show that Development Corridor approach is a widespread global phenomenon present in all continents except Antarctica. I find that best practice in biodiversity impact mitigation is rarely applied in the Development Corridor approach, as described in the literature. This includes a poor application of the mitigation hierarchy and very few assessments of indirect and cumulative impacts on biodiversity and ecosystem services. The rest of my thesis focuses on continental Africa as part of the Development Corridors Partnership (DCP) project. Collaborating with DCP researchers, I co-led the creation of the first African Development Corridors database and show that there were more than twice as many planned and ongoing Corridors in 2022 (79) compared to 2015 (33). I use this database to develop a spatially explicit framework to estimate indirect and cumulative biodiversity impacts from Development Corridors that considers existing pressures as well as potential new impacts. I then develop the Potential Impact Intensity metric to quantify the intensity of ecological impact due to either new infrastructure influence, existing pressures, or both. I calculate Potential Impact Intensity for all mapped planned and ongoing Development

Corridors and show significant risks for Protected and Conserved Areas and Key Biodiversity Areas across all Africa. Moreover, I find that indirect and cumulative impacts are likely to be significantly larger than direct impacts, up to 200% more. Finally, I focus on East Africa and lead a collaborative and multidisciplinary review of Development Corridor implementation challenges in Kenya and Tanzania based on DCP field and desk-based research. Overall, in this thesis, I find that neither the scientific nor grey literature provides sufficiently robust approaches to treating indirect and cumulative biodiversity impacts for projects in Development Corridors. However, I show that by taking a systematic and nuanced spatial approach, we can measure the potential spatial extent and order of magnitude of indirect and cumulative impacts to support comprehensive design of impact mitigation measures. Actions can then be taken at a policy level or on the ground level. Policy level actions are those that take place independently of project approval but that could have a strong influence in the approval processes (e.g. impact assessment regulations). On the ground actions are specific mitigation measures elucidated through impact assessment (e.g., wildlife crossings). This research has important implications for the practice of biodiversity impact assessment, specifically in informing Strategic Environmental Assessments and their necessary interaction with project level Environmental Impact Assessments.

Keywords: Development Corridors, Biodiversity Mitigation, Environmental Impact Assessment, Strategic Environmental Impact Assessment, Cumulative Impact Assessment, Cumulative impacts, Direct impacts, linear infrastructure.

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1. Chapter 1 Introduction

1.1. Conservation of nature and infrastructure development

Researchers and practitioners have long recognised the need to strike a balance between biodiversity conservation and human development (DeFries et al. 2004). This tension has deep historical roots. Concerns about forest depletion, wildlife decline, and soil degradation emerged soon after industrialisation accelerated resource extraction and land conversion at unprecedented scales (Adams 2004). However, the conservation movement has shifted in the way to approach the problem, from prioritising wilderness and intact natural habitats that excluded people in the first half of the 20th century, to a conservation paradigm where interactions between people and nature are at the centre (Mace 2014). This evolution has not been linear and intense debates about the paradigm that underscores nature conservation have continued to evolve to a range of different perspectives (Holmes et al. 2017; Sandbrook et al. 2019). In parallel, conservation policy has also evolved through a myriad of conventions and agreements, mostly emerging from the 1992 Rio Conventions (namely the Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, and the United Nations Convention to Combat Desertification), which have shaped regional and national legislation that focus on managing the impacts of human activity on nature (Clemencon 2012; Prip 2018).

Perhaps a milestone point of this evolution of policy and practice were the Sustainable Development Goals. In 2015 the United Nations member states agreed to the 2030 Agenda for Sustainable Development (United Nations 2015). It proposed 17 Sustainable Development Goals (SDGs) and 169 indicators to realise its vision for a prosperous and peaceful planet for people and nature. The SDGs comprise societal, environmental, and economic goals. Examples of societal goals include ending poverty (Goal 1), zero hunger (Goal 2), and gender equality (Goal 4). Environmental goals include Goal 15 which requires countries to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss", and a similar SDG for the sea (SDG 14).

Of the economic goals, Goal 9 is to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation". The term infrastructure refers to the facilities that allow humans to fulfil their need for power (e.g. coal, wind, solar, waves, power lines, oil pipelines, etc.), water (e.g. canals, dams, pipelines, etc.), transport (e.g. ports, roads, and railways), and telecommunications (e.g. internet cables) (Woetzel et al. 2016). Infrastructure development is considered a fundamental requisite to achieving other sustainable development goals (The Economist Intelligence Unit 2019). Similarly, environmental goals underpin the societal and economic goals (Folke et al. 2016). This is supported by the latest global assessment reports on biodiversity and ecosystem services by the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (Diaz et al. 2019), the UN Convention on Biological Diversity (Romanelli et al. 2015), and the UN Food And Agricultural Organisation (FAO 2019). Infrastructure development and ecosystem protection are therefore central to achieving sustainable development. However, meeting these conservation and infrastructure goals requires a complex balancing of socio-economic and political choices, which ultimately entails making spatially explicit decisions about how and where land is used.

1.2. The global infrastructure boom and Development Corridors

Taking a spatially explicit approach for economic development is not new. Spatial Development Initiatives (SDIs), which are defined as an agglomeration of economic activity in a specific location where businesses gain advantages through co-location, have been ongoing since the 1970s (Reeg 2017). Infrastructure development however has grown exponentially in the past 10 years to the extent to be called an *infrastructure tsunami* (Laurance 2010) or *global infrastructure boom* (zu Ermgassen et al. 2019). It includes proliferation of extractive industries, expansion or development of agricultural schemes, cities, resorts, and ambitious road and rail development plans, ports and transport hubs to serve them. When these infrastructure projects happen , under a spatially oriented and common economic development strategy, they are referred to as “development”, “resource”, “economic” or “growth” corridors (Laurance et al. 2015a; Nogales 2014; Hope and Cox 2015). The Belt and Road Initiative is an example of taking this concept to a planetary scale, as it is a prominent and ambitious Chinese economic and political programme comprising at least six Development Corridors across over 15 countries in Asia and Europe, and expanding collaborations to Africa and Latin America (BRI 2019). In total, 65 countries are actively engaging in the Belt and Road Initiative (Elish and AboElsoud 2024).

1.3. Development Corridors and the mitigation of their impacts on biodiversity

Development Corridors are designed and implemented through a number of development projects, mainly infrastructure projects at different points in time (Laurance et al. 2015a; Nogales 2014; Hope and Cox 2015). The differing nature and variety of scope and scale of these projects require careful consideration on the likely effects of these initiatives on people and nature. Regarding biodiversity, there is ample evidence of the negative effects of infrastructure development on species and ecosystems (Forman et al. 2015; van der Ree et al. 2015). These include habitat fragmentation (Forman and Alexander 1998; Bennett 2017), wildlife mortality (Benítez-López et al. 2010; Denneboom et al. 2024), wildlife disturbance (Shannon et al. 2016), pollution and spread of invasive species (Trombulak and Frissell 2000), land use change facilitated by improved access (Laurance et al. 2014), and cumulative landscape degradation due to accumulation of impacts (Whitehead et al. 2017). The impacts on biodiversity from the proliferation of Development Corridors have also been the focus of a number of publications (Laurance et al. 2015a; Hughes 2019; Sloan et al. 2019; Mahmoud et al. 2017; Alamgir et al. 2017). Beyond Development Corridors, recent evidence suggests that planetary scale initiatives such as China's Belt and Road Initiative have contributed to significant ecological degradation over the past 10 years in Africa (Elish and AboElsoud 2024).

In most countries there are national legal regulatory frameworks and processes in place to manage impacts of economic development activities on the biodiversity and people, and these apply to development corridors projects. Environmental Impact Assessment (EIA) and, less so, Strategic Environmental Assessment (SEA) are commonly used instruments in national legislation (UNEP 2018). The first one deals with social and environmental impacts at a project level, while SEA is focused on the potential impacts of policies, plans and programmes (OECD 2006). Over the years, some financial institutions have added additional processes to manage their social and environmental risks. The International Finance Corporation, the European Bank for Reconstruction and Development, the Asian Development Bank and the

InterAmerican Development Bank all have developed environmental and social performance standards, which aim to minimise the risks and maximise the opportunities from their investments and include policies that specifically address impacts on biodiversity. A notable example is the International Finance Corporation Performance Standard 6 for Biodiversity Conservation and Sustainable Management of Living Natural Resources (IFC PS6), which is recognised as a benchmark for biodiversity impact mitigation (IFC 2012).

In parallel, the use of decision making to guide the management of biodiversity impact frameworks such as the mitigation hierarchy (Bigard et al. 2017), and the publication of corporate commitments to achieve no net loss or net gain of biodiversity in projects or production of commodities with minimal impacts (i.e. zero deforestation) are becoming mainstream in large corporates (Bull and Strange 2018). Specifically, the mitigation hierarchy is a central framework to manage impacts on biodiversity from development and potentially for aspiring to achieve positive outcomes for nature and people (Arlidge et al. 2018; Jones et al. 2019; Maron et al. 2020; Griffiths et al. 2019; Bull et al. 2020). It generally includes four steps to manage impacts on biodiversity: avoid, minimise, restore and compensate or offset. Each of these steps are planned and implemented to ensure that either no biodiversity is lost in the life cycle of the project in relation to a baseline (No Net Loss) or more biodiversity is created after the project (Net Gain). However, achieving no net loss and net gain has not been free of controversy (Maron et al. 2018), especially in relation to biodiversity offsetting (Gardner et al. 2013). Maron et al. (2018) refer to issues with reference scenarios under which No Net Loss is measured. Gardner et al. (2013) discuss the difficulties to design and implement biodiversity offsets that deliver the desired outcomes. Despite these controversies, the mitigation hierarchy remains a widely accepted and effective impact management framework to achieve better biodiversity outcomes in development projects (Damiens et al. 2021; Kiesecker et al. 2010; Bull et al. 2013).

The impacts of development corridors on biodiversity have been quantified to an extent as described above. However, it is unclear which approaches and tools have been used to assess these impacts and whether these align with best practice. Moreover, fundamental to an effective application of mitigation hierarchy is to account for all impacts that need to be avoided and mitigated (CSBI & TBC 2015). Considering the existing impact assessment frameworks and tools summarised above, in the Development Corridors literature there seems to be a focus on assessing the direct footprint of the projects only and on creating buffers from the source of impacts to account for other indirect impacts. This results in a lack of emphasis on solutions, as there are few spatially explicit impact analyses at an appropriate scale that could allow a more comprehensive quantification of potential biodiversity losses. This is key for the identification of specific actions on the ground to manage biodiversity impacts, and possibly of key importance in the case of Development Corridors were accumulation of impacts across the landscape are likely. In this context, ‘Death by a thousand cuts’ means that many individual impacts or stressors, when accumulated over space and/or time, produce large, possibly irreversible environmental degradation (Laurance 2010; Noble 2010). However, in the case of Development Corridors, the infrastructures proposed are often large national or transnational major projects that could have the same devastating results in just a dozen cuts.

1.4. Thesis goal and objectives

This thesis started as part of the Development Corridors Partnership project (hereafter referred as DCP) which funded the time, travel, and expenses to carry out most of the research. DCP was a 4-year research and capacity building project (December 2018 to December 2022) looking at the effects on nature and people from Development Corridors in Kenya and Tanzania. Its main research question was "How can Development Corridors be designed and implemented to deliver sustainable, inclusive and resilient economic growth?". Around 50 researchers (including Masters students, PhD students and post-doctoral scientists) from 11 organisations explored this question from different angles with the goal of building local capacity to address the key issues identified (See Chapter 5). This thesis builds on the scientific literature introduced above and the goal of this thesis is to contribute to advance the science of assessing the impacts of landscape scale development, by investigating ways to quantifying direct, indirect, and cumulative impacts on biodiversity from multiple projects within Development Corridors Africa.

The objectives of this research are to:

- Evaluate the state of scientific knowledge on biodiversity mitigation approaches for managing the impacts of Development Corridors. This includes identifying key issues and gaps for effective impact mitigation and investigating what other approaches not used specifically for Development Corridors could be adapted to be useful in this context.
- Building on this evaluation of the scientific knowledge, develop pragmatic and repeatable analytical frameworks and tools to quantify potential impacts for multiple projects and

Development Corridors interacting in the same landscapes, considering direct, indirect and cumulative impacts.

- Understand how Development Corridor proponents design, implement, and monitor Development Corridors, based on in-depth case studies from Kenya and Tanzania.

Figure 1.1 presents a conceptual framework linking these objectives into a logical workflow within the structure of the thesis.

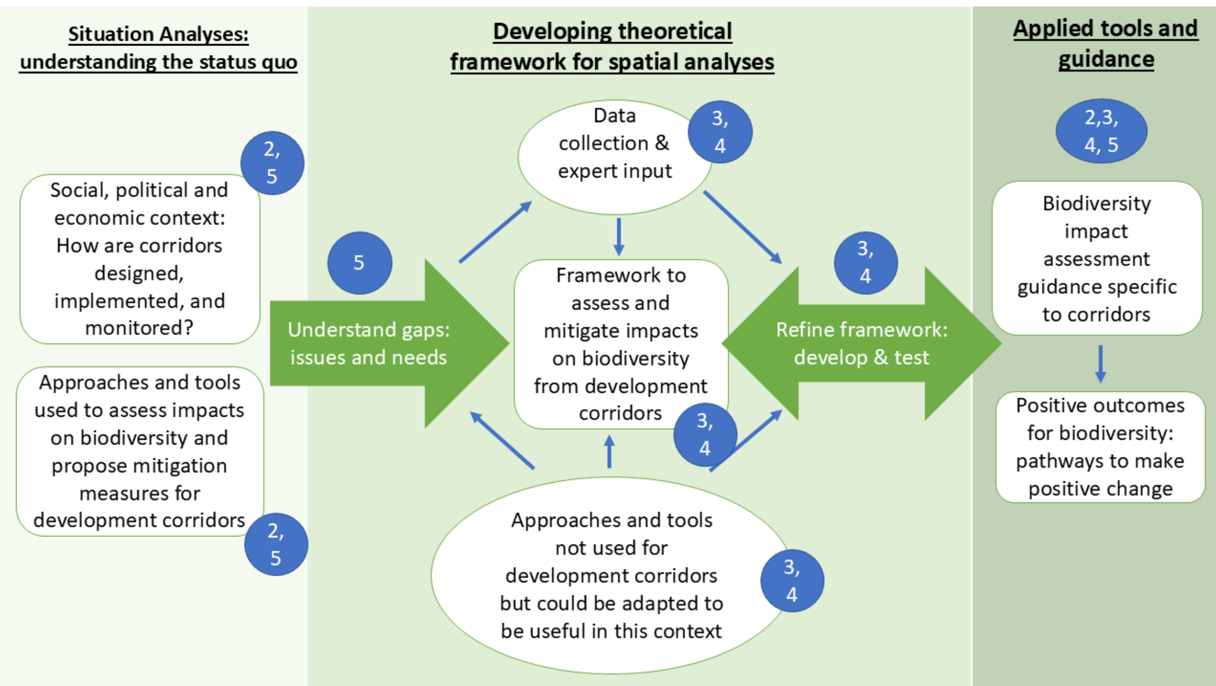

Figure 1.1 Conceptual framework of this thesis and related chapters (blue circles).

1.5. Thesis outline

This thesis has a strong focus on developing theoretical frameworks and applied tools for spatially explicit impact assessment and consists of the following chapters:

Chapter 2. Mitigating the Impacts of Development Corridors on Biodiversity: A Global Review. Published in Frontiers in Ecology and Evolution.

https://doi.org/10.3389/fevo.2021.683949

Chapter 3. The African Development Corridors Database: a new tool to assess the impacts of infrastructure investments. Published in Nature Scientific Data.

https://www.nature.com/articles/s41597-022-01771-y

Chapter 4. Exploring indirect and cumulative impacts on nature from infrastructure development.

Chapter 5. Towards more sustainable and inclusive Development Corridors in Africa. Published in Environmental Research: Infrastructure and Sustainability.

https://iopscience.iop.org/article/10.1088/2634-4505/ad7887

Chapter 6. Discussion: Review of key findings, results and relevance of this thesis, further research needed, and final conclusions.

2. Chapter 2 Mitigating the Impacts of Development Corridors on Biodiversity: A Global Review

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Manuscript published as: Juffe-Bignoli D, Burgess ND, Hobbs J, Smith RJ, Tam C, Thorn JPR and Bull JW (2021). Mitigating the Impacts of Development Corridors on Biodiversity: A Global Review. Front. Ecol. Evol. 9:683949. Doi: 10.3389/fevo.2021.683949

Abstract

Development Corridors are extensive, often transnational and linear, geographical areas targeted for investment to help achieve sustainable development. They often comprise the creation of hard infrastructure (i.e., physical structures) and soft infrastructure (i.e., policies, plans, and programmes) involving a variety of actors. They are globally widespread, and likely to be a significant driver of habitat loss. Here, we describe the Development Corridors phenomenon from a biodiversity perspective and identify the elements of best practice in biodiversity impact mitigation. We use these to carry out a review of the peer reviewed literature on corridors to respond to three questions: (i) how impacts on biodiversity and ecosystem services are assessed; (ii) what mitigation measures are discussed to manage these impacts; and (iii) to what extent do these measures approximate to best practice. We found that of 271 publications on Development Corridors across all continents (except for Antarctica) mentioning biodiversity or ecosystem services, only 100 (37%) assessed impacts on biodiversity and 7 (3%) on ecosystem services. Importantly, only half of these (52, 19% of the total 271 articles) discussed mitigation measures to manage these impacts. These measures focused on avoidance and minimisation and there was scant mention of restoration or ecological compensation illustrating a deficient application of the mitigation hierarchy. We conclude that the academic literature on corridors does not give sufficient consideration to comprehensive mitigation of biodiversity impacts. To change this, impact assessment research needs to acknowledge the complexity of such multi-project and multi-stakeholder initiatives, quantify biodiversity losses due to the full suite of their potential direct, indirect and cumulative impacts, and follow all the steps of the mitigation hierarchy impact framework. We suggest a series of

research avenues and policy recommendations to improve impact assessments of corridors towards achieving better biodiversity outcomes.

2.1. Introduction

2.1.1. Infrastructure, Biodiversity, and the Sustainable Development Goals

In 2015, all United Nations member states agreed to the 2030 Agenda for Sustainable Development (United Nations General Assembly 2015). The Agenda proposes 17 Sustainable Development Goals (SDGs) and 169 indicators to realise its vision of a prosperous and peaceful planet for people and nature. Goal 9 calls to "build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation." The term infrastructure refers to the facilities that allow humans to fulfil the need for energy (e.g., coal, wind, gas, solar, hydropower, waves, power lines, oil, and gas pipelines), water (e.g., canals, dams, pipelines), transport (e.g., ports, roads, railways), and telecommunications (e.g., internet cables) (Woetzel et al. 2016). Infrastructure development is considered a fundamental requirement to help achieve other SDGs (The Economist Intelligence Unit 2019). Similarly, environmental goals underpin societal and economic goals (Folke et al. 2016), as supported by the latest Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services global assessment report (IPBES 2019), UN Convention on Biological Diversity (Romanelli et al. 2015; CBD 2020), and UN Food and Agricultural Organisation (FAO 2019). Balancing infrastructure development and biodiversity conservation goals is therefore central to achieve sustainable development but also involves socio-economic and political choices on how land is used, with likely trade-offs with other objectives.

2.1.2. What Is a Development Corridor?

The current and ongoing global expansion in infrastructure development has been described as an "infrastructure tsunami" (Laurance 2010) or a "global infrastructure boom" (zu Ermagssen 2019). When these infrastructure projects are implemented, usually under a spatially oriented and economic development strategy, they are referred to as "development," "resource," "economic," or "growth" corridors (Nogales 2014; Hope and Cox 2015; Laurance et al. 2015a; Reeg 2017; Schindler and Kanai 2021). Notable examples are the 33 corridors in Africa potentially crossing 400 protected areas (Laurance et al., 2015), or initiatives in Latin America, Asia, Europe, and Oceania (Nogales 2014; Hope and Cox 2015; Laurance et al. 2015a; Reeg 2017; Schindler and Kanai 2021; Sloan, Campbell, et al. 2019). The Belt and Road Initiative is an example of this concept being taken to a global scale: a Chinese economic and political programme which was launched in 2013, comprising at least six interconnected corridors across the land and sea and over 15 countries in Asia and Europe (Belt and Initiative 2019), and has now has expanded to 140 countries including Sub-Saharan Africa, Latin America, and the Caribbean (BRI 2021).

Although the term "Development corridor" has been often used as an umbrella term for these initiatives (Mulenga 2013; Laurance et al. 2017; Enns 2018; Collinson et al. 2019; Dong et al. 2019; Heinicke et al. 2019; Sloan, Alamgir, et al. 2019; Müller-Mahn 2020), corridor terminology is diverse, not standardised, and it depends on the purpose of the corridor, the actors involved, and the stage at which it is. As such there are transport, trade, utility, agricultural, or resource corridors, among others (Nogales 2014; A. Hope and Cox 2015; The Development Corridors Partnership 2022). Although they may start as such, in the long term these are not individual isolated projects. They usually comprise several infrastructure projects that serve to link growth nodes or anchor projects with urban centres, markets and/or points of imports and exports, such as ports. Mulenga (2013) uses the terms Development Corridors and economic corridors interchangeably as "the concept of using transport corridors as a means to develop the regions around the corridors." Hope and Cox (2015) propose planning development corridor as a systematic process which may start with a transport corridor but then evolves into a more complex economic corridor as different infrastructure, programmes, plans, and policies are incorporated. Nogales (2014) agrees, but employs the term "growth corridor" and proposes to use Spatial Development Initiates (SDI) as an umbrella term for all types of corridors (i.e., an agglomeration of economic activity in a specific location where businesses gain advantages through co-location; see Reeg, 2017). Therefore, crucially, Development Corridors are not static entities but rather a process which evolves towards a coordinated spatial development strategy with multiple stages—each involving different objectives and stakeholders.

Here we define Development Corridors as large, often transnational and linear, geographical areas targeted for investment under a spatially oriented and common economic strategy towards achieving long-term sustainable development. To avoid confusion, in this article we use the term "Development Corridors" to refer to all corridors, but we recognise and reflect on the varied terminology and complex nature of these initiatives (see Box 2.1).

We propose four broad ideal stages that should be common to all Development Corridors : concept planning, approval, implementation, and monitoring, and evaluation (Box 2.1 and Figure .1A). In addition to these four stages, Development Corridors tend to evolve from simpler initiatives to a spectrum of different types of more complex Development Corridors (Nogales 2014; Hope and Cox 2015; Reeg 2017). For example, a road or railway connecting key cities or trade hubs to resources is initially considered as a transport corridor and, as hard and soft infrastructure are created and other economic and non-economic dimensions are integrated into the system, it can evolve into a logistics corridor, and economic corridor or true development corridor (Box 2.1 and Figure .1B).

2.1.3. Best Practice in Biodiversity Impact Mitigation

The most widely used tool to assess and mitigate the impacts of development activities on the environment at a project level is Environmental Impact Assessment (EIA), adopted as a national legal instrument by 180 countries and territories (Craik 2019). At the strategic planning level, at least 40 countries had Strategic Environmental Assessment (SEA) legislation in place (UNEP 2018). The scope of an SEA is broader than that of an EIA and refers to "a range of analytical and participatory approaches that aim to integrate environmental considerations into policies, plans and programmes and evaluate the interlinkages with economic and social considerations" (OECD 2006). SEAs are thus more directly relevant to Development Corridors although each individual project within a corridor will need to have an EIA mandated by local regulations.

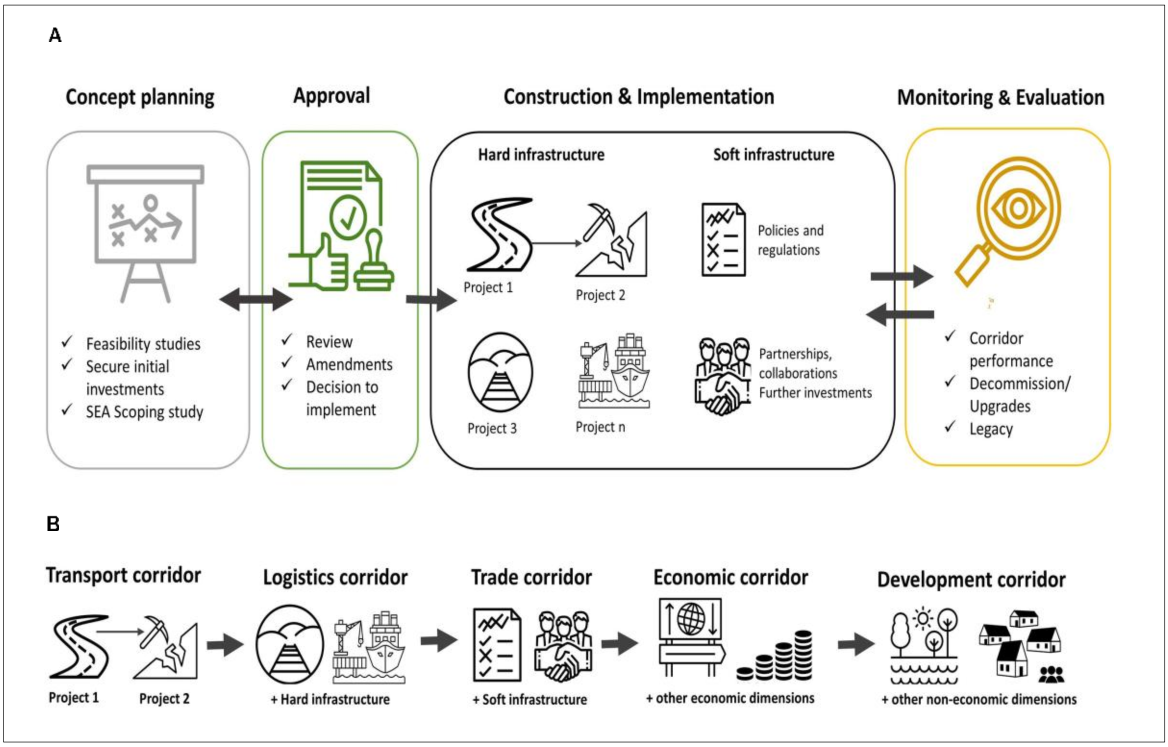

Figure 2.1 Main phases of a development corridor

(A)*Each individual project in the construction and implementation phase will have its own project cycle phases (i.e., conception, design, execution, operation, upgrade, closure, or decommission). Specific project level surveys, baseline assessments, feasibility studies, and EIA are conducted for each of those projects following the laws and regulations of the countries where they are implemented and complying with the standards and procedures required by lenders.* ***(B)*** *A simplified example on how a transport corridor may evolve to a development corridor as hard and soft infrastructure and other economic and non-economic dimensions are incorporated (adapted from Nogales, 2014 and Hope and Cox, 2015). (A) Attributions for icons. Concept planning: created by jokokerto; Approval: created by Template; Road: Created by art shop; Mining: created by Hamed; Port: Created by ATOM; Railway: created by Sedlac; Policies & Regulations: created by Becris; Partnerships and collaboration: created by Priyanka; Monitoring & evaluation: created by JunGSa. (B) Attributions for icons. Road: Created by art shop; Mining: created by Hamed; Railway: created by Sedlac; Port: Created by ATOM; Policies & Regulations: created by Becris; Partnerships and collaboration: created by Priyanka; Trading: created by Made; Investment: created by gilbert bages; Ecosystem: created by Made x Made; Village: created by Martina Krasnayova; People: created by Support Designs.*

Box 2.1 Key phases and evolution of Development Corridors.

1. **Concept planning:** The aim of concept planning is to determine whether the proposed development corridor in a country or region is economically, social and environmentally viable, which is often led by government agencies and financial institutions. When an agreement is reached, feasibility and scoping studies are conducted, key initial projects are identified, initial stakeholder consultations take place, and key initial investments are secured, ideally conducted under a SEA framework. Here, risks and potential significant biodiversity impacts should be identified, and plans made for minimisation, restoration, and compensation. The most important mitigation strategy in this phase is avoidance. Concept planning is finalised when the development corridor initiative is approved.
2. **Approval:** Approval to undertake the initiative occurs when assessments (e.g., scoping, feasibility, EIA, SEA reports) and plans developed in the first phase should be scrutinised for compliance with legal and lender requirements. If some changes are required, the process could come back to phase one (concept planning). If the initiative is not approved the process ends or is put on hold.
3. **Construction and implementation:** Implementation involves the construction of the development corridor. Ideally this phase is coordinated by designated authorities which could be a new or an existing institution (e.g., Lamu Port, South Sudan, Ethiopia Transport corridor (LAPSSET) is coordinated by the LAPSSET authority). Agreed design and plans are implemented through hard and soft infrastructure supported by further investment. Hard infrastructure refers to several physical projects that compose the corridor, implemented sequentially or at different times (e.g., a road to a mined area, a dam, or railway). Each individual project will require an EIA according to the law in the country where it is proposed, with its own phases: from conception, design, execution, operation, and upgrade or closure or decommission (CSBI, 2013). Soft infrastructure refers to the policies, regulations, partnerships and collaborations that need to be put in place to facilitate implementation of the development corridor. The implementation phase is typically when the majority of beneficial and detrimental impacts on biodiversity actually occur, but not necessarily when they can be mitigated. Rather, phases 1 and 2 represent the best opportunities for impact avoidance. Implementation may last for many years or constantly evolve as some operational projects are decommissioned or closed, others are expanded or upgraded, or new projects are proposed and developed. The most important mitigation strategies during implementation are avoidance and minimisation, and in this phase, restoration and compensation measures commence.
4. **Monitoring and evaluation:** This phase involves tracking the economic, social, and environmental performance of the development corridor and its individual projects through the indicators identified in previous phases. Evidence of positive and negative impacts are documented as in post development audits. Monitoring and evaluation should be led by designated corridor authorities and lenders and government agencies of individual projects, and it should start with implementation. Most significant impacts have occurred or are ongoing and monitoring of minimisation measures are place. It is in this phase when it can be assessed how well the predictions and recommended management measures perform in practice and ideally apply the necessary corrections. The main mitigation strategies here are restoration and compensation.

In addition to what is required by national law, the use of decision-making frameworks is becoming mainstreamed in policy for governments, lender, and multinational corporations. One such framework is the mitigation hierarchy, which guides the management of biodiversity and people impacts from development (CSBI & TBC 2015; Bigard et al. 2017), supports corporate commitments to achieve no net loss, or net gain of biodiversity in projects' lifecycles or commodity production (Bull and Strange 2018; Silva et al. 2019). Achieving no net loss for biodiversity means that the implementation of a project has not resulted in net biodiversity loss in comparison to an established baseline or counterfactual. Net gain proposes going even further so that new biodiversity is created through the life cycle of the project. The mitigation hierarchy is central to achieve these objectives and ultimately seen as a path towards better outcomes for biodiversity and people (William et al. 2018; Jones et al. 2019; Griffiths et al. 2019; Maron et al. 2020; Bull et al. 2020). It proposes four sequential but iterative stages, typically phrased as: avoid, minimise, restore, and offset. Avoid and minimise are preventive actions which focus on anticipating and preventing an impact, while restore and ecological compensation are remediative actions which aim to repair existing impacts (CSBI & TBC 2015).

More importantly, over the past decades financial institutions have developed environmental and social performance standards, aimed to minimise the risks and maximise opportunities of their investments, some of which specifically address impacts on biodiversity and ecosystem services. A well-recognised example of such a standard is the International Finance Corporation Performance Standard 6 or IFC PS6 (IFC 2012). To provide funding, the IFC PS6 requires that projects should assess direct impacts (direct footprint of a project), indirect impacts (not directly attributed to a project but caused indirectly by the project), and cumulative impacts (interactions between other projects in the landscape plus other external pressures) on biodiversity (IFC 2013). IFC PS6 then requires impact mitigation measures to be put in place, such that the net outcome is no net loss and net gain for biodiversity to be achieved (IFC, 2012). PS6 is seen as an example of best practice in biodiversity impact mitigation (Narain et al. 2020). However, a study on best-practice on biodiversity safeguards for the Belt and Road Initiative's financiers revealed that most associated lenders do not follow such best practice (Narain et al. 2020). Moreover, there is no consensus around common standards and sustainability metrics for infrastructure development, as shown in a review of 12 sustainability standards for financing infrastructure (Bennon and Sharma 2018).

The impacts on biodiversity from the proliferation of Development Corridors have been highlighted for the African continent (Laurance et al. 2015a), Indonesia (Sloan et al. 2019), Papua New Guinea (Sloan et al. 2019), and the Belt and Road Initiative (Ascenscao et al. 2018; Hughes 2019), among others, revealing significant risks for biodiversity conservation in the long-term. Although fundamentally important in raising awareness, such studies scarcely detail which methods and approaches are being used or proposed to assess impacts of these developments and recommendations on specific mitigation measures. More importantly, it is not clear the extent to which existing research on Development Corridors follows best practice frameworks and tools mentioned above, despite them becoming mainstream in sustainability standards and corporate commitments. Given the wide geographic scope, the global proliferation of these initiatives, and their particular complexity (i.e., many ongoing projects and numerous stakeholders involved), there is a need to better understand how they develop and, more importantly, how impacts they have on biodiversity and ecosystem services (if any) are being assessed and managed.

Here, we describe corridors from a biodiversity perspective and identify the elements of best practice in biodiversity impact mitigation, considering related ecosystem services where possible. We focus on the specific nature of these complex initiatives acknowledging that the science to understand and manage the impacts of individual infrastructure projects has many years of history (Spellerberg and Morrison 1998) and is well-advanced, especially for roads (Coffin 2007; Fahrig and Rytwinski 2009; van der Ree et al. 2015; Forman et al. 2015; Bennett 2017; Collinson et al. 2019) but also railways (Barrientos et al. 2019; 2017). Here we are particularly interested in Development Corridors more broadly and how impacts on biodiversity are assessed and what mitigation measures (if any) are proposed. Applying a Rapid Evidence Assessment of peer-reviewed publications on corridors and biodiversity impact mitigation, we therefore aim to: (i) understand how impacts on biodiversity and ecosystem services are assessed; (ii) document the mitigation measures proposed to manage these impacts; and (iii) assess how these approximate to best practice. We then discuss key gaps identified, explore alternatives to fill these with existing tools and approaches, and put forward policy relevant recommendations.

2.2. Methods

We carried out a Rapid Evidence Assessment (Collins et al. 2015) to compile academic articles that assessed impacts of biodiversity and ecosystem services from the specific case of corridors. Whether approved impact assessments linked to existing corridors followed best practice was out of the scope of this study. There is evidence that formal impact assessments often lack enough detail on biodiversity impact mitigation (Bigard et al. 2017; Simmonds, Reside, et al. 2020) and specific guidance to better integrate biodiversity into impact assessment has been developed to fill in this gap (Secretariat of the Convention on Biological Diversity and Netherlands Commission for Environmental Assessment 2006).

The review was conducted following three main steps (Figure 2.2): (i) use of specific search terms in the title, abstract, or key words to find relevant articles in the Scopus and Web of Knowledge Core Collection databases in all languages from when records are available up to December 2020; (ii) apply inclusion and exclusion criteria to all titles and abstracts found; and (iii) code full articles included in the review.

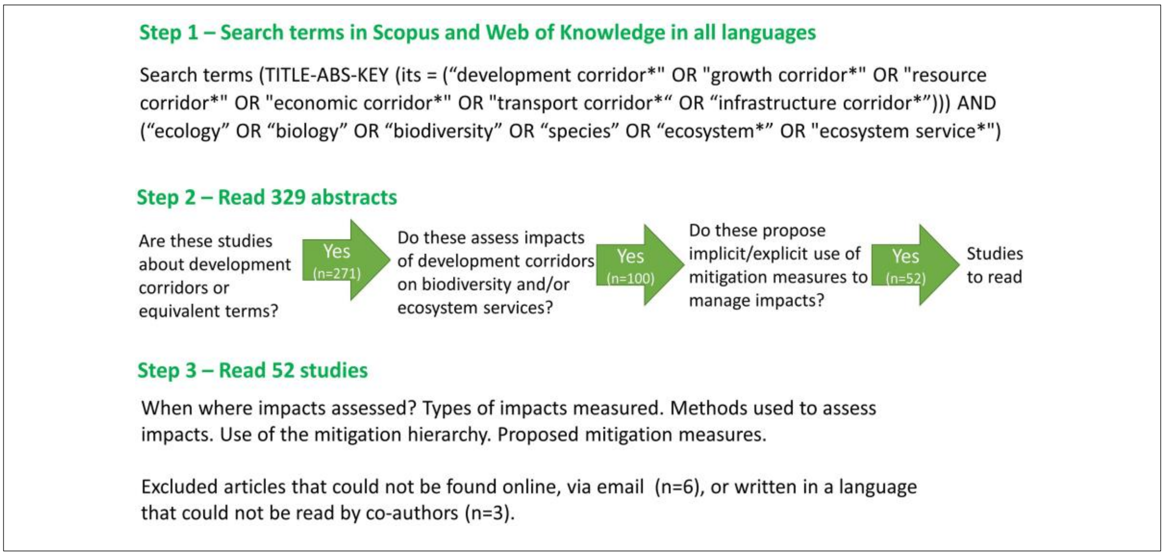

Figure 2.2 Steps of rapid evidence review including search terms, screening and inclusion and exclusion criteria.

The search terms were related to corridors terminology with a focus on biodiversity and ecosystem services (Figure 2.2, Step 1). The most commonly used terms were compiled from expert opinion through 3 years of work in the Development Corridors Partnership project between 2018 and 2020 (DCP, 2021). The results from Scopus (n = 347) and Web of Knowledge (n = 82) were combined to eliminate duplicates (n = 329) and screened at title and abstract level for three inclusion criteria (Figure 2.2, Step 2). Our search did not capture impact assessment studies of individual projects, because our interest was to find studies considering the specific nature of corridors not individual projects within them. However, we acknowledge these studies might have applied best practice. We address this gap in the discussion by identifying other methodological approaches not yet applied to corridors specifically but that could prove useful in this context. We excluded articles that: were not about Development Corridors (i.e., despite using similar terms, such as transport corridors of sediments or develop greenways for sustainable urban transport); or where corridors were not the primary focus of the research (Figure 2.2).

For studies included in the review, we extracted data on the country, countries, or regions (i.e., more than one country included in the same article) of the corridors studied, stage of the corridor addressed, metrics used to measure biodiversity and ecosystem services, and methodological aspects related to best practice in impact mitigation outlined in Table 2.1. In this step we excluded articles that could not be found to be read due to not being accessible online, and those written in a language that could not be read by the authors.

Table 2.1 Methodological aspects of biodiversity mitigation evaluated for studies screened at full text level.

Coded variables	**Best practice recommendation**	**Definitions and scope of assessment**
When were impacts assessed	Assess potential impacts in early stages of development to avoid significant impacts before the projects start.	· Stage of corridor when impacts were assessed. · Assessment completed before (ex-ante) or after (ex post) construction of a project within a corridor.
Types of impacts measured	Account for all potential direct, indirect, and cumulative impacts associated to development.	We searched for three types of impacts on biodiversity (BBOP, 2018): · Direct impacts: impact directly attributable to a defined action or project activity (e.g., a road) · Indirect impacts: impacts triggered in response to the presence of a project, rather than being directly caused by the project's own operations (e.g., habitat loss due to population increase caused by the presence of the road). · Cumulative impacts: total combined impact arising from another project (under the control of the developer); other activities (that may be under the control of others, including other developers, local communities, government), and other background pressures and trends which may be unregulated (e.g., other roads, other causes of population growth resulting in additional impacts, climate change impacts, etc.).

Methods used to assess impacts	Select appropriate metrics to account for all biodiversity losses due to development, including assessments of biodiversity extent and condition.	· Metrics used to measure biodiversity impacts. · Use of geographically referenced data and/or spatial analyses tools to assess impacts. · Techniques and combinatorial tools used to assess impacts for spatial and non-spatial analyses (e.g., modelling, buffer overlaps, field data collection, stakeholder surveys).
Use of the mitigation hierarchy	Follow all phases of the mitigation hierarchy (avoid, minimise or reduce, restore or rehabilitate, offset or compensate) to manage impacts of development and aim for no net loss or net gain of key biodiversity.	· Explicit use: publications mentioning or using the mitigation hierarchy as a framework to manage impacts. · Implicit use: publications mentioning phases of the mitigation hierarchy and/or actions that equal to mitigation hierarchy actions. · No mention of the mitigation hierarchy
Proposed mitigation measures	Consider existing biodiversity impact mitigation policies and develop strategies and action plans focusing on priority biodiversity elements and identify specific management actions. Monitor performance and impacts and do adaptive management.	· General to specific measures proposed to manage impacts on biodiversity. · In which phases of the mitigation hierarchy were those measures proposed. · Proposed indicators to monitor impacts and mitigation management.

2.3. Results

We found 271 articles about Development Corridors published from 1971 to 2020, 73% in the past 5 years. Of these, 196 articles studying one specific development corridor and 75 looking at multiple corridors. In total 94 individual corridors were studied across all articles. The term economic corridors was the most used, followed by transport corridors and Development Corridors (Figure 2.2). Other terms used in the articles included growth corridor tourism corridor, infrastructure corridor, and to a less extent scenic conservation corridor, resource corridor, and agricultural corridor.

Of the 271 articles, 189 were country level analyses and 82 transnational level (more than one country) studies. The geographic focus was biased towards Asia (n = 127, 47%), followed by Africa (n = 40, 15%), Europe (n = 29, 16%), and then Oceania and North America with 7 and 5%, respectively (Figure 2.3Figure). There were two studies in Central America, and no studies in South America. Over 70% of the studies were country specific (n = 189, 72%), covering a total of 45 countries (Figure 2.3) while 30% took a regional approach. The country with the most articles was Pakistan (n = 46) followed by Australia with 15 and Russia and Tanzania with 11 each. All of the Pakistan case studies were about the Belt and Road Initiative, which in total was the focus of 25% of the studies (n = 68).

2.3.1. Assessment of Impacts on Biodiversity and Ecosystem Services

Of the included 271 articles, 37% (n = 100) assessed the impacts of corridors on biodiversity but only seven assessed impacts on ecosystem services. Thirty-seven per cent (n = 37) of assessments were conducted in the conception planning stage of a corridor (Figure 2.3). Of these 74% where country case studies across 33 countries (Figure 2.4). The reduction of studies assessing biodiversity or ecosystem services impacts from 271 to 100 articles was particularly prominent in Africa (75% reduction), Asia and Latin America (over 60% reduction each). The number of countries represented went down from 45 to 33.

Over half of studies used either ecosystems (37%) or species (25%) to measure impacts on biodiversity. Fewer publications (14%) used a mix of biodiversity metrics combining species, protected areas or other important conservation areas (e.g., Mahmoud et al., 2017; Laurance et al., n.d.; Sloan et al., 2019a). Notably, 14% of studies assessed impacts on the environment not using any specific quantitative metrics related to biodiversity. This includes measuring pollutants generated (Valentukeviciene and Ignatavicius, 2011) but not linking these to biodiversity impacts, or changes on different land uses over time which could or could not relate to biodiversity loss and degradation (Subasinghe et al., 2016). The three studies assessing impacts on ecosystem services were specifically on water quality (Valentukeviciene and Ignatavicius, 2011; Er et al., 2014) and carbon sequestration (Chen et al., 2017). There were four studies that used carbon emissions as an environmental impact metric but did not focus on ecosystem services.

2.3.2. Biodiversity Mitigation Measures in Corridors

Of the 100 studies assessing impacts on biodiversity and ecosystem services, 61 proposed mitigation measures. The studies that did not comply this inclusion criteria only assessed trends or impacts of land use or biodiversity change but did not propose or discuss explicitly or implicitly any mitigation measures. In addition, we excluded studies that could not be found (n = 6), and those written in a language that could not be read by the authors (n = 3), leaving 52 studies to be fully read.

These final 52 studies account for 19% of the initial 271 studies on corridors. While the number of studies decreased, from 271 to 52, the geographical coverage remained similar with Europe as the second continent with more studies followed by Oceania and Africa (Figure 2.4). At a country level, case studies from 19 countries were excluded as they did not propose any mitigation measures leaving a total of 45 studies across 26 countries (Figure 2.4). 34 of these 52 publications used spatially explicit methods and modelling techniques were the most used (Figure 2.5). The modelling was used to assess impacts on ecosystems, species, land use or from invasive species. Seventeen studies used more simple techniques, such as assessing linear proximity and overlaps with the planned corridor footprint or overlaps with a buffer created around the corridor. Eleven studies based their impact assessment on data collected through field surveys. Non-spatial methods were qualitative assessments of impacts (10) and mainly reviews of existing research (3), with no actual quantification of impacts. Notably, two indicator prioritisation studies selected best indicators to monitor corridor performance (Zhang et al., 2017; Yogeswari and Bala Keerthana, 2019).

Sixty-two percent of the articles only assessed direct impacts on biodiversity. Those which assessed indirect impacts as well (37%) evaluated linear proximity or overlaps with buffers drawn from the main linear infrastructure of the corridor (Laurance et al., 2015; Mahmoud et al., 2017; Sloan et al., 2019b), by measuring land cover changes over time in the area of influence of the corridor (Petty et al., 2012; Villarreal et al., 2013; Wilson et al., 2013), or combining both (Heinicke et al., 2019).

The application of the mitigation hierarchy was explicitly mentioned in only two studies (Bastille-Rousseau et al., 2018; Heinicke et al., 2019). Similarly, we found no studies that assessed restoration or offsets alternatives for corridors nor any discussion or evaluation of no net loss or net gain achievement, although the existence of these approaches was briefly mentioned in some of them. There was, however, implicit use of the mitigation hierarchy in other studies proposing minimisation measures (56%) and avoidance (21%). The remaining 23% combined avoidance and minimisation measures. The main avoidance action proposed was to not develop infrastructure in important places for biodiversity (e.g., Laurance et al., 2015; Pomazkova et al., 2019). Regarding minimisation, most measures were species specific (e.g., moose (Wierzchowski et al., 2019), West African chimpanzees (Heinicke et al., 2019), elephants (Bastille-Rousseau et al., 2018), or invasive species (Liu et al., 2019)], while one study proposed minimisation measures for several species (Cserkész and Farkas, 2015). Only one study was found that assessed direct, indirect, and cumulative impacts (Lechner et al., 2017).

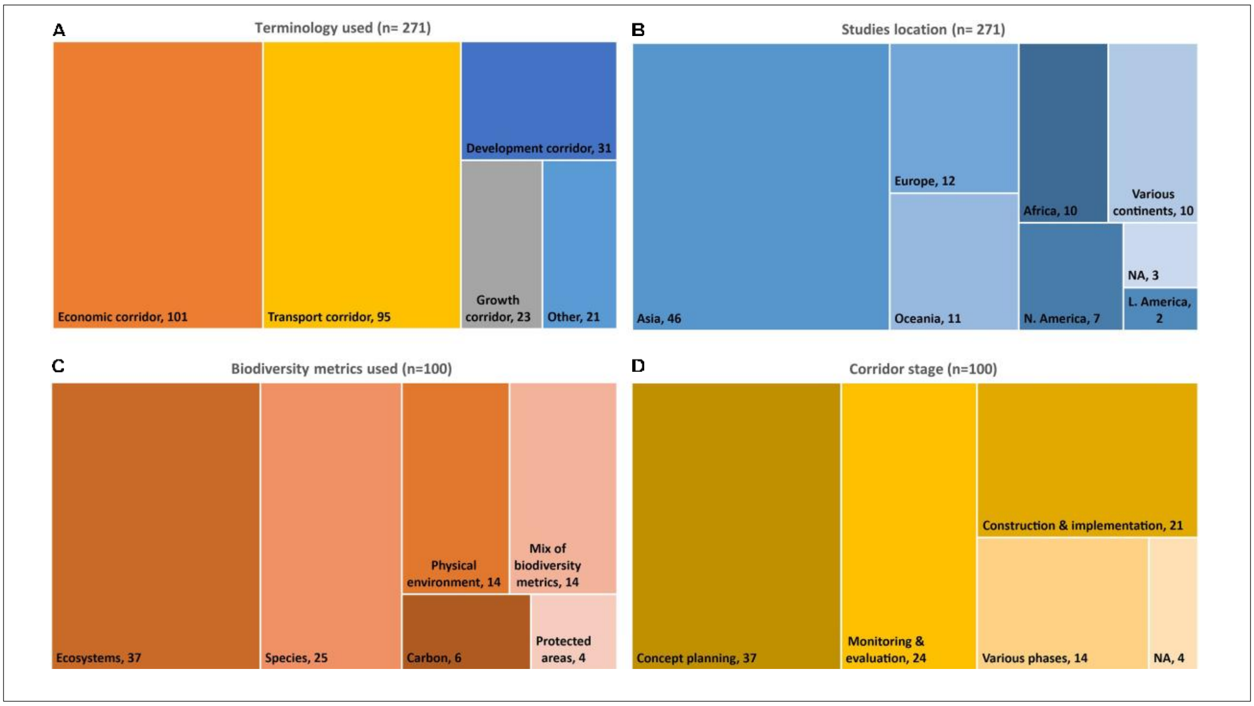

Figure 2.3 Number of articles classified as (A) terminology used, (B) continental coverage, (C) metrics used, and (D) stage of corridor when assessment was conducted. n = 271 includes all abstracts that mentioned corridors in any of the search terms (Step 1). n = 100 includes abstracts where impacts on either biodiversity or ecosystem services were assessed (Step 2). NA = not applicable when the studies did not focus on a specific geographic location or when the corridor stage was not a consideration of the study.

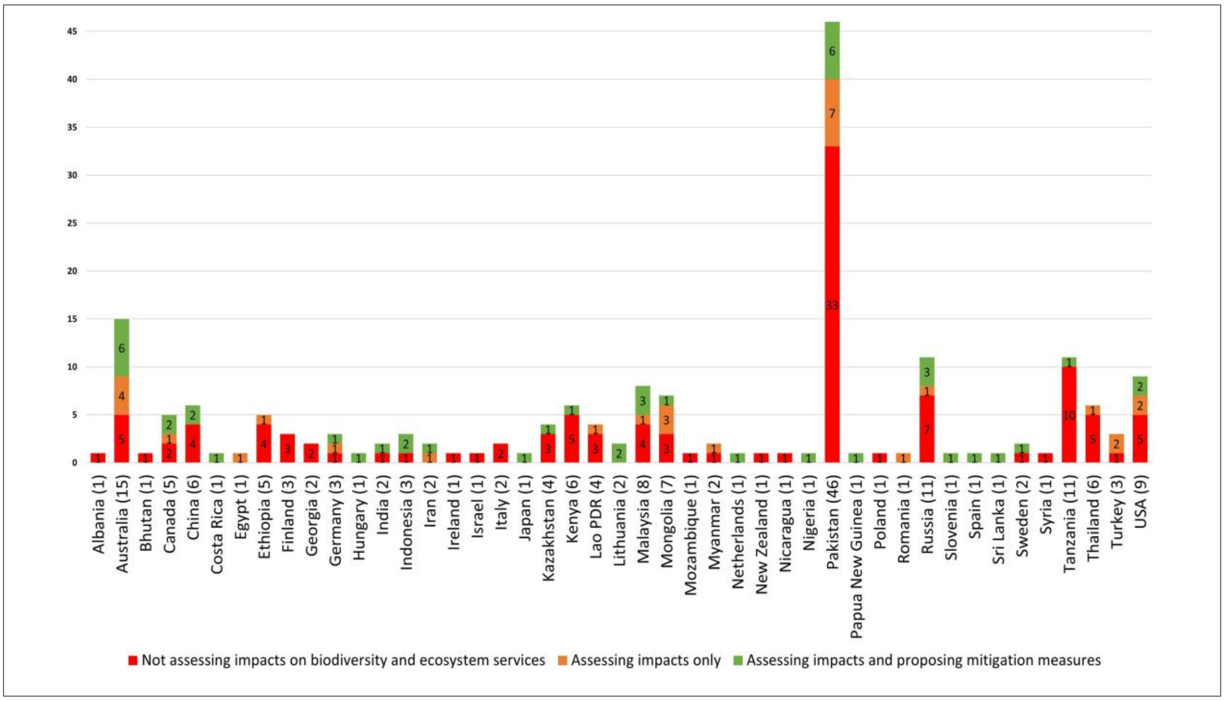

Figure 2.4 All country case studies.

Divided by: those not assessing impacts on biodiversity and ecosystem services (red); those assessing impacts on biodiversity and ecosystem services (orange); and those which in addition to assessing impacts and proposing biodiversity mitigation measures to manage those impacts (green). Total number of case studies are in brackets by the country name.

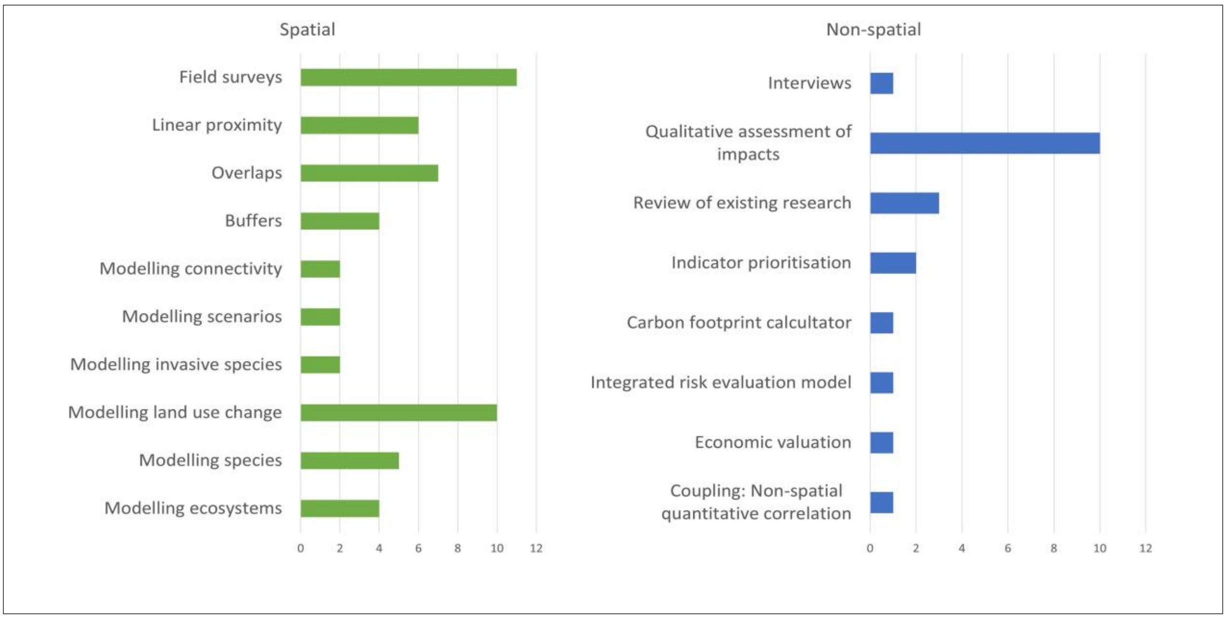

Figure 2.5 Methods used to assess impacts on biodiversity for the 47 case studies. Some studies used more than one method.

2.4. Discussion

2.4.1. Key Evidence Gaps

We find three major evidence gaps. First, less than half (37%) of the peer reviewed literature on Development Corridors assess impacts on biodiversity and even less so (3%) on ecosystem services. Those studies that assess impacts on biodiversity do not follow best practice as defined in this review (Table 2.1) and only one in 5 (19%) propose mitigation measures to address those impacts. Second, the review found only one study in South America, 10 in Africa, and 11 in Oceania which assess impacts on biodiversity. These are continents with high levels of biodiversity and also where Development Corridors are expanding (Laurance et al. 2015a; Sloan et al. 2019; Sloan, Alamgir, et al. 2019; Vilela et al. 2020). Third, the lack of impact assessments on ecosystem services suggests at best partial consideration of how Development Corridors might bring socio-economic benefits to local people. Moreover, there is evidence that infrastructure corridors can negatively impact ecosystem services (Mandle et al. 2015;

Nyumba et al. 2021). In this discussion, we focus on impacts on biodiversity within Development Corridors from two perspectives: how impacts are assessed and how impact mitigation is approached.

How Biodiversity Impacts Are Assessed.

Most studies in this review only assess direct impacts on biodiversity; indirect impact assessments were restricted to buffers or linear proximity analyses from the proposed development. There was only one specifically looking at cumulative impacts (Lechner et al. 2017). These findings align with Collinson et al. (2019) who, in a review on road ecology research in Africa, found that most publications examined the direct impacts of roads only and focused on single species assessments. Notably, there were only two publications specifically assessing the impacts of Development Corridors on ecological connectivity (Heinicke et al. 2019; Wierzchowski et al. 2019), despite that habitat fragmentation is one of the most well-established effects of infrastructure development (van der Ree et al. 2015; Barrientos et al. 2019), which often occurs in early stages of corridor construction.

Although the metrics used to measure impacts were diverse, very few studies did this in a systematic and comprehensive way, and one-fifth of studies did not use quantitative metrics to measure biodiversity loss. Quantitative metrics were restricted to areas of habitat loss or only assessing overlaps of proposed development projects without estimation of ecological degradation or condition. The latter is generally needed to account for all potential biodiversity losses due to development and to estimate potential gains through mitigation actions when alternative options are proposed. This misalignment on metrics used to assess impacts has been already identified as a gap in impact assessment in the context of biodiversity offset implementation (Marshall et al. 2020). Moreover, the lack of use of quantitative metrics seems to be a common issue in corporate reporting of biodiversity impacts which makes it difficult to assess whether mitigation measures work or positive outcomes for biodiversity can be achieved (Addison et al. 2019).

How Biodiversity Impact Mitigation Is Approached

Collinson et al. (2019) also found that only one-third of publications on impacts of roads on biodiversity provided recommendations for interventions to reduce or mitigate the impacts. Comparatively, in this review, only one-fifth (52 out of 271) of publications that assessed impacts on biodiversity discussed mitigation measures; meaning that most publications assessing impacts of corridors on biodiversity do not propose recommendations to manage the impacts they foresee. When impact mitigation measures are proposed the focus was on minimisation, avoidance or a combination of minimisation and avoidance. The observed stronger emphasis on minimisation suggests that mitigation measures are generally considered in the design or implement stage, despite avoidance being the most reliable strategy for reducing impacts (Phalan et al. 2018; Sonter et al. 2020).

Perhaps one of the most important gaps is that only two publications explicitly mentioned the mitigation hierarchy as a framework to manage impacts—and none used it to explore the achievement of no net loss or net gain for biodiversity. Consequently, there were no studies considering the two last stages of the mitigation hierarchy: restoration and offsetting. Biodiversity offsets or compensation are a particularly important last step to fully applying the mitigation hierarchy framework, and in principle are either already part of development policy or soon will be for a majority of countries in the world (GIBOP 2020).

2.4.2. Addressing Evidence Gaps

Although there is substantial practical and scientific knowledge on how to manage the impacts on biodiversity from linear infrastructure, this review found little specific application of this knowledge to the specific case of Development Corridors. Nevertheless, there have been important advances in impact mitigation science in recent years that could be adapted to Development Corridors. On the one hand, holistic frameworks exist that identify key risks and opportunities for conservation and development, by taking a spatially explicit approach to map biodiversity priorities in relation to predicted impacts. For example, the Development by Design framework (Kiesecker et al. 2010; Tallis et al. 2015) combines the application of the mitigation hierarchy with Systematic Conservation Planning (Margules and Pressey 2000) to take into account conservation priorities when planning for developments. It has already been applied in several countries, such as Mongolia (Heiner et al. 2019a), India (Kiesecker et al. 2020), and Colombia (Saenz et al. 2013). Similarly, Vilela et al. (2020) take an approach that combines economic and environmental assessments. The environmental and social impacts of 75 road projects in the Amazon were assessed to find that 45% of these will generate economic losses as planned. However, they showed that choosing the right projects and strategies through a multicriteria analyses of positive and negative outcomes, could result in achieving 77% of the economic benefit at 10% of the negative predicted impact. Of paramount importance is to design approaches that consider needs of people in addition to biodiversity. Heiner et al. (2019b) show how development at a landscape level can be planned by using the mitigation hierarchy as a framework to proactively map values and mitigation actions considering synergies and trade-offs between social, cultural and environmental priorities in Australia.

In addition to adopting an holistic framework, it is important to consider the full suite of direct, indirect and cumulative impacts that developments can generate—considering these impacts are likely to be much more severe than only assessing direct impacts (Johnson et al. 2020). For example, Tulloch et al. (2019) used expert opinion and spatial prioritisation analyses to assess the impacts of planned roads, railways and pipelines in southern Australia. They found that the footprint of indirect impacts could be four times higher than only assessing direct impacts. Whitehead et al. (2017) used spatial prioritisation techniques to map cumulative impacts produced by multiple projects. Their approach identified minor alterations to the original development plans that could result in reductions in biodiversity impacts and informed expansion of the protected area network in Western Australia. Recently, data on cumulative impacts at a large scale has been made available. For example, global datasets mapping cumulative pressures in the seas (Halpern and Fujita 2013; Shackelford et al. 2018) and land (Venter et al. 2016; O'Bryan et al. 2020) at one kilometre resolution are available and can further inform strategic impact assessments for Development Corridors.

Whether Development Corridors can be designed and implemented to at least achieve no net loss or better for biodiversity remains an unanswered question. In general, achieving no net loss or better for biodiversity is challenging and controversial (Maron et al. 2018), especially in relation to biodiversity offsetting technical implementation (Gardner et al. 2013; zu Ermgassen et al. 2019) and governance (Damiens et al. 2021). Sonter et al. (2020) modelled the achievement of no net loss under 18 different national policy settings in Brazil, Australia, Indonesia, and Mozambique and found that no policy achieves no net loss for biodiversity in any of the scenarios they modelled. They conclude that avoidance is the most important action to achieve no net loss goals. Similar approaches of participatory scenario planning could be applied to Development Corridors to identify where the environmental impacts can more effectively be mitigated and understand potential effects of specific policies on achieving a no net loss goal. Similarly, target-based ecological compensation has been proposed to overcome offset challenges (Simmonds et al. 2019). Novel approaches are being explored to encourage proactive conservation actions across all sectors of society building from the mitigation hierarchy (Milner-Gulland et al. 2021). None of these have been yet considered for Development Corridors.

2.4.3. Policy Implications

No net loss or net gain goals are not only becoming increasingly mainstream for industry but also in global and national policies. Achieving positive outcomes for biodiversity and ecosystem services will likely be a critical component of the post-2020 global biodiversity framework of the Convention on Biological Diversity. In this context, Díaz et al. (2020) propose a strict no net loss goal as a highly ambitious end point that can only be achieved through a coordinated and holistic approach that considers socio-economic and environmental trade-offs.

Notwithstanding the challenges to achieve no net loss, the policies under which it could be pursued for Development Corridors already exist in some countries where they are ongoing or planned (Figure 2.6). The Global Inventory on Biodiversity Offset Policies (GIBOP), which summarises the degree to which biodiversity compensation policies and the mitigation hierarchy are embedded within national environmental policy frameworks, shows that 100 countries have or are developing biodiversity compensation and/or offset policies (Bull and Strange 2018).

According to GIBOP, 36% of our initial 45 countries already have regulatory requirements for offsets for at least some projects in some circumstances, 38% provide guidance or have measures in place to facilitate voluntary offsetting (GIBOP, 2020), and 13% have no provisions could be found with regards to compensation/offset (Figure 2.6). In Africa, we know that at least 33 Development Corridors are or will be dissecting the continent in the next decades (Laurance et al., 2015). Yet, only three country case studies and four regional studies in Africa assessed impacts on biodiversity and proposed mitigation measures but none proposed the use of offsets despite most countries having voluntary or compulsory provisions already in place (Figure 2.6B). It seems urgent and necessary that future impact assessment of Development Corridors in peer reviewed literature consider not only best practice but also existing compulsory or voluntary policy guidance on impact mitigation at a national level.

Tools for impact assessment, such as EIA and SEA could be the conduit through which best practice and regulatory requirements are implemented at a national level. SEAs seem particularly well-suited to do this as SEAs necessarily involve stakeholders coming together to assess environmental, social, and economic risks and alternatives to development at policy, planning and programming levels. This approach is critical for responding to the transboundary nature of Development Corridors, while ensuring these align with broad sustainability strategies and national policies. Still, in our review only one publication focused on developing methods to improve SEAs outcomes (Ramachandran and Linde 2011). Similarly, lessons learned from jurisdictional approaches to REDD+ (i.e., reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks) could provide some insights into how to achieve positive outcomes from initiatives that comprise multiple projects across a landscape. Jurisdictional approaches to REDD+ were taken acknowledging that significant reductions in deforestation could not be achieved by individual projects and that success in protecting forests and climate relied on successful implementation government-led policies and programs at multiple levels (Boyd et al. 2018).

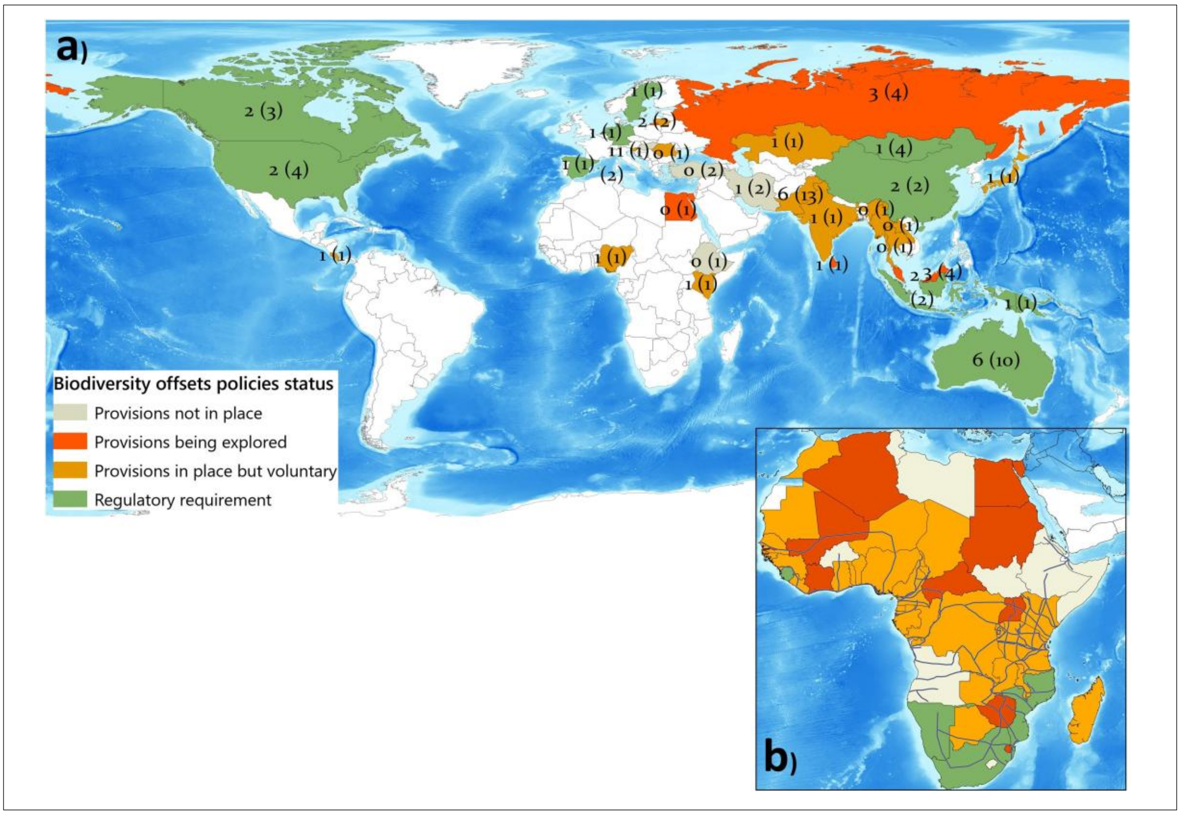

Figure 2.6 Number of country case studies proposing biodiversity mitigation measures in each country and, between brackets, total of country case studies. Colours indicate the status of national biodiversity offset policies according to the Global Inventory of Biodiversity Offset Policies (GIBOP, 2020), shown for country case studies picked up by our review only. (A) Global overview of the results per country of this review. (B) Case study for the African continent where blue lines represent 33 ongoing or planned development corridors (Laurance et al., 2015). The map shows that most countries in Africa where development corridors are planned or ongoing have the policy mechanisms in place to pursue better outcomes for biodiversity through ecological compensation.

2.5. Conclusion and further research

Our review compiled 271 articles from across all continents, 189 country level and 82 transnational case studies, confirming Development Corridors are a globally widespread phenomenon. We find that, for the specific case of Development Corridors, impact mitigation in peer reviewed literature does not give sufficient consideration to biodiversity impact mitigation following best practice and there is a lack of an integrated approach that considers the whole suite of potential economic, environmental and social impacts of these complex multi-project and multi-stakeholder initiatives. While impacts of Development Corridors on biodiversity have been assessed to some extent, there is little research focusing on testing different alternative configurations to minimise losses and maximise opportunities. Moreover, assessment of impacts on ecosystem services seems almost absent in the literature, which is problematic if Development Corridors are to deliver sustainable development. We argue that research needs to be scaled up and learn from other advances in impact mitigation science to assess and quantify direct, indirect and cumulative impacts on biodiversity and ecosystem services, apply the mitigation hierarchy in full and consider synergies and trade-offs in a spatially explicit way. SEAs seem like an appropriate framework to integrate these approaches into a better impact assessment process.

Given the direction global and national policy, industry and civic society are taking in pursuing positive outcomes for biodiversity from human development, as explained in this review, Development Corridors design and implementation need to explore at least the viability of no net loss. There are policies and methodological approaches available that can be adapted to assess the technical feasibility and policy conditions needed for doing this. We do not know whether current Development Corridors are achieving the social and economic objectives they set out for, but we are confident that the numerous risks they pose to biodiversity and ecosystem services have not been sufficiently addressed to date.

3. Chapter 3 The African Development Corridors Database: a new tool to assess the impacts of infrastructure investments

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Manuscript published as: Thorn, Jessica P. R., Diego Juffe Bignoli, Ben Mwangi, and Robert A. Marchant. 2022. 'The African Development Corridors Database: A New Tool to Assess the Impacts of Infrastructure Investments'. Scientific Data 9 (1): 679. https://doi.org/10.1038/s41597-022-01771-y.

Abstract

The large-scale expansion of built infrastructure is profoundly reshaping the geographies of Africa, generating lock-in patterns of development for future generations. Understanding the impact of these massive investments can allow development opportunities to be maximised and therefore be critical for attaining the United Nations' Sustainable Development Goals and African Union's Agenda 2063 aims. However, until now information on the types, scope, and timing of investments, their evolution and spatial-temporal impact was dispersed amongst various agencies. We developed a database of 79 Development Corridors across Africa, synthesizing data from multiple sources covering 184 projects on railways, wet and dry ports, pipelines, airports, techno-cities, and industrial parks. The georeferenced interlinked tabular and spatial database includes 22 attributes. We expect this database will improve coordination, efficiency, monitoring, oversight, strategic planning, transparency, and risk assessments, among other uses for investment banks, governments, impact assessment practitioners, communities, conservationists, economists, and regional economic bodies.

3.1. Background

Investment in infrastructure globally is at an all-time high (Thacker 2019; zu Ermgassen et al. 2019) while in recent decades Africa has seen accelerating construction of complex networks (Laurance et al. 2015a). This exponential increase in investment is situated against a long history of under-investment (Lakmeeharan et al. 2020), being home to some of the fasting growing economies (Signé 2021), having an urban population estimated to grow by over 60% by 2060 (United Nations Economic Commission for Africa 2017; UNDESA et al. 2015), and a growing appetite from domestic and foreign direct investors. Although the numbers are contested, Africa only has about 1% of the world's railways, about a third of the rural population has access to roads, less than 5% has irrigated agriculture, while only 40% has electricity, and there are few direct flights connecting parts of the continent (African Development Bank & Worldwide Fund for Nature 2015; Global Infrastructure Hub and Oxford Economics 2018). Consequently, infrastructure needs are high: between 2013–2017 the annual funding was USD 77 billion, double the annual average between 2000–2006, which is estimated to further double to USD 150 billion by 2025 (Lakmeeharan et al. 2020). With the promises of the Belt and Road Initiative, the G7 Build Back Better World Partnership and the European Union's Global Gateway, such investments are likely to increase.

Although there are multiple definitions (e.g. Hope and Cox (2015); Reeg (2017); Müller-Mahn (2020)), infrastructure corridors generally deliver services such as energy, water, waste management, transport, and telecommunications; and often lead to spatial development between rural peripheries and urban growth poles (Thacker 2019; Pederson et al. 2021). Infrastructure corridors become Development Corridors when larger, often transnational, and linear, geographical areas are targeted for domestic and international investment (Juffe-Bignoli et al. 2021). Development Corridors typically go beyond individual investments, have political-economic weighting, are attached to Master Planning processes, are positioned as flagship initiatives (Schindler and Kanai 2021), and ideally, under-pinned by Strategic Environmental Assessments (Juffe-Bignoli et al. 2021; Thorn et al. 2021).

Such Development Corridors have the potential to offer development gains but also open extensive areas of land to new environmental pressures and are not without social-economic challenges (The Development Corridors Partnership 2022). On the one hand, Development Corridors are considered as “dreamscapes of modernity” and critical elements for promoting trans-formational change, sustainable development, and synergistic climate change mitigation and adaptation (Müller-Mahn 2020; Teo et al. 2020). On the other, Development Corridors can lead to significant biodiversity loss, habitat fragmentation (Lakmeeharan et al. 2020; Juffe-Bignoli et al. 2021) , pollution, spread invasive species (van der Ree et al. 2015), increase illegal logging, poaching and fires (Laurance et al. 2009), severely affect river deltas and coastal and marine ecosystems (Ascensão 2018), and consume large volumes of greenhouse gas intensive products such as steel and cement (Enns 2018). Beyond environmental impacts, Development Corridors can widen inequalities between stakeholders who are not party to the planning process but affected by it (Hope and Cox 2015), lead to transformations in local livelihoods (Tate 2015), increase adjacent communities’ exposure to natural hazards, leave an unsustainable burden of debt, and are often fraught with anxieties of social contestation (Müller-Mahn 2020; Tate 2015). As infrastructure enters more remote areas, the significance increases (Sterl et al. 2021).

There have been previous attempts to map corridors - not least the work of the Programme for Infrastructure Development in Africa Information Centre (African Union PIDA 2021), the G20’s Global Infrastructure Hub (G20’s Global Infrastructure Hub 2021), the European

African Infrastructure Trust Fund Information Centre (European African Infrastructure Trust Fund Information Centre 2021), the Tripartite Transport and Transit Facilitation Programme (TTTFP 2021), the African Transport Policy Programme, the African Union's NEPAD Africa Infrastructure Database, the World Bank's Public Private Partnership Knowledge Lab, and various private sector portals tracking traffic, logistics and trade. However, these have not been integrated in a continental database to understand impacts on people and biodiversity. Contributing to this, is a lack of fine-grained, disaggregated data that can be systematically compared across space and time. Moreover, Development Corridors rarely have clearly demarcated boundaries, titles, stages of evolution, and durations (Juffe-Bignoli et al. 2021). Limited GIS capacity and understanding of assumptions in data preparations for analyses feed into a lack of data standardisation which yields non-comparable results (Brooks 2016). The clear lack of data on impacts furthermore leads to the following challenges (Juffe-Bignoli et al. 2021; Teo et al. 2020; Sterl et al. 2021; Arnold et al. 2013): (1) governance, coordination, and transparency difficulties; (2) inefficiencies in operations and maintenance; (3) scale mis-matches (e.g., national interests outweigh local welfare or international connectivity); (4) trade-offs across sec-toral domains (e.g., economic interests outweigh land conversion); (5) contradicting, scattered and ambiguous information allows manipulation depending on priorities, diverse interests, and outcomes; (6) inadequate or rare implementation of best practice mitigation measures; and (7) politically polarised discourse in the media, which can reflect popular attitudes and shape opinion. These are only some of the challenges that are realised at the local level (e.g., for environmental practitioners tasked with undertaking timely Environmental Impact or Strategic Environmental Assessments), and at a global level (e.g., where international assessments such as recent the Global Environmental Outlook (UNEP 2019), Global Infrastructure Outlook (Global Infrastructure Hub and Oxford Economics 2018) or the International Panel on Biodiversity and Ecosystem Services (IPBES 2019) may rely on inaccurate information). Governments and private sector players need to step up to prepare, plan, and manage Development Corridors and their constituent projects with a new level of rigour and robustness.

Here, we present a new comprehensive African Development Corridors Database, and document where, when, and how Development Corridors have evolved across the continent. Our work builds on and offers a wider scope and level of detail than previous efforts by research of mapping Development Corridors in Africa.

Overall, our dataset increases:

1. the scope of possible analyses, featuring spatial, temporal, and sectoral resolutions of development corridor networks that were so far not publicly available,
2. the comparability of these analyses based on a standardised and comparable dataset, and
3. reproducibility as we provide a common input data framework using a data standard and provide open access to the data.

In using this database, we emphasise the necessity of future regional and subregional analyses to ensure data is kept up-to-date and accounts for the dynamic nature of investments. Such analyses should be combined with capacity building of users to analyse these data with other complementary knowledge products, such as carbon, water, biodiversity, risk of ecosystem collapse, capacities for conservation response, proxies for resilience, inequality, electricity access, or land tenure (Brown M. 2022). Clear guidelines of how to standardise data among regions will be necessary, as well as making explicit assumptions underlying the data (Brooks 2016).

3.2. Methods

The methodology was set in three main stages: first, a global review involving the searching and screening for data, second, the manual digitisation of spatial features, spatial temporal distribution, and volume calculation procedures, and third, technical validation. The main steps for each stage are summarised in Figure 3.1.

Search strategy: Standard methods were used to access, appraise, and synthesise peer reviewed and grey literature about infrastructure projects within Development Corridors in Africa. We developed a search protocol to ensure rigor, objectivity, verifiable procedures, and clarity of the study design (Bangor University 2013). The search strategy was established through discussions researchers and stakeholders during eleven months of fieldwork in Tanzania and Kenya between 2018 and 2019, and consultations with the executive board of scientific experts in the Development Corridors Partnership (https://developmentcorridors.org). The Development Corridor Partnership is a collaborative capacity building research programme in Kenya, Tanzania, China, and the UK involving universities, Development Corridors agencies and NGOs. Three reviewers conducted searches and screening over 18 months between the 28th of January 2020 and 19th May 2021.

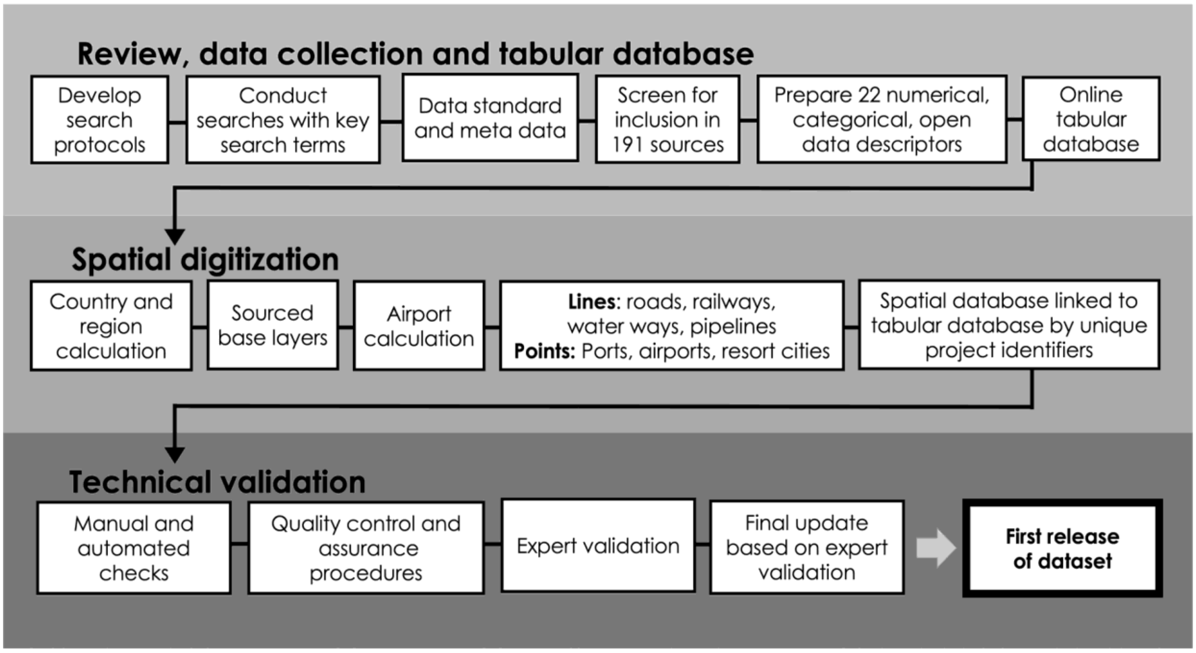

Figure 3.1 Workflow diagram of Development Corridors review, mapping, and technical validation procedure to compile the African Development Corridors database.

Sources of publications and key search terms: We combined a multitude of data sources (n = 190), and ran searches on websites of corridor authorities, regional economic bodies, national government bodies, private companies, INGOs, international and national media houses, research groups, public private partner-ships, regional associations, research groups, and multilateral agencies (see Supplementary Information for a summary of these data sources). In addition, we searched multilateral development banks across the world (e.g., African Development Bank, Asian Development Bank, European Central Bank World Bank, Islamic Development Bank), which have approved funding for infrastructure development projects with wider socio-economic developmental benefits. We also searched infrastructure databases, including e-platforms for information and knowledge sharing on infrastructure development in Africa. Four key e-journals whose topic areas closely aligned with the research focus were hand searched, including Geographical Review, Economic Geography, African Studies Quarterly and International Journal of Applied Engineering Research. We further contacted researchers involved in past and ongoing projects to source data, such as African Ecological Futures and the Global Infrastructure Mapping and Modelling Project.

After testing the key search terms on 20 Development Corridors to confirm that the search strings captured relevant literature, and balanced specificity and sensitivity (Pullin et al. 2013), the final string consisted of: "transport corridor *", "economic corridor *", "development corridor *", "infrastructure corridor*", "resource corridor*", and "growth corridor*". These terms were applied to all databases and sources for all African countries, subject to their individual search requirements, following. We used Boolean operator terms and wildcards, i.e., a character that can be used to substitute for other character(s) in a string, connected search terms, which were disaggregated using truncation ("*" in most databases).

Inclusion criteria: We only included infrastructure projects for which we could see a clear connection to a development corridor programme as defined above. We divided infrastructure within Development Corridors into the following types: airports; dry ports; wet ports; electricity transmission lines; freight railways; industrial parks; passenger and freight railways; pipelines (oil); pipelines (water); resort cities; and roads. We included electricity transmission lines only when multiple countries had partnered to develop the infrastructure to enhance trade. Waterways included all forms of transport of goods and people traversing water, including catamarans and large ships. We included wet ports that cater for large shipping vessels, as well as dryland inland ports. We included international airports which are written into development strategic planning or policy documents, are international hubs which allow for the inflow and outflow of traded goods and services in Development Corridors or are physically connected or near Development Corridors included in our database. We excluded dams, domestic electricity transmission lines, small ferry links, freshwater inland ports, local airports, agricultural corridors, bridges (unless part of roads in a development corridor), and other forms of infrastructure not connected to Development Corridors.

Searches were completed for 53 countries in continental Africa. Islands of Comoros, Mauritius, Reunion, Mayotte and São Tomé and Principe were excluded because we did not find Development Corridors present in these areas. English, Swahili, Portuguese, and French sources were reviewed, but we did not include other languages due to the skillset of the review team. We expect that these languages captured most key documents regarding Development Corridors in Africa, and suggest future iterations include languages such as Arabic, Yoruba and Hausa. Research articles, reviews, and reports were included, while book chapters, conference proceedings and graduate theses were excluded. There was no time limitation on the searches.

Spatial digitisation of corridors: Mapping of the spatial features of the African Development Corridors Database was made using ArcGIS Desktop 10.8.1 and ArcGIS Pro 2.5.2. Each development corridor project was identified with a unique project code, to which all tabular and spatial parameters were associated, recorded as point or line features. We sourced available base layers using the results of Laurance et al. (2015), Open Street Maps (2021), the World Food Programme GeoNode Global Airports dataset (2021) including international airports or airports that were within a buffer of 40 km to nearby Development Corridors, and data from partners linked to the Development Corridors Partnership. We also looked for maps in reports and websites and digitised them. Approximately 79.1% (n = 140 projects) were fully mapped, while the remaining 44 (23.9%) were unmapped.

For those Development Corridors that were mapped, we identified which countries boundaries Development Corridors features intersected with. For those corridors which were not mapped, we identified countries based on the literature. We used the country name as per ISO 3166 standard (ISO 3166 standard 2021) and the country boundaries as per the Level 1 from Global Administrative Boundaries dataset version 3.6 (Global Administrative Boundaries dataset 2018). All distances were computed for the line features using the calculate geometry tool in ArcGIS. Before measuring the geodesic distance, we ran the dissolve tool to remove the overlaps and therefore avoid overestimating the distances when two different corridors share the same portion of a given road or railway. We then calculated the total sum of the length of corridors for each country. We did not include berths, quays, and wharfs due to wide range in sizes of these structures, depending on the country, ship size and study context.

3.3. Data Records

The African Development Corridors database is publicly available. The visualisation of the database that can be explored interactively here: https://dcp-unep-wcmc.opendata.arcgis.com/. The data is deposited in the Dryad Digital Repository referenced as Thorn, J. P.R., Mwangi, B.; Juffe Bignoli, D., The African Development Corridors Database, Dryad, Dataset, https://doi.org/10.5061/dryad.9kd51c5hw (2022). The final data were compiled into an online Master database spreadsheet, using the project code data as the merging attribute of the spatial and tabular database (AfricanDevelopmentCorridorsDatabase2022.csv). The African Development Corridor Database is presented as a GeoPackage file (.gpkg) and ESRI file Geodatabase (.gdb) composed by line and point feature datasets with the 22 associated attributes for all mapped corridors, a table with corridors that could not be mapped (also with the attributes), and a table with all sources consulted for each project code.

We created a data standard to ensure a systematic and standardised data collection (Supporting information Chapter 3). Each data record in the database represents a project within a development corridor. To group all projects within the same development corridor we used a unique identifier composed by three letters that identified the corridor plus a number unique for each project or record. For example, the Lamu port project in Kenya within the Lamu Port South Sudan Ethiopia Transport Corridor (LAPSSET) was represented as LAP000. In this corridor we identified 20 projects, from LAP0001 which is the Lamu Port to LAP0020 which is the Isiolo-Lokichar-Lodwar-Nadapal Highway in Kenya. In addition to the unique identifier for each project, the data standard includes data attributes that provide detailed information about each project. Table 3.1Table describes the attributes included in the database. Supplementary Information summarises the 79 corridors included in the database.

Infrastructure types and status of Development Corridors in Africa: The data consists of a total of 79 corridors consisting of 184 projects (Figure 3.2). Of the 12 infrastructure types, the most predominant form of infrastructure in Africa's Development Corridors is roads (n = 64, 34.8%), followed by wet ports (n = 38, 20.7%), passenger and freight railways (n = 33, 17.9%), and airports (n = 14, 7.6%). Fewer resort cities, electricity trans-mission lines, dry ports, industrial parks, and water pipelines comprise Development Corridors (all ≤ n = 3, 1.6%) (Figure 3.3). We acknowledge our study might not include many infrastructure developments that are components projects of larger programmes but are not yet labelled as corridors. A total of 107 (58.7%) projects are operational, 35 (19%) are in progress, 25 (13.6%) are planned, 25 (13.9%) are being upgraded, and 2(1%) are on hold.

Spatial distribution: The linear distance of Development Corridors in Africa is 122,294 km – which approximates to three times the Earth's circumference, with an average of 1703.84 ± 213.19 km (mean, SE), ranging from 4–11,141 km. In terms of number of projects per country, Kenya has the most projects (n = 34, 18.5%), followed by Tanzania (n = 18, 9.8%), South

Africa and Democratic Republic of the Congo (n = 17, 9.2% ea.), Ethiopia (n = 15, 8.2%), Mozambique and Zambia (n = 14, 7.6%), Angola, Uganda, Guinea and Cameroon (n = 12, 6.5%), Namibia (n = 11, 6.0%), Republic of Congo (n = 10, 5.4%), Burundi and Chad (n = 9, 4.9%), Malawi, Senegal, and Zimbabwe (n = 8, 4.4%), and Burkina Faso and Ghana (n = 7, 3.8%). Due to differences in the frequency and quality that countries publish data on infrastructure and development corridor investments, coverage may be lower for some regions, or some periods (i.e., recent, or further in the past).

Investments in Development Corridors: Adjusting for inflation, the total investment of Development Corridors that is captured in the database ranges between USD 547.29–658.62 billion. The average cost of a corridor ranges between USD 3.46 ± 1.92 billion and USD 4.17 ± 2.04 billion. This is a notable sum, considering the average GDP in sub-Saharan Africa is USD 1.48 billion (World Bank 2021). The most expensive development corridor project is the first of the nine Trans African Highway projects at USD 78.20 billion (when adjusted for inflation) – comprising transcontinental roads across Africa. We were able to capture the budget (or at least a proportion of the budget) for 84.7% of all projects.

Table 3.1 List of the attributes included in the African Development Corridors Database.

No.	Attributes	Format	Description	Validation requirement
1	Project code	Code	Unique identifier of development corridor project	Three letters, four numbers
2	Project name	Text	Commonly used name to refer to a project within a development corridor.	Number of characters <100
3	Corridor name	Text	Specific name of the development corridor often formed by multiple projects.	Number of characters <100

4	Infrastructure/ development type	Text	Dry port; electricity transmission; freight railway; industrial park; passenger and freight railways; oil pipelines; water pipelines; port; resort city; road; waterway.	From list
5	Status	Text	In progress; on hold; operational; planned; upgrade	From list
6	Country	Text	Country(s) where the development corridor project is located.	From list (ISO 3166 codes)
7	Region or province	Text	Region(s) where the development project is located	From list
8	Description	Text	Short narrative of main objectives, functions, and features of the project of a development corridor	Free text
9	Launch year	Num ber	Year of completion and inauguration of the project	Year (must be in the past)
10	USD amount (million) min	USD	Investment cost minimum	Numerical digits
11	USD amount (million) max	USD	Investment cost maximum	Numerical digits
12	Amount description	Text	Description of what the minimum and maximum amount refers to: partial project cost; total project cost; or cost of upgrade	Free text
13	Distance (km) min	km	Minimum linear distance of corridor element as reported in the sources reviewed	Numerical digits
14	Distance (km) max	km	Maximum linear distance of corridor element as reported in the sources reviewed	Numerical digits
15	GIS distance	km	Linear distance calculated in ArcGIS	Numerical digits
16	Area	km2	Total area of corridor element in square kilometres as reported in the sources reviewed if data is available for all infrastructure except for ports and airports which we are represented as points	Numerical digits
17	Supplier or recipient of goods or services	Text	Specifies whether the project is predominantly a net supplier or recipient of goods or services	From list
18	Key beneficiaries	Text	Describes who are the beneficiaries of the corridor	From list
19	Commodities traded or transported	Text	Lists key commodities traded, exchanged, or transported within the corridor.	From list
20	Name of donors or financiers	Text	Name of entity or entities funding the amount specified in the amount field.	From list
21	Amount funded (USD	USD	Specifies the amount funded for each donor.	Numerical digits

	million) per donor type			
22	Type of major donor/financiers	Text	Entity or entities funding each amount: international development agencies; national development agencies; multilateral banks; national governments; national governments; public private partnerships; private companies; regional development banks; regional economic communities.	From list

Temporal evolution of growth of Development Corridors: Investments started in the 1800s and have increased exponentially (Figure 3.4). Over a fifty-year period, the greatest number of investments took place between 1950 and 2000. Spikes in investments occurred particularly around 1900, which was when there was a wave of new imperialism across the continent, followed in the 1960s when many countries across sub-Saharan Africa gained independence. The third spike in investment was in the last decade, particularly since 2013, when we have seen rapid growth in foreign direct investment in Africa under initiatives such as the Belt and Road Initiative. According to the Ernst and Young Africa Attractiveness Survey (Ernst and Young 2020), the largest foreign direct investment (in terms of capital) between 2014–2018 came from China (USD 72,235 million), France (USD 34,172 million), USA (USD 30,885 million), the United Arab Emirates (USD 25,278 million) and the United Kingdom (USD 17,768 million).

Donors that are funding Development Corridors: Across Africa, regional development banks invested the most in Development Corridors (30.8%), with the African Development Bank funding almost one fourth (24.3%) of all projects. Outside of Africa, the regional development banks that invested in the most projects are the Export-Import Bank of China (n = 13, 3.8%), the European Investment Bank (n = 10, 2.8%) and the Arab Bank for Economic Development in Africa (n = 4, 1.2% ea.). National governments funded about 29.8% of all projects. The Government of Kenya funded the most projects (n = 26; 7.5%), followed by the

Governments of Tanzania (n = 7, 2.0%) and South Africa (n = 4, 1.2%). Multilateral banks funded 10.9% of projects - mostly from the World Bank (n = 33, 9.54%) and a few from the International Finance Corporation (n = 4, 1.6%). The international development community funded only 6.1% - of which the OPEC Fund for International Development funded four projects. Private companies continue to invest in a small percentage of Development Corridors (3.5%), but this is higher than national banks that invest in 3.2%. Regional Economic Community bodies have invested in 15 (4.8%) of all 184 projects. The average number of donors per corridor ranged from one to 12.

Table 3.2 Experts from across Africa who contributed to the technical review assessment.

Institution type	Institution
Multilateral agency	United Nations Environment Programme Sustainable Infrastructure Partnership
	United Nations Environment Programme Economic Research Unit
	United Nations Environment Programme Gender and Safeguards
Development Bank	African Development Bank - Safeguards and Compliance Department
	World Bank
	International Finance Corporation
Private companies	Constellation Group
	Independent consultant
	Southern Agricultural Growth Corridor of Tanzania
	Biotope
	Business Continuity Planning
	CR Attorneys
	Jabu
	WSP Environmental Consulting
Organisations	Worldwide Fund for Nature Africa
	Worldwide Fund for Nature Cameroon
	Worldwide Fund for Nature Madagascar
	Worldwide Fund for Nature Uganda
	Worldwide Fund for Nature Kenya
	Worldwide Fund for Nature Tanzania
	Worldwide Fund for Nature Norway
	African Conference on Linear Infrastructure Ecology
	Wildlife Conservation Society
	Endangered Wildlife Trust
	Grevy's Zebra Trust
	Birdlife
	International Union of the Conservation of Nature Thematic Group on Impact Mitigation and Ecological Compensation

Research institutions	University of Stellenbosch
	London School of Economics
	Yale University
	ETH Zurich
	Centre for Science and Technology Innovations
	UNIBAS - Coloniality of Infrastructure conference chair
	University of York
	South African National Biodiversity Institute

Weighting of investments by donor type: In terms capital funded per donor type, Regional Development Banks invested the most (totalling USD 30.72 billion), followed by national governments (USD 20.45 billion). The figure then drops substantially to international development agencies (USD6.17 billion) and multilateral banks (USD 3.76 billion). These results are limited by the fact that we were only able to capture the amount funded delineated by donor type for 22.58% (or USD 70.24 billion) of the minimum of all investments (USD 311.14 billion) before adjusting for inflation.

Commodities transported: A total of 147 commodities were captured. The top twenty commodities traded were rice (n = 52, 28.7% of all projects), sugar (27.0%), fish and petroleum (24.3% ea.), passengers (21.6%), textiles (21.1%), maize (19.5%), coffee (18.9%), cement and timber (17.8% ea.) followed by cotton, crude petroleum, vehicle spare parts, beverages, copper, fruit, fertilisers, gold, pharmaceutical products, and tobacco.

Beneficiaries and net supplier or receiver: Approximately 213 different beneficiaries were identified – predominantly local communities (n = 134 of projects, 72.8%), followed by national and local governments (63.0%), traders (51.1%), agricultural farmers and livestock producers (27.7%), ports (27.2%), industries (25.5%), truck drivers (22.3%), tourists (17.4%), entrepreneurs (12.0%), and logistics companies (11.4%). Almost all (89.1%) of corridors are net receivers and suppliers of commodities, while only 13 (7.1%) are net suppliers and seven are net receivers (3.8%).

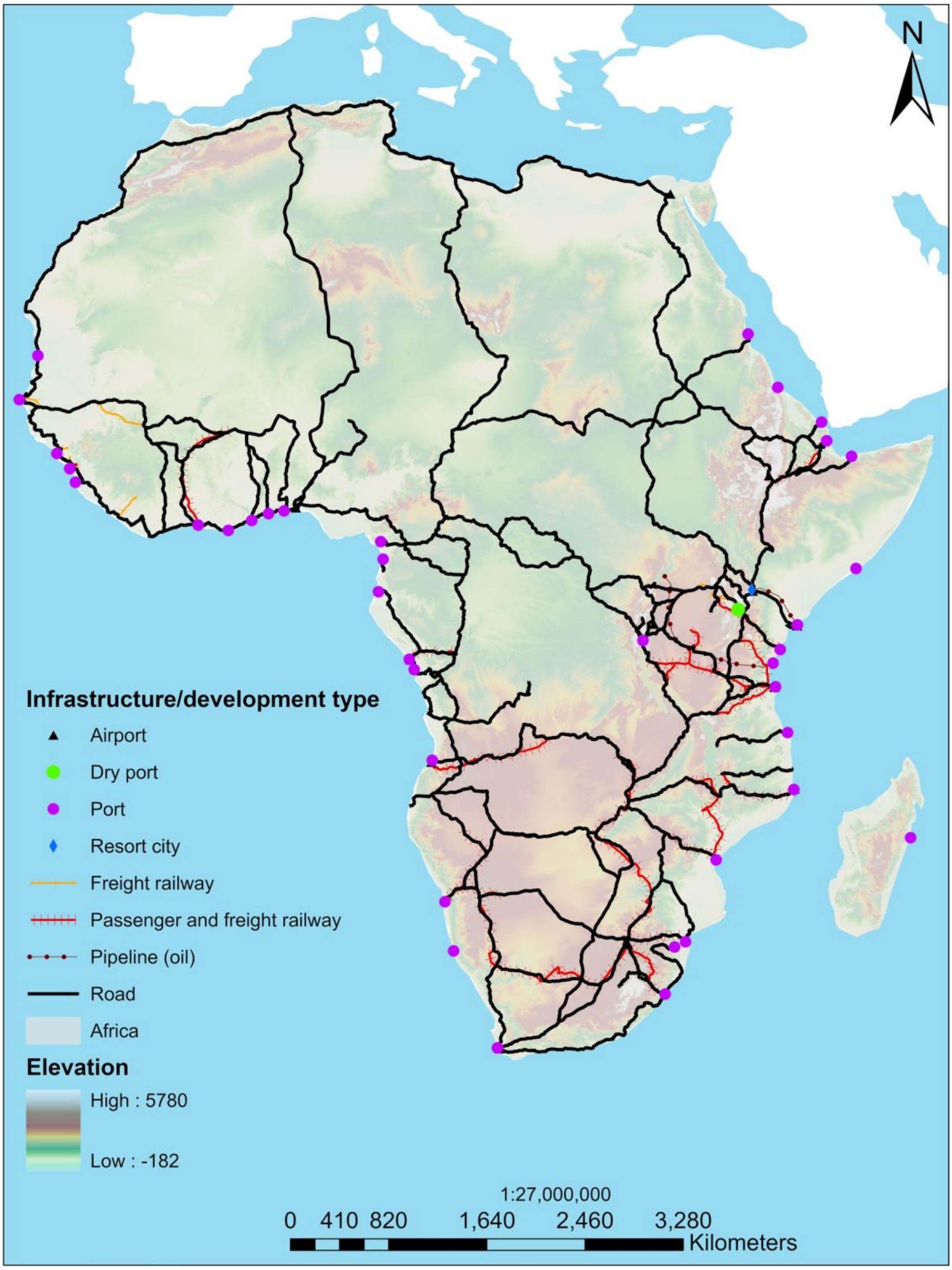

Figure 3.2 Map showing the distribution of all the Development Corridors included in the African Development Corridors Database and their infrastructure type.

3.4. Technical Validation

The database represents a collation of publicly available data published by official sources. Therefore, we con-ducted a critical appraisal to ensure the database represents an accurate record of the official data. We used the following four main strategies.

First, all data collected, whether obtained from official channels or from third-party repositories of official data, was subject to initial manual verification when it was added to our database for the first time (Hasell et al. 2020). Five quality criteria were used to assess whether sources were of sufficient quality for inclusion (following Thorn et al. (2020); Gutiérrez Rodríguez et al. (2016)): (1) data collection methods, both qualitative and quantitative, are thoroughly explained, (2) methods are clear and replicable, (3) key terms were well defined, (4) conclusions are logically derived, and (5) conclusions supported by presented evidence. We only used international and national media sources which are well-reputed when no other data source could be identified. This process was iterative, including reassessments of the validity and robustness of the data sources, and checks of updated website links.

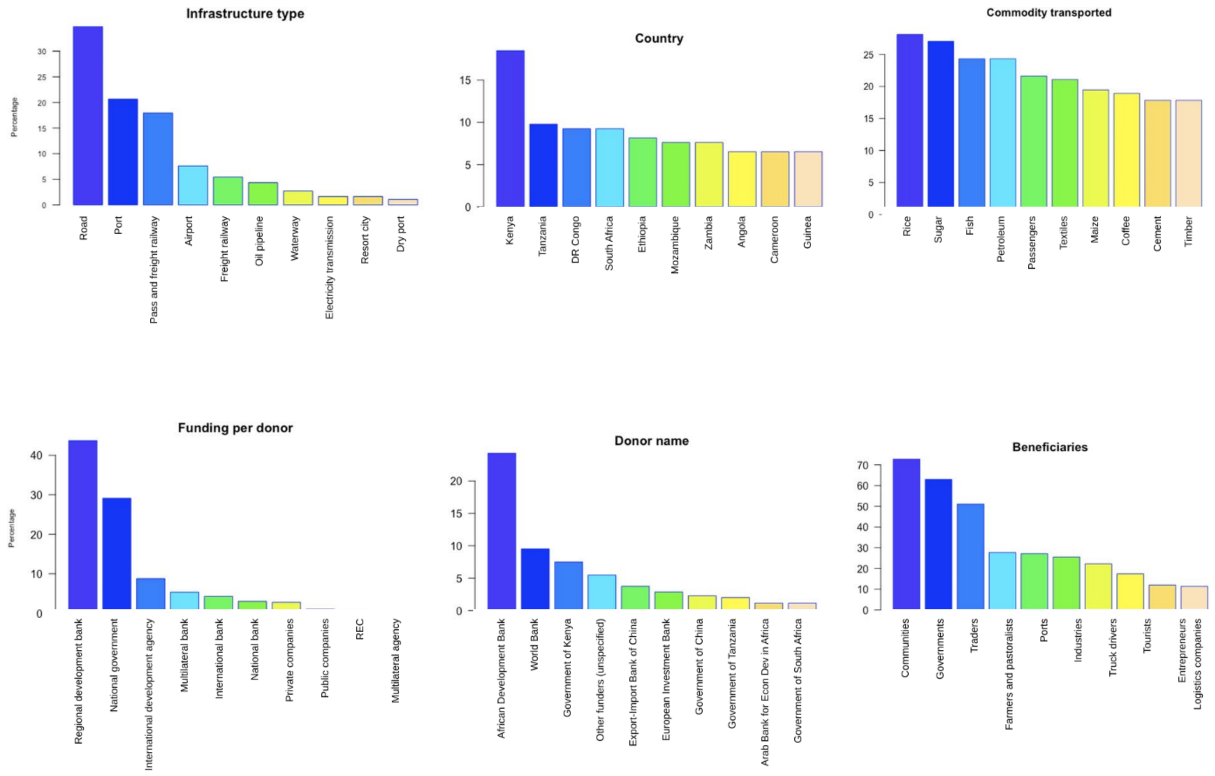

Figure 3.3 Subset of highest frequencies of key attributes captured in the database.

Second, we applied a range of quality control and quality assurance procedures to verify, collate, and standardise both the manual and automated data added to the database. We continually ran manual checks throughout the workflow to check for invalid data. Ambiguities were discussed in regular weekly meetings, and secondary reviewers verified decisions. For other metrics, we compared data across all different sources available and used a range to determine if our lowest and highest values are reasonable. We monitored changes in development corridor status in each country throughout the data extraction process. To ensure data integrity was maintained throughout the project, and limit data transcription errors and eliminate naming inconsistencies during manual input, we designed dropdown lists of predefined values, which were regularly modified to list new possibilities. We furthermore limited the number of 'free text' fields. Completeness of data entry was man-dated by users, i.e., the user could not continue with the workflow unless all input fields were completed, following (Martin et al. 2020). Alongside eliminating naming inconsistencies, input validation against specified parameters was associated with each field. A summary of these validation requirements is presented in Table (e.g., Project code - Unique identifier of development corridor project – three letters, four numbers).

For economic cost and account for annual inflation, where the launch year of the project was available, we adjusted the investment value using the Consumer Price Index (United States Bureau of Labour Statistics 2021). This index represents changes in prices of all goods and services purchased for consumption by urban households from 1913 to the present. For years before 1913, we used the 1913 value, and for years beyond 2021, we used the 2021 value. For years that did not have information on the launch year, we did not adjust the investment value. We acknowledge that this inflation rate does not account for changing costs over time (e.g., operation and maintenance), nor the fact inflation rates fluctuate from the start to the completion of a given project. We also acknowledge these data are limited by the financial data publicly available and may not include information about costs such as compliance requirements, permitting processes, contracts, or easements.

Third, visual checks were carried out. Since some of the routes were outdated, routes were verified and updated using Open Street Maps which is updated daily. We then verified these layers using an ESRI World Imagery map (ESRI 2021). Spatial and tabular datasets were reviewed and evaluated against selected studies that have mapped Development Corridors in Africa (Laurance et al. 2015a). Where the relative position of the position of the development corridor projects and previous mapping efforts were not aligned, differences were discussed between authors and with regional experts until a consensus of the updated route or position was reached. When a project within a particular corridor overlapped in space with another project or corridor, we kept these routes as separate records in the database to allow independent future analysis per development corridor or project. Prior to the date when the African Development Corridors Database was made available online, it was thoroughly tested and verified following protocols developed by the authors in (Ravilious 2020).

Fourth, we conducted an expert review over one month. This involved getting feedback from 50 secondary reviewers. These experts worked across Africa with a deep knowledge in infrastructure developments, representing a diversity of countries and organisations. We drew from the networks of the authors and the Development Corridors Partnership advisory board that had been developed between 2017–2021. Snowball sampling also allowed us to contact referrals to recruit a wider array of secondary reviewers. We then shared the review call on email, social media, and websites. We provided access to a dynamic online version of the database where the spatial and tabular data could be interrogated interactively. We captured reviewers' comments in a standardised feedback form. We obtained a 40% rate of response for the expert review which resulted in a new updated version of the database (Table).

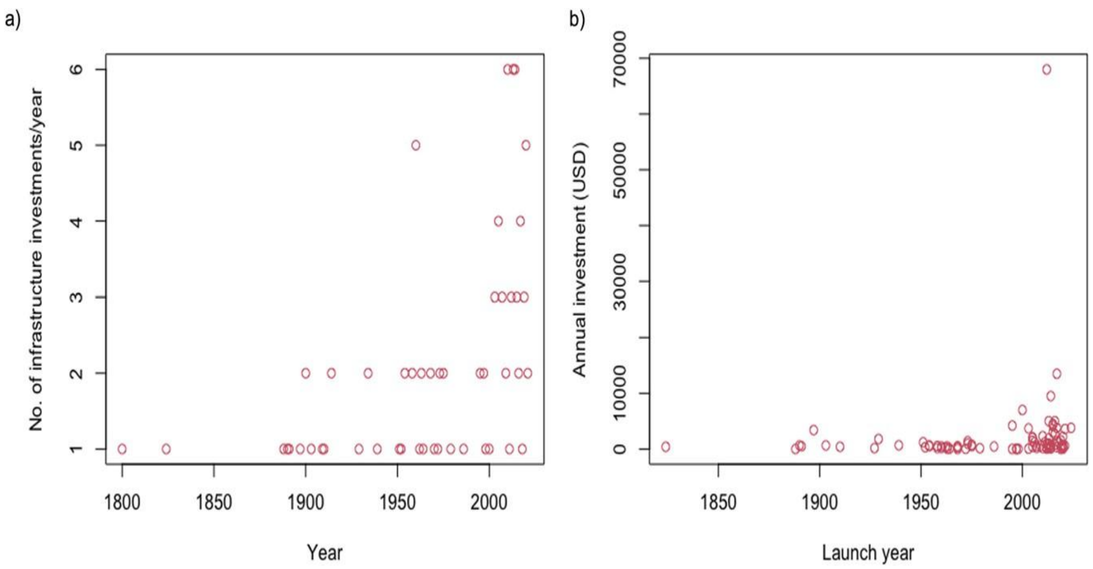

Figure 3.4 (a) Temporal evolution of investment in Development Corridors in Africa. (b) Annual investments per annum in Development Corridors in Africa (USD maximum, before adjusting for inflation).

3.5. Usage Notes

We provide a spatially explicit database of Development Corridors in Africa. This newly compiled dataset builds upon previous efforts to map corridors at a continental level (e.g., Laurance et al. 2015). Of particular use is the wider scope, level of detail and rigour, including 22 data attributes. This provides a valuable resource for improving our quantifiable understanding of large-scale impacts of infrastructural Development Corridors on biodiversity, protected areas, hydrological processes, and ecosystem services, their spatial dynamics, and their interactions with climate, land use and global environmental change. To assess the potential risk of impact on conservation areas, analyses can be undertaken to evaluate the spatial relationships between this dataset and others. For example, one can determine how Development Corridors overlap spatially with protected areas by assessing the intersection of the corridor line feature dataset with the World Database on Protected Areas and Other Effective Area Based Conservation Measures (WDPA/OECM) (UNEP-WCMC and IUCN 2024) and apply different buffer choices to corridor lines to estimate the geographic extent of that risk (e.g. Laurance et al. 2015).

Additionally, the inclusion of the cost of corridors within the database can contribute to our understanding of economic losses when stranded infrastructure assets are written down, devalued, or converted to liabilities due to growing intensity and frequency of extreme events, or resource scarcity. The inclusion of different infrastructure types and their distribution can help inform integrated regional in-country strategic planning – allowing planners to consider infrastructure more easily as a system of systems across all stages of infrastructure's lifecycle. When overlaid with other variables, data can be used for environmental impact assessments or strategic environmental assessments to determine how where proposed developments may minimise harm and maximise socio-economic and environmental co-benefits over time (e.g., considering fossil fuel lock in) and space (e.g., densification vs. sprawl) and intensity of the development corridor use under different scenarios (e.g., demographic trends, consumer demand). Data can be used to inform decisions of how to mobilise financial and non-financial resources, build capacity, improve coordination, and facilitate policy formulation and improve transparency on reporting and monitoring. Data can moreover help network traditionally separate firms and industries to utilise resources for newly built, upgraded, or retrofitted infrastructure. As such, we provide an example of how the database can assess impacts (i.e., on protected areas) but leave the manipulation and interpretation of the data up to the discretion of the user.

The database can be used under the license of Creative Commons (CC BY), meaning that the work can be distributed, adapted, and built upon with acknowledgement of authors. There are several ways to access and download the information contained in the database – with options in *.CSV, *.KML, Shapefiles or GEOJSON formats. Detailed information about the variables in the database can be found in Supplementary Information for this Chapter, which corresponds to the *.CSV files in the data portal.

The recent and ongoing negotiations of global development targets have brought attention to improving the accessibility and sustainability of infrastructure to the fore and how this relates to other interrelated goals. For instance, the Sustainable Development Goal 9 aims to "build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation", while SDG 11 aims to "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations General Assembly 2015). Meanwhile, the Convention on Biological Diversity's post-2020 Global Biodiversity Framework calls for 30% of globally important land for biodiversity and its contributions for people to be effectively and equitably managed, well-connected, and integrated into the wider landscape (Lechner 2018). We therefore hope this database is one step to develop greater clarity on the potential impacts of Development Corridors on social-ecological outcomes at large spatial-temporal scales and take action to ensure synergistic delivery of benefits (Jung 2021).

However, given there are limits to regional mapping approaches, our database must be complemented by contextually rich, empirical assessments and situated knowledge and practice that build regional understandings from the ground up (Wyborn et al. 2021). To ensure the ongoing reliability of the data - we envision the database will be updated as more data is digitised and made available - if resources allow. Further contributions, regular updates or analysis based on, and complementing the African Development Corridors Database will be welcome.

4. Chapter 4 Exploring indirect and cumulative impacts on nature from infrastructure development

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Abstract

Africa is experiencing an infrastructure development boom that could improve people's wellbeing but also have negative consequences for biodiversity and the benefits humans obtain from it. Potential impacts on nature include direct project footprint impacts, alongside indirect and cumulative impacts derived from the project itself, other planned projects, or existing land use change trends. However, while assessment of direct impacts is the norm, indirect and cumulative are often evaluated poorly or not at all. Adequately accounting for all biodiversity impacts from infrastructure development is fundamental to proactively avoid and mitigate these impacts. Here we present a spatially explicit methodology to estimate biodiversity impact risk of infrastructure projects beyond their direct footprint. We develop the metric Potential Impact Intensity that quantifies the intensity of likely ecological impact due to either new infrastructure influence, existing pressures, or both. The workflow allows accounting for potential effects of indirect and cumulative impacts up to a chosen maximum distance from the direct footprint of the project. Potential Impact Intensity also allows understanding the relative contributions of existing pressures and new pressures to the overall potential impacts in different contexts. We apply our methodological framework in Protected and Conserved Areas (PCAs) and Key Biodiversity Areas (KBAs) for 87 existing and planned infrastructure projects forming 51 Development Corridors across continental Africa. We find that existing pressures contribute between 6%-58% and new pressures between 42%-94% of the mean Potential Impact Intensity value in each African country. More importantly, we show that considering indirect and cumulative impacts increases the Potential Impact Intensity in corridor areas compared to only considering direct footprints. For example, the number of PCAs and KBAs potentially at risk in Africa increases 257% and 159% respectively, affecting 2,486 PCAs and 649 KBAs. Similarly, we show significant increases (up to 225%) in Potential Impact Intensity values in PCAs when combining all project Potential Impact Intensity values versus considering them

separately. We conclude that, for large infrastructure projects, a systematic quantification of cumulative impacts on biodiversity is needed to better inform the impact assessment process.

4.1. Introduction

Infrastructure development is a driver of socio-economic progress, contributing to human wellbeing and playing an important role in achieving the United Nations Sustainable Development Goals (SDGs) (United Nations General Assembly 2015) though SDG 9: Industry, Innovation and Infrastructure. Indirectly, infrastructure can also contribute to SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), and SDG 11 (Sustainable Cities and Communities), among others. Infrastructure therefore underpins essential services such as healthcare delivery, water access, energy provision, and urban development, which are especially vital to the development trajectories of mid-low-income countries (Prud'homme 2004; Tu et al. 2025).

Despite these benefits, infrastructure development can also have negative impacts on nature and on the benefits people obtain from it. Poorly planned construction of roads, dams, railways, and industrial zones often leads to habitat loss, fragmentation, pollution, and disruption of species and their habitats, and ecosystem services across landscapes (van der Ree et al. 2015; de Jonge et al. 2022). Thus, the development of infrastructure can undermine key ecological functions that sustain local communities and hinders progress on other SDGs such as 13 (Climate Action), 14 (Life Below Water), 15 (Life on Land), or even 6 (Clean Water and Sanitation). These impacts could be especially significant in Africa, where many infrastructure projects intersect with ecologically sensitive regions such as tropical forests, wetlands, and marine habitats (Laurance et al. 2015b).

To address the sometimes-conflicting objectives of infrastructure development and biodiversity conservation, environmental impact assessments are designed to identify, predict, and mitigate environmental impacts before projects are approved and executed. Key among these are

Environmental Impact Assessments for project-level developments and Strategic Environmental Assessments for broader policy and programmatic planning (UNEP 2018). In addition to impact assessment processes, which tend to be a regulatory requirement in many countries, there are further concepts that are widely incorporated and can be used to refine the results and recommendations of impact assessments. A key concept, which is often integrated into impact assessments concerning biodiversity, is the mitigation hierarchy (CSBI & TBC 2015; Arlidge et al. 2018). The traditional mitigation hierarchy captures an iterative four-step approach to managing biodiversity impacts: i) Avoid impacts by choosing alternative locations or project designs; ii) Minimise unavoidable impacts through design and operational changes; iii) Restore ecosystems that have been degraded during project construction; iv) Offset residual impacts through full compensation elsewhere to achieve no net loss or a net gain in biodiversity (Bull et al. 2016). The use of a robust mitigation hierarchy to realise an objective of 'no net loss of biodiversity or better' is a widely accepted good practice among international financial institutions, conservation organisations, and environmental agencies (Jones et al. 2022; Milner-Gulland et al. 2021; Bull et al. 2019). However, in many African contexts, mitigation measures often do not follow best practice, especially when implementing the mitigation hierarchy steps (Collinson et al. 2019; Juffe-Bignoli et al. 2021; Kormos et al. 2014; Brownlie et al. 2017). This increases the likelihood of irreversible environmental damage.

All infrastructure projects are likely to generate at least three categories of impact: direct (actual footprint of the project), indirect (not directly caused by the project but triggered by it, such as increased deforestation in the area), and cumulative impacts (interactions between other projects, climate change, and land cover change over time) (Juffe-Bignoli et al., 2021). Assessment of direct impacts is the norm while indirect and cumulative are often evaluated poorly or not at all (Kruger and Pohlo 2022; Cooper and Sheate 2002; Canter and Ross 2010;

Collinson et al. 2019; Whitehead et al. 2017; Juffe-Bignoli et al. 2021). However, indirect impacts can be four times higher than direct impacts (Tulloch et al. 2019). On the other hand, cumulative impacts arise when multiple projects interact with each other or with existing environmental pressures such as climate change, pollution, or invasive species (Kiesecker et al., 2020). There is guidance for industry on how to assess cumulative impacts (IFC 2013; Bennun et al. 2024), but to date, there is little research that has specifically quantified the magnitude of these impacts at a large scale and compared them with direct and indirect impacts.

Development Corridors are multi-sectoral initiatives that combine infrastructure with land use and economic planning to promote regional growth (Juffe-Bignoli et al. 2021). In practice each development corridor includes several infrastructure projects that are related to each other. This results in road, railway, pipeline, and urban development projects planned within a shared spatial extent. In Africa, there are at least 184 ongoing major infrastructure projects that can be grouped into 79 Development Corridors (Thorn et al. 2022). Especially in the case of Development Corridors, which propose a suite of projects across hundreds of kilometres, adequately accounting for potential indirect and cumulative impacts is fundamental to designing measures that follow the mitigation hierarchy to proactively avoid or mitigate potential impacts. Failing to adequately assess these types of impacts undermines the effectiveness of mitigation and can lead to environmental degradation. Previous studies have assessed the impacts of Development Corridors or large infrastructure development in Africa by considering buffers around infrastructure to estimate risks (Laurance et al. 2015b; Mahmoud et al. 2017; Kormos et al. 2014), but these do not explicitly account for indirect or cumulative impacts, nor their interactions with exiting pressures (Juffe-Bignoli et al. 2021).

Here we present a spatially explicit methodology to estimate biodiversity impact risk of infrastructure projects across large scales and considering direct, indirect and cumulative impacts. We use the case of Development Corridors in Africa to explore how different types of impacts interact with each other. First, we develop a methodological framework based on a new metric that represents the combined intensity of ecological impact due to either infrastructure influence, existing pressures or both. We then implement that framework for development corridor projects across Africa and use the metric to understand the magnitude and relative contributions between direct, indirect and cumulative impacts across the landscape and in two types of sites of conservation importance Protected and Conserved Areas and Key Biodiversity Areas.

4.2. Methods

4.2.1. Overview of workflow and datasets

We developed a seven-step methodological framework (Figure 4.1) in the JavaScript based spatial platform Google Earth Engine (GEE), to take advantage of its capacity for cloud-based processing of large geospatial datasets and ease of replicability. Our approach integrates slope-adjusted cost surfaces, exponential decay functions, and a spatial measure of existing pressures to explore the potential extent and magnitude of direct impacts (within the immediate footprint of the project route), indirect impacts (propagating beyond the project route at a slope adjusted exponential decay rate), and cumulative impacts (where indirect impacts and existing pressures overlap spatially).

This workflow can be applied to any new infrastructure project or set of projects and to any spatially explicit conservation feature of interest. It considers the intensity of impact within a chosen conservation feature combining new with existing pressures up to a chosen maximum distance from the infrastructure project.

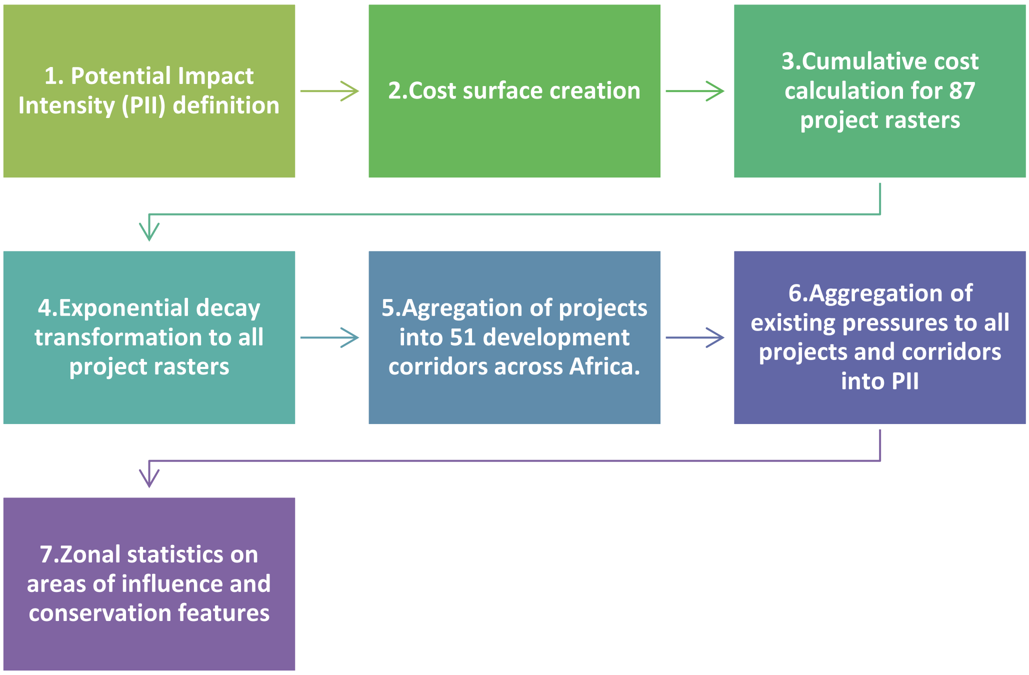


Figure 4.1 Workflow for the proposed seven step methodological framework.

The five main inputs into this workflow are infrastructure projects, a digital elevation model, existing pressures data known as the Human Modification Index, conservation features data, and administrative boundaries (see Table for sources of data and usage notes). The main outputs are 87 project level raster layers, 51 corridor level raster layers and one Africa level raster layer. This is not a comprehensive list of planned and ongoing development corridor projects in Africa but rather a snapshot in time provided by Thorn et al. (2022) which, in our case, adds 18 corridors more than those described by Laurance et al. (2015). In the following sections we develop this workflow in more detail.

Table 4.1 Main inputs into the modelling workflow.

Input	Dataset	Use	Citation
Infrastructure projects	The African Development Corridor Database: Vector data representing individual infrastructure projects in Africa belonging to a development corridor initiative building from Laurance et al. (2015). Each project is associated to a development corridor with a unique project code that share the same prefix if they belong to the same corridor. For example: the projects LAP0002 and LAP0003 belong to the LAP corridor.	Codification is used to aggregate raster layers. We only used line data to reduce uncertainty of spread of impacts from point data. Due to the inherent uncertainty of project development since 2022, we included all projects irrespective of their status to account for all potential indirect and cumulative impacts.	(Thorn et al. 2022)
Digital Elevation Model	The USGS SRTMGL1_003 dataset (30 m resolution)	Basis for creating an obstacle mask and a cost surface raster for the cost distance accumulation function.	(Farr et al. 2007)
Existing pressures	Human Modification Index for Africa: A continental-scale raster of human modification at 90 meters resolution. Values form 0 (no modification) to 1 (maximum modification).	Use to represent existing cumulative human pressures.	(Theobald et al. 2020)
Conservation Features	The World Database on Protected Areas and Other Effective Area Based Conservation Measures (WDPA/OECM) dataset filtered to African countries. The World Database on Key Biodiversity Areas (WDKBA)	To represent protected and conserved areas and Key Biodiversity Areas for zonal statistics.	(UNEP-WCMC and IUCN 2024) (BirdLife International 2024)
Administrative boundaries	The U.S. Department of State Large Scale International Boundaries (LSIB).	To represent African countries for zonal statistics.	(USDOS 2017)

4.2.2. Sensitivity analyses

Our main assumption is that the influence of infrastructure on ecological systems diminishes with distance from the source (i.e. where the infrastructure is located) but that this relationship is influenced by topography and existing pressures. Existing literature finds most significant impacts on biodiversity from infrastructure range between ~1 km and ~5 km from infrastructure for birds and mammals, respectively (Benítez-López et al. 2010) to 14 km for forest (Hughes

2019b). Common assessments for large spatial extents have been at 50km (Laurance et al. 2015b; Hughes 2019), although (Ng et al. 2020) explicitly evaluated potential impacts at multiple distance thresholds (1, 5, 25, and 50 km). Therefore, reported distances vary with taxon, mechanism, habitat, landscape context, and purpose of the analysis. Regarding slope, (Chen and Xu 2023; Wu et al. 2023; Weiss et al. 2018) show that road construction and human activities are greatly limited at slopes steeper than 16 degrees (see Appendix 3, Section 1.2. for full justification).

To test the sensitivity of our approach, we explored how outputs change when key input parameters change. We ran the same analyses for different maximum propagation, obstacle slopes, and resolutions. Based on the results of the sensitivity analyses, we performed our analyses at 250 metres resolution, up to 15 km distance from the source of impact and masking impassable terrain unsuitable for Development Corridors in areas with more than 20% slope. Below we describe in detail the workflow, inputs, metrics and quantification of impacts (See in Appendix 3, Section 1 for further justification of distance and slope, Section 2 for access to the scripts and more details about the parametrisation and functions used, and Section 3 for details and results of the sensitivity analysis).

4.2.3. Potential Impact Intensity

We start by dividing the landscape equally into pixels or raster cells, representing the individual development corridor lines, and the hypothetical extent of potential impacts from one infrastructure project (Figure 4.2). In one cell, the potential impact intensity in a conservation feature of interest from one development corridor project can be represented as the combined likelihood of a human derived impact for both project-related and existing pressures.

Formula 1: Potential Impact Intensity for one project

$$PII_1 = 1 - (1 - PI_{pr}) * (1 - PI_{ep})$$

Where:

PII: potential impact intensity of project 1 in one cell

PI_{pr}*: probability of human impact due to a development corridor project in one cell.*

PI_{ep} *: probability of human impact due to existing pressures in one cell.*

$(1-PI_{pr}) * (1- PI_{ep})$ *represents* the probability that neither *existing human pressures nor project impacts due to humans* occur. The likelihood of at least one event occurring is the complement of the probability that no events occur. Thus, the probability of human impact from either the corridor project or existing pressures (or both) is $1 - (1-PI_{pr}) * (1- PI_{ep})$.

This formulation captures the non-additive nature of overlapping risks: for example, two moderate probabilities do not simply sum to a value greater than 1 but combine in a way that respects probabilistic principles.

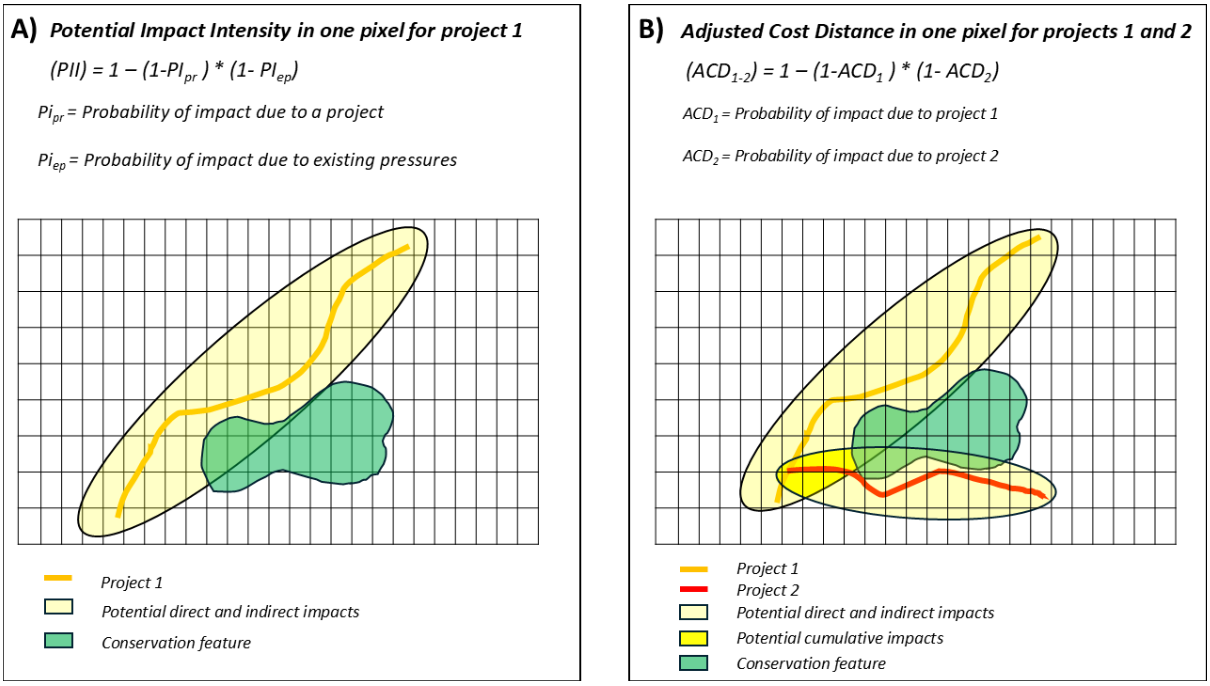


Figure 4.2 (A) Simplified graphic representation of Potential Impact Intensity in one pixel for one project near a conservation feature. (B) Simplified graphic representation of Adjusted Cost Distance (ACD) in one pixel for two development corridor projects near a conservation feature.

4.2.4. Cumulative cost function

We define Adjusted Cost Distance (ACD) as the intensity of human impact due to a development corridor project in one raster cell (*PI_{pr}* in Formula 1*)*. We develop this as a function of distance to the source of impact and the slope across the landscape (See Appendix 3, Section 1) and use the Google Earth Engine *cumulative cost* function (See Appendix 3, Section 2) to model slope-adjusted least cost distance paths from the source of impact (the project infrastructure) to the chosen maximum distance (15 km) and applied the decay function to the result. The least cost distance paths represent areas where human impact is more likely. This process consists of two steps: cost surface creation and cumulative cost calculation.

Cost surface creation

Through the GEE script (Appendix 3, Section 2), we create a cost surface raster from a digital elevation model using slope as a cost (Table). The cost surface is used as a cost for the cumulative cost function and to mask out areas with slope higher than 20°. This represents the slope beyond which human activity is unlikely to occur (see section 1.2 in Appedix 3 for full justification).

Cumulative cost calculation

We use the cost surface raster as the first input into the GEE's `cumulativeCost` function (Appendix 3, Section 1), to obtain least-cost distances from each source pixel. Each development corridor project from Thorn et al. (2022) was turned into a binary raster of source pixels to represent presence/absence of projects to use as second input into the cumulative cost function. We then run `cumulativeCost` for each project set to a maximum influence distance from the source pixels of 15 km. (See Appendix 3, Section 1).

Exponential decay transformation

We then parametrise the outputs of `cumulativeCost` following an exponential decay function such that influence falls to ~1% at the 15 km limit (See Appendix 3, Section 1). The decay function is applied to the slope adjusted least-cost distances of the 87 project raster layers to account for the potential impact propagation following a trend that aligns with existing evidence on how impacts propagate across the landscape.

The use of least-cost slope-impeded distance rather than Euclidean distance aligns the decay with plausible movement and access pathways. Together, these settings can capture indirect and cumulative propagation along low-cost routes and avoid edge effects when multiple projects or corridors overlap, without implying uniform ecological effects out to tens of kilometres.

4.2.5. Aggregation of projects into corridors

A 'development corridor' project potentially spans across many cells and is characterized by having several projects under the same infrastructure development programme crossing several landscapes (Juffe-Bignoli et al. 2021). Moreover, indirect impacts that go beyond the direct footprint of each project are likely, as are cumulative impacts in places where there is a spatial overlap between several projects. To represent this, *ACD* needs to measure the intensity of impacts including all project overlaps in a given cell (Figure 4.2). Here we assume impacts from multiple infrastructure projects are additive and overlapping influence areas increase total impact intensity. Similar approaches have been taken to estimate accumulation of pressures in terrestrial (Venter et al. 2016; Theobald et al. 2025) and marine realms (Halpern and Fujita 2013).

For corridor and Africa-wide analyses, all ACD raster layers representing each of the development corridor projects are aggregated to produce cumulative influence ACD raster layers for each of the corridors they belong to. This is then aggregated at the continental level.

Thus, for more than 2 projects in the same pixel:

$ACD_{1\text{-}n} = 1 - (1\text{-}ACD_1) * (1\text{-} ACD_2) * \ldots * (1\text{-} ACD_n)$

Where:

n = number of projects that are part of a given development corridor.

ACD_1= Adjusted cost distance *potential impact of project 1*

ACD_2 = Adjusted cost distance *potential impact of project 2*

ACD_n = Adjusted cost distance *potential impact of project n*

4.2.6. Aggregation of existing pressures

We define Existing Pressures (EPs) as the existing pressures in the landscape before considering the potential impacts of a new project (PI_{ep} in Formula 1*)*. Instead of developing new metrics to quantify this, here we use the Human Modification Index (Theobald et al. 2020; 2025). This is a global metric mapped at 90 m resolution that measures the degree of human modification of terrestrial systems, assigning values from 0 (baseline state, no detectable human modification) to 1 (complete human modification). It integrates 13 anthropogenic stressors including urban development, agriculture, mining and energy production, existing roads and railways, night-time lights, and population density. Human Modification values between 0 and 1 can be interpreted as a relative likelihood that human-driven modification is present or ongoing in each cell. The assumption here is that existing human modification represents the cumulative baseline pressure that interacts with new infrastructure impacts. It is important to note that the human modification index includes some roads and railways that already exist. However, transportation and service corridors included in this analyses are derived from Thorn et al. (2022) where they compiled planned or existing corridors. These initiatives almost in all cases involve upgrading of existing infrastructure, if there is one, and increased development intensity (Juffe Bignoli et al. 2021; Thorn et al. 2022).

Incorporating Human Modification as a measure of existing pressures (EP), the final expression of PII in one cell is:

Formula 2: Potential Impact Intensity for n projects in one cell

PII = 1 – (1- ACD1) * (1- ACD2) *…* (1- ACD n)* (1- EP)

Where:

PII: potential impact intensity of n projects.

n = number of projects that are part of a given development corridor.

ACD: Slope-adjusted least cost distance for n projects in one cell.

EP: probability of impact due to existing pressures in one cell measured through the Human Modification Index.

The formula represents the intensity of ecological impact due to either infrastructure influence, existing pressures, or both.

4.2.7. Exploring the contributions of Potential Impact Intensity components

The Potential Impact Intensity metric is composed of the combined intensity of existing (EP) and new (ACD) pressures. Estimating which of these two components contribute the most to the Potential Impact Intensity values help to better understand risk of impact. To calculate these contributions in relation to the Potential Impact Intensity value, we applied Shapley fair attribution (Shapley, 1953) to the mean values of Potential Impact Intensity and its components.

Potential Impact Intensity is the probability of human impact following:

PII= 1 - (1 - EP)*(1 – ACD)

This represents the probability that either existing pressures or new corridor pressures (or both) contribute to impact. The Shapley value for each pressure is then given by the average of its standalone and marginal contributions:

Contribution of EP=1/2 * (EP+(PII−ACD))

Contribution of ACD=1/2 * (ACD+(PII−EP))

Which means both contributions always sum to PII.

We report these contributions as relative percentages of the PII mean value (Contribution of EP /PII and Contribution of ACD/PII) at country level, in Protected and Conserved Areas, and

Key Biodiversity Areas. This provides a fair decomposition of PII into shares attributable to existing human modification (EP) and new corridor development pressures (ACD).

4.2.8. Using PII to quantify direct, indirect and cumulative impacts

We evaluate the mean Potential Impact Intensity value across each country in continental Africa, for each project, each corridor, in Protected and Conserved Areas (PCAs), and Key Biodiversity Areas (KBAs). We include PCAs because they are the most common area-based approach in conservation (Gurney et al. 2023; Bhola et al. 2021), although many sites are not located in the most important places for biodiversity (Joppa and Pfaff 2009). To address this, we also include KBAs because they have a clearer biodiversity importance component. KBAs are sites that contribute significantly to the global persistence of biodiversity identified through globally standardized criteria and thresholds (IUCN 2016). Some KBAs might fall partially or totally within PCAs boundaries but many are not legally protected. Globally, the mean percentage of each KBAs within PCAs is 47.72% (UNEP-WCMC and IUCN 2024). Direct impacts are measured by calculating the overlap of project routes with countries, PCAs and KBAs. Instead, indirect and cumulative impacts are measured by quantifying overlaps with the Potential Impact Intensity raster.

To explore further how impacts accumulate we compare Potential Impact Intensity for single development corridor projects with the same metric at a corridor level, and country level. We choose as a case study the Lamu Port–South Sudan–Ethiopia Transport corridor (LAPPSET), which spans across Ethiopia, Kenya, and South Sudan, and for which our dataset includes six projects (Figure 4.3). To examine differences between project and corridor impacts in conservation sites we focus on PCAs, specifically in an area with high project and corridors overlaps within LAPSSET. Among the PCAs impacted, we select the three PCAs where more project overlaps occur to examine Potential Impact Intensity values at a project, corridor and country level.

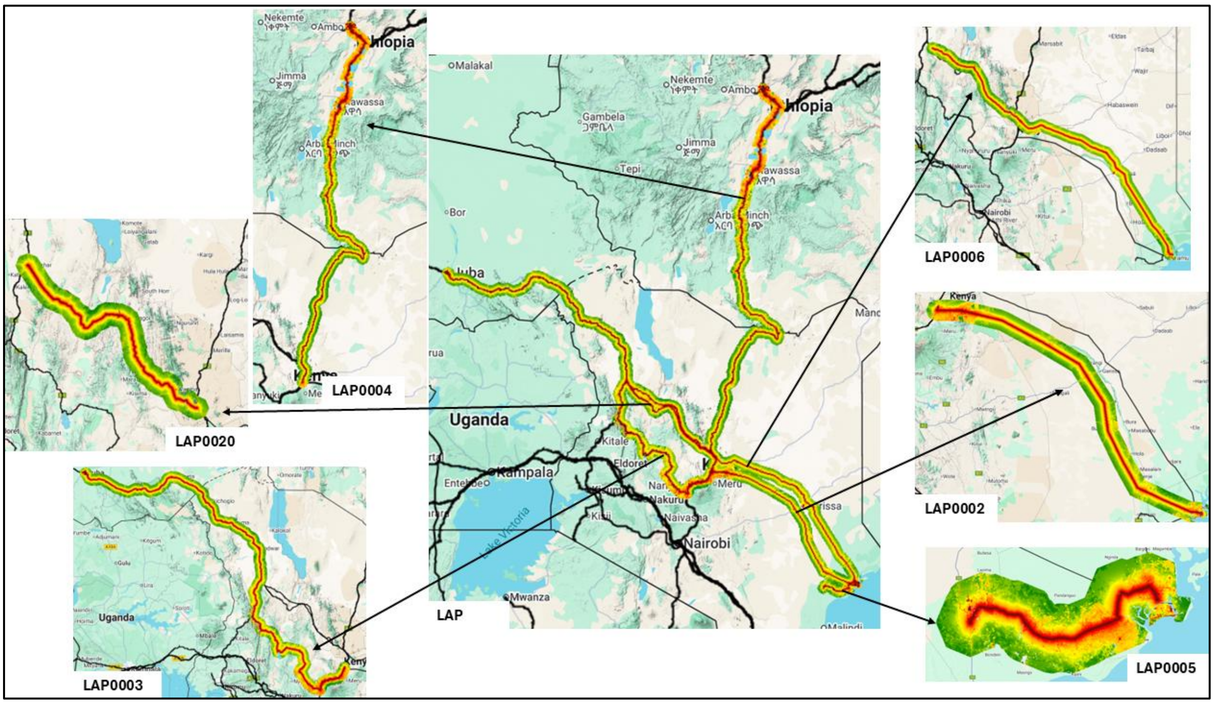


Figure 4.3 The Lamu Port–South Sudan–Ethiopia Transport LAPPSET development corridor (LAP) and the six projects included in this analysis.

4.3. Results

4.3.1. Overview of Development Corridors in Africa

Projects and corridors per country and overlaps, Human Modification baseline

The Development Corridors included have a footprint in 48 countries in Africa (Figure 4.4). The country with the most projects (20) and corridors (13) is the Democratic Republic of Congo, and the corridor initiative crossing most countries (38) is the Trans African Highway (TAH). In some cases, corridor initiatives are using, or propose to use or upgrade, the same existing infrastructure, in other they include new infrastructure across the same landscapes. In Africa, we find between from 2 to 7 projects overlap (Figure 4.4).

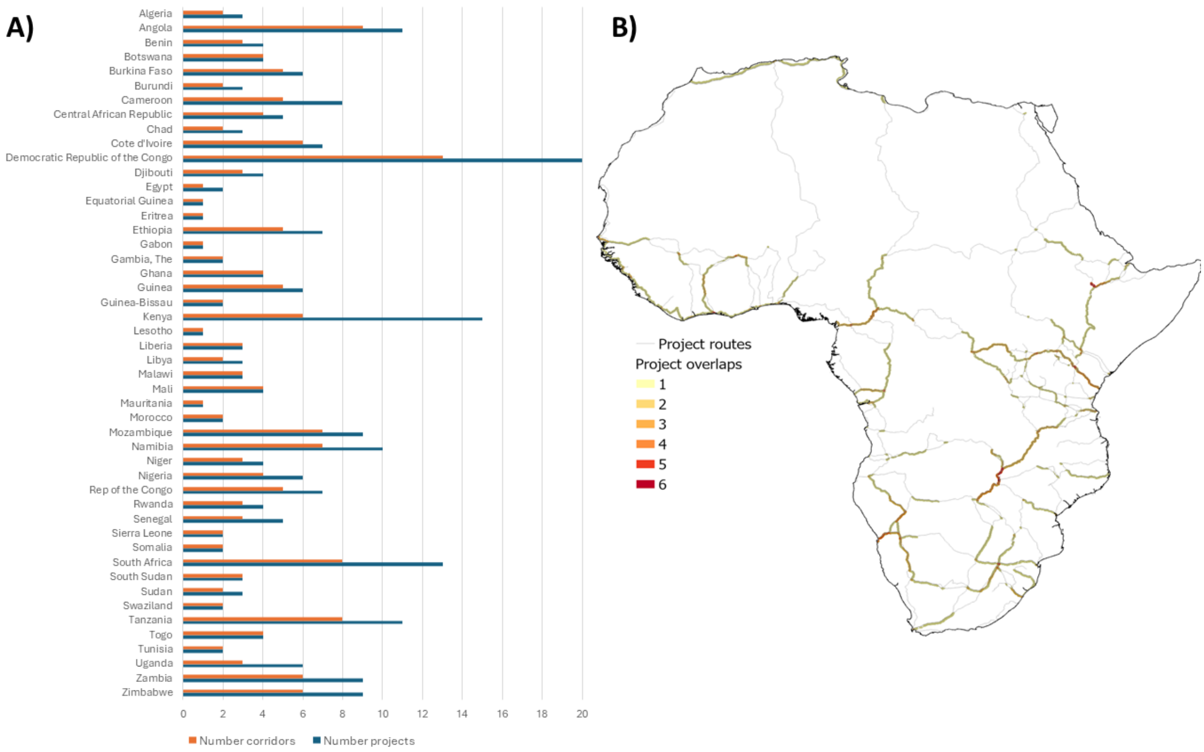


Figure 4.4 A) Number of corridors and projects crossing countries in Africa. B) Number of overlaps of Development Corridors projects in continental Africa.

Conservation sites: Protected and Conserved Areas and Key Biodiversity Areas

Examining direct impacts, the routes of the development corridor projects cut through 8.6% (n = 697) of all protected and conserved areas in continental Africa (n = 8,151) (Figure 4.5) including nine UNESCO World Heritage sites (Appendix 3, Section 4). Similarly, corridor routes directly intersect 297 KBAs, 8.6% of KBAs in continental Africa (n = 1,593).

4.3.2. Cumulative and indirect impacts across Africa

Potential Impact Intensity (PII) in Africa

The mean Potential Impact Intensity value for all African countries is 0.39 (Table). Gambia has the highest PII mean value while the lowest is in South Sudan. Across Africa, incorporating existing pressures (Human Modification) contributes between 6% and 58% to the mean

Potential Impact Intensity value and new pressures (Adjusted Cost Distance) from development corridor projects contribute 42% to 94% (Table 4.2).

Table 4.2 Potential Impact Intensity and associated metrics per country. HM = existing human pressures; ACD = new corridor pressures; PII = combined probability of HM and ACD (see methods). Contributions are shown as fair shares of HM and ACD to PII respectively, calculated by averaging each factor's standalone and joint effects (Shapley, 1953).

Country	HM mean	ACD Mean	PII mean	Existing pressures contribution to PII	New pressures contribution to PII
Algeria	0.25	0.37	0.44	37%	63%
Angola	0.16	0.36	0.36	23%	77%
Benin	0.23	0.35	0.44	37%	63%
Botswana	0.17	0.37	0.36	22%	78%
Burkina Faso	0.22	0.39	0.45	31%	69%
Burundi	0.29	0.40	0.52	39%	61%
Cameroon	0.20	0.42	0.44	24%	76%
Central African Republic	0.08	0.37	0.34	6%	94%
Chad	0.14	0.34	0.34	21%	79%
Cote d'Ivoire	0.19	0.41	0.44	26%	74%
Democratic Republic of the Congo	0.18	0.40	0.43	24%	76%
Djibouti	0.13	0.40	0.40	16%	84%
Egypt	0.41	0.34	0.46	58%	42%
Equatorial Guinea	0.20	0.37	0.38	29%	71%
Eritrea	0.13	0.34	0.33	19%	81%
Ethiopia	0.18	0.40	0.45	25%	75%
Gabon	0.19	0.34	0.36	29%	71%
Gambia, The	0.29	0.50	0.63	34%	66%
Ghana	0.23	0.40	0.49	33%	67%
Guinea	0.12	0.43	0.41	12%	88%
Guinea-Bissau	0.13	0.46	0.46	14%	86%
Kenya	0.18	0.42	0.46	24%	76%
Lesotho	0.25	0.35	0.55	41%	59%
Liberia	0.17	0.42	0.42	20%	80%
Libya	0.23	0.37	0.42	33%	67%
Malawi	0.32	0.36	0.51	46%	54%
Mali	0.17	0.35	0.39	27%	73%
Mauritania	0.10	0.35	0.35	14%	86%
Morocco	0.26	0.38	0.49	38%	62%
Mozambique	0.19	0.38	0.40	26%	74%
Namibia	0.16	0.44	0.42	16%	84%
Niger	0.19	0.33	0.36	31%	69%
Nigeria	0.30	0.36	0.49	44%	56%
Republic of the Congo	0.16	0.42	0.41	19%	81%
Rwanda	0.40	0.37	0.58	52%	48%

Senegal	0.19	0.42	0.51	28%	72%
Sierra Leone	0.15	0.44	0.44	17%	83%
Somalia	0.10	0.34	0.35	16%	84%
South Africa	0.21	0.39	0.42	29%	71%
South Sudan	0.09	0.33	0.30	9%	91%
Sudan	0.19	0.35	0.39	30%	70%
Swaziland	0.25	0.30	0.42	44%	56%
Tanzania	0.25	0.37	0.44	36%	64%
Togo	0.26	0.34	0.44	41%	59%
Tunisia	0.29	0.45	0.54	35%	65%
Uganda	0.29	0.41	0.52	38%	62%
Zambia	0.19	0.46	0.48	22%	78%
Zimbabwe	0.22	0.35	0.37	31%	69%

Potential Impact Intensity (PII) in conservation sites across Africa

Based on our Potential Impact Intensity metric, in total 327,406 km^2 of land within PCAs in Africa is at risk from infrastructure development. This covers 30.5% of the 2,485 PCAs in continental Africa and 8.6% of their combined PCA area (Figure , Appendix 3, Section 4 for full results). Compared to only considering direct impacts (i.e. only corridor routes) this is 1,788 more sites, a 257% increase. South Africa (605), Tanzania (342), and Uganda (225) have the greatest number of PCAs at risk by Development Corridors.

For KBAs, 679 are at risk, 129% more than considering only direct impacts (Figure 4.7), with 234,666 km^2 of land in KBAs at risk. This represents 7.7% of the combined KBA area in continental Africa, a 129% increase (Figure , Appendix 3, Section 4 for full results). Importantly, 45.1% of KBAs at risk are in protected and conserved areas.

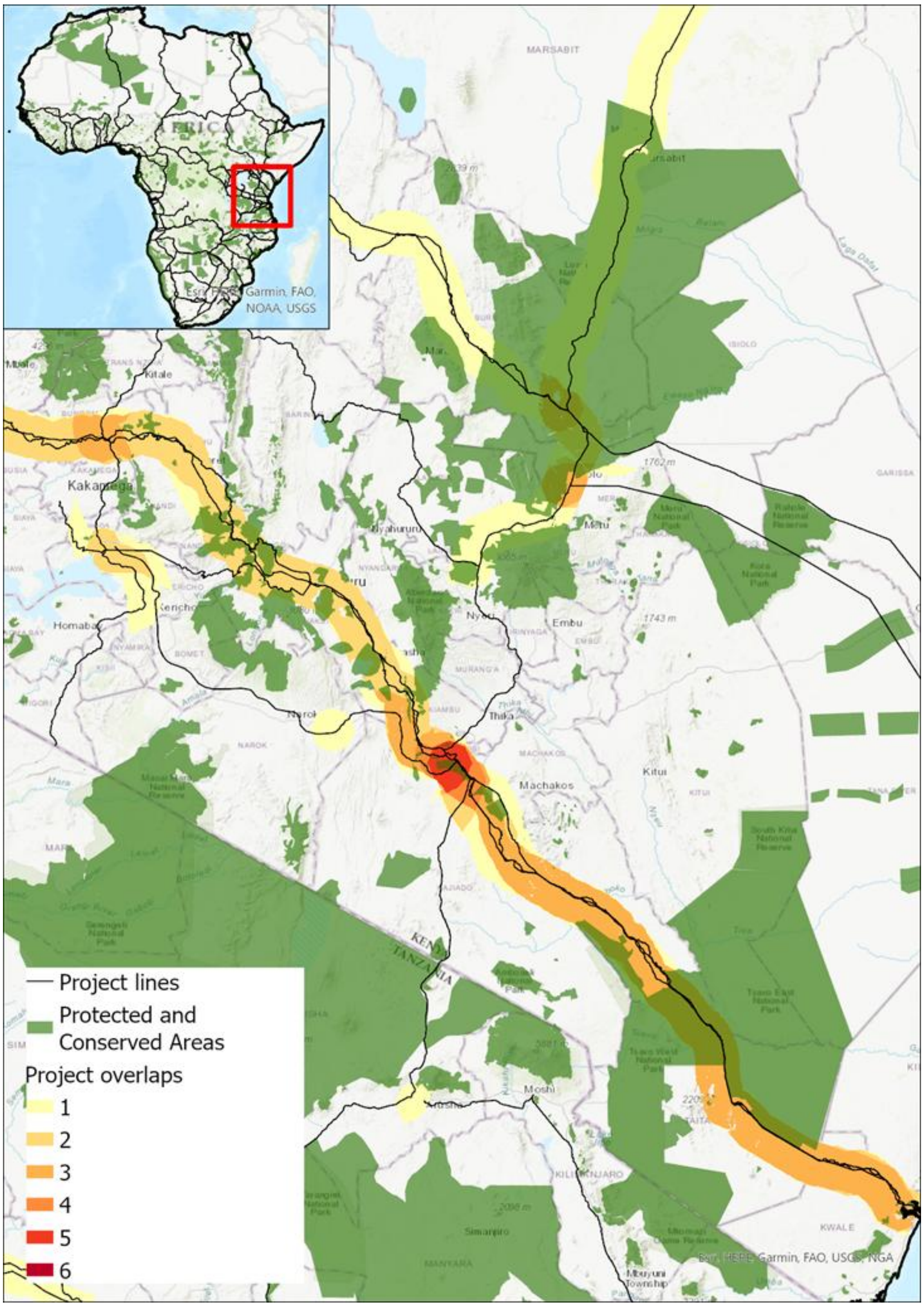


Figure 4.5 Numbers of overlaps of Development Corridors projects and location of Protected and Conserved Areas (PCAs). Map detail into southern Kenya and northern Tanzania.

Contributions of existing pressures to PII values in protected and conserved areas (Figure 4.7A) range from 9%-54% and for new pressures between 46%-91%. Gambia has the highest mean PII in PCAs, with an 81% contribution from Development Corridors pressures. Rwanda is the only country where existing pressures (54%) have a higher contribution to PII than new pressures (46%). KBAs follow a similar pattern: existing pressures contribute 14% to 74% to the PII values and new pressures 26% to 86% (Figure 4.7B).

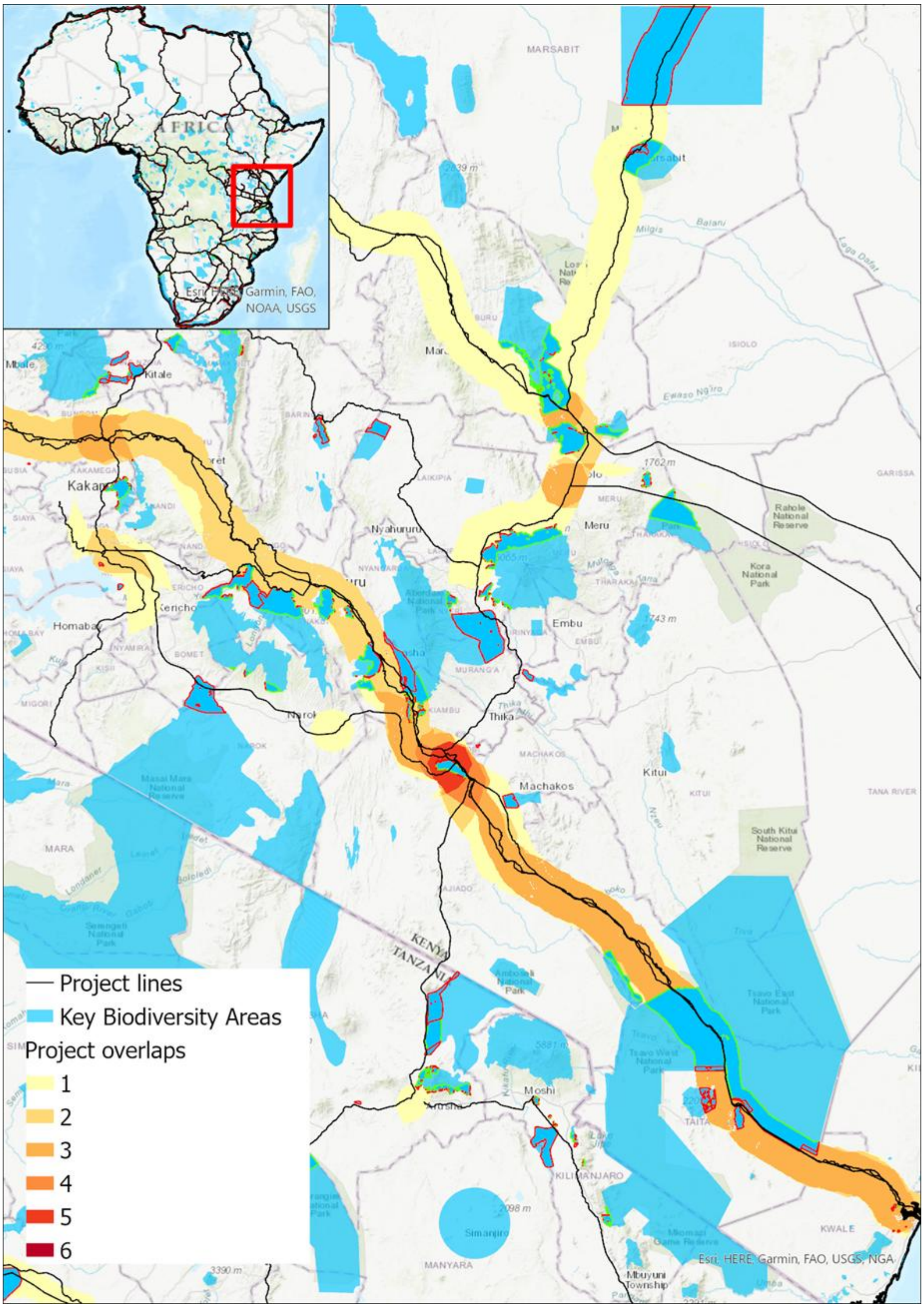
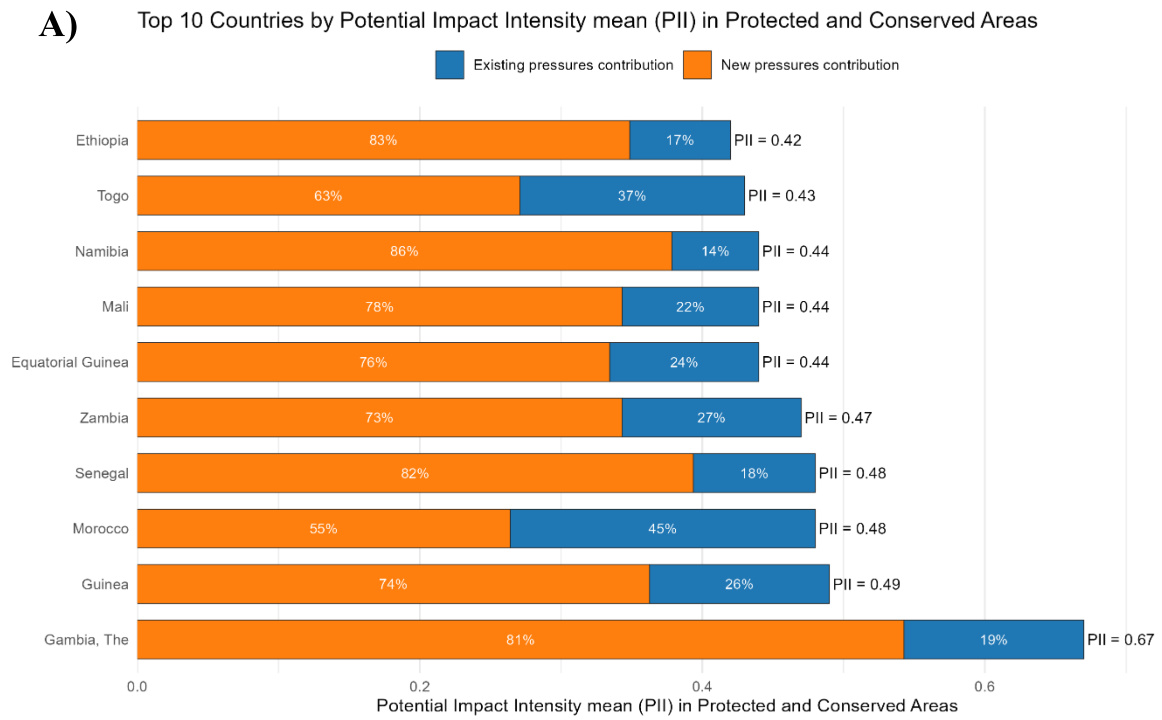


Figure 4.6 Number of overlaps of Development Corridors projects and location of Key biodiversity Areas. Map detail into southern Kenya and northern Tanzania. Portions of KBAs within 15 km of the projects are marked with red border: not in PCAs and Green Border: in PCAs



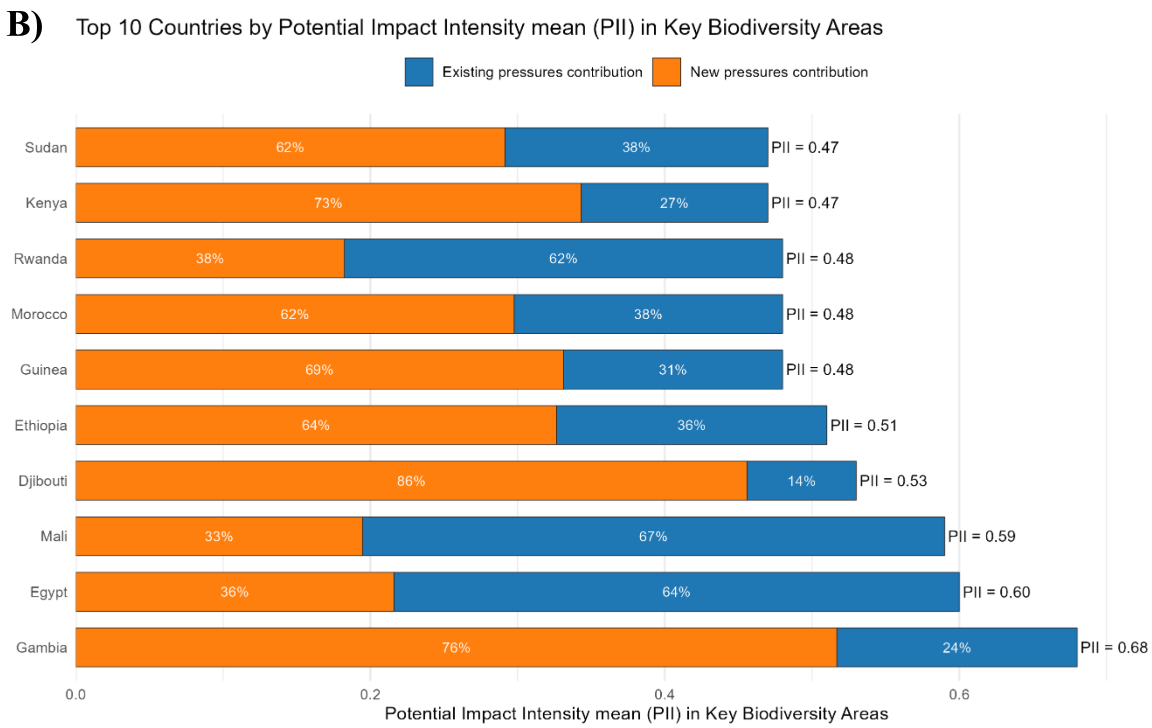


Figure 4.7 Potential Impact Intensity and associated metrics for the 10 top countries in (A) Protected and Conserved Areas, (B) Key Biodiversity Areas Contributions are shown as fair shares of HM and ACD to PII respectively, calculated by averaging each factor's standalone and joint effects (Shapley, 1953) (See methods).

Comparing single project vs corridor initiatives; LAPPSET case study

Potential Impact Intensity values in LAPPSET area increase by a range of 2-15% when single projects are combined into the LAPSSET corridor, and by 38% in Kenya, 9% in Ethiopia and 3% in South Sudan when all Development Corridors in each country are considered (Figure 4.8).

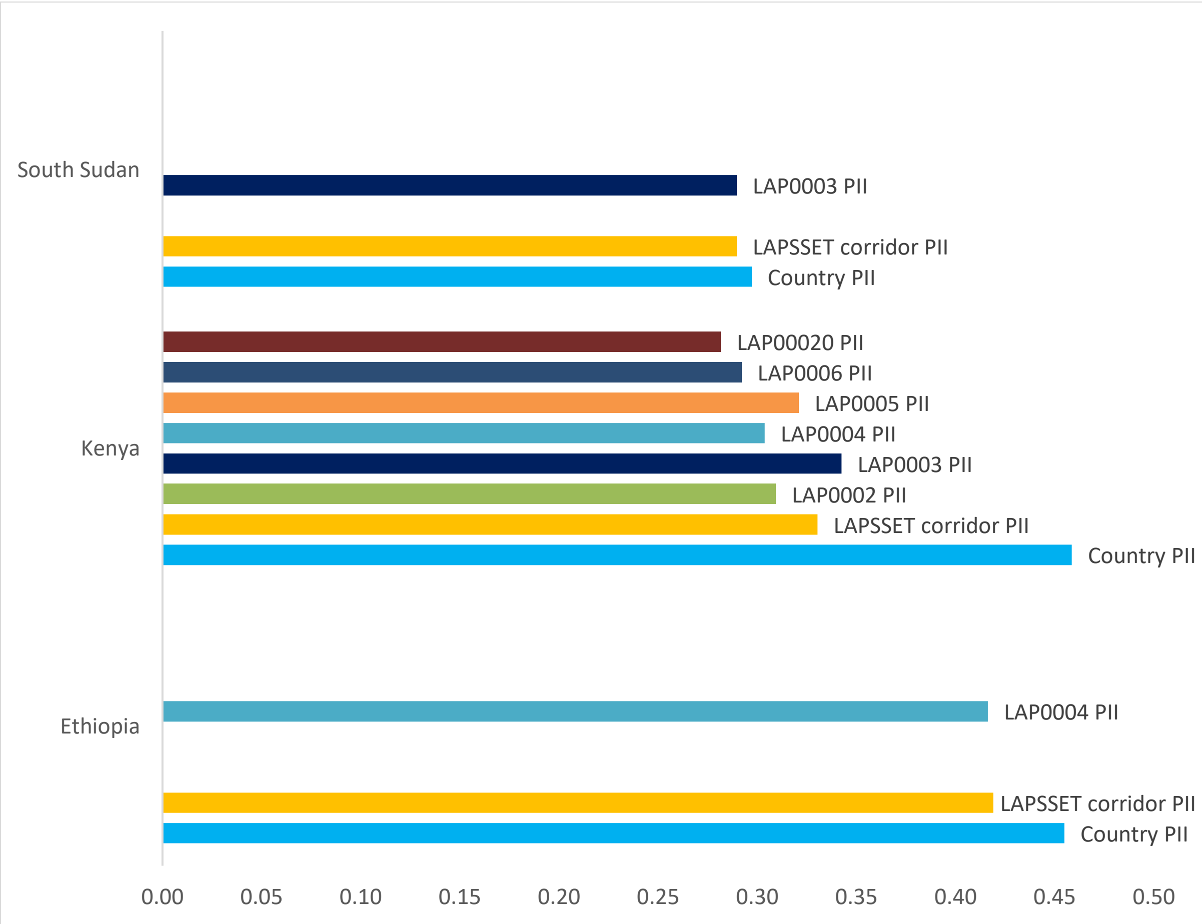


Figure 4.8 Potential Impact Intensity (PII) mean values for the LAPSSET corridor (in orange) area in each country (Country PII in light blue), and project (From LAP0002 to LAP 00020 in different colours). See Appendix 3, Section 4 for full results.

In total, 71 PCAs are at risk from projects included in the LAPSSET corridor but also from other projects from other corridor initiatives planned in Kenya. Between 3-4 projects cross the 3 protected areas included in our case study (Figure 4.9). We find, for example, that LAPSSET corridor Potential Impact Intensity in ILRI Conservancy Wildlife Conservancy is up to 118% higher (0.72) than only considering project LAP004 PII (0.33). We find similar increases between LAPSSET and project LAP0003 (0.35 and 0.16, 118% increase) in Kalama Community Wildlife Conservancy, and less between Trans African Highways corridor and project TAH0008 (0.64 and 0.48, 33% increase) in Nairobi National Park. Considering country PII values in the same sites, which include aggregation of all projects in Kenya in that space, values are up to 225% (ILRI Conservancy), 156% (Nairobi National Park), and 100 % (Kalama Community Wildlife Conservancy) higher than considering only project PII values (Figure , full results in Appendix 3, Section 4).

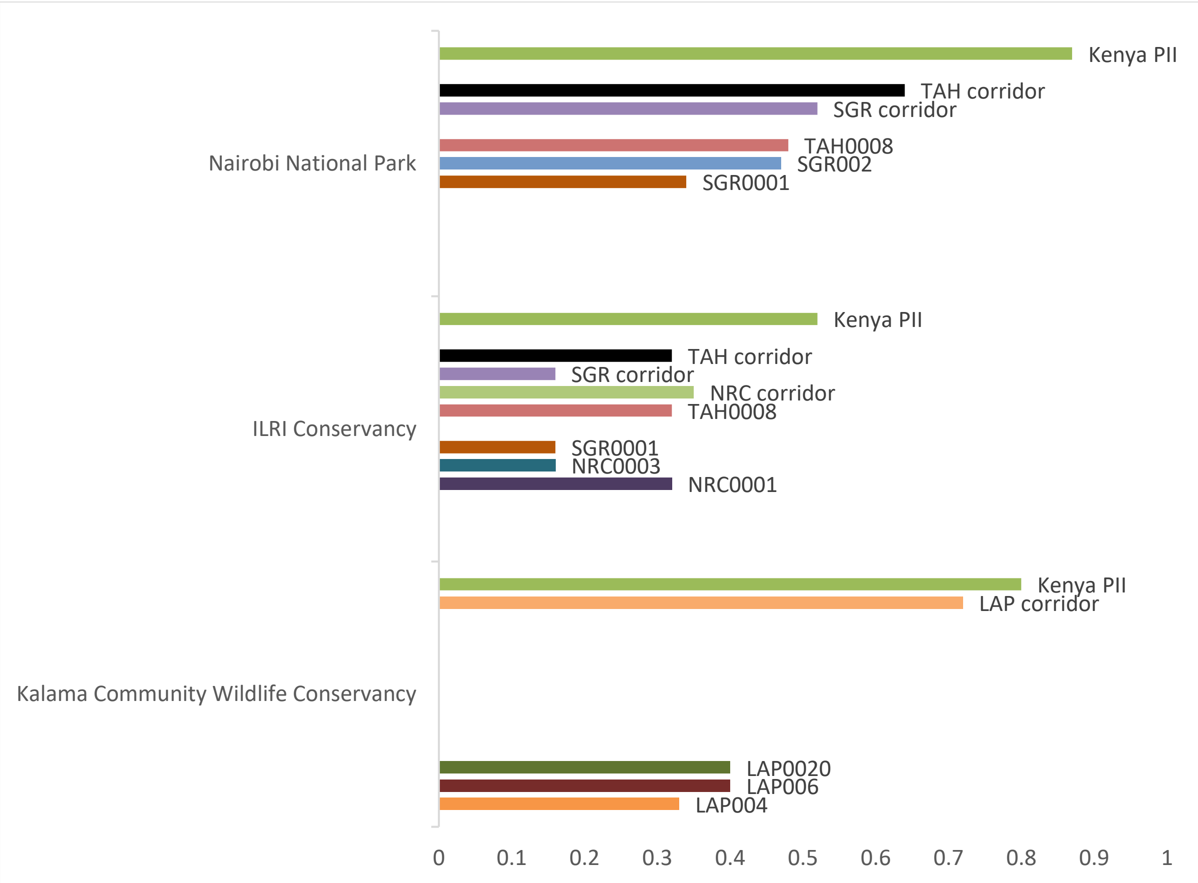


Figure 4.9 Potential Impact Intensity (PII) mean values for projects and corridors in three Protected and Conserved Areas in Kenya. LAP: LAPSSET corridor; TAH: Trans African Highways corridor; SGR: Standard Gauge Railway; NRC: Northern Corridor. Number codes correspond to projects in each corridor found in each site. For example, SGR0001 is a Standard Gauge Railway project crossing ILRI Conservancy and Nairobi National Park.

4.4. Discussion

We developed a spatially explicit methodological framework to explore potential direct, indirect and cumulative impacts when several large infrastructure projects interact in the same landscapes, and applied it to 87 projects from 51 Development Corridors across continental Africa. When aggregated from projects into corridors, PII quantifies the intensity of impact in the landscape combining new with existing pressures, and accounts for potential effects of direct, indirect and cumulative impacts up to a chosen maximum distance to the source of impact. Here we discuss the contribution of this work to research quantifying effects of indirect and cumulative impacts on biodiversity; and to what extent our framework could support actions to improve impact assessment in practice.

4.4.1. Quantifying the effects of indirect and cumulative impacts indirect

We can distinguish two broad approaches to assess potential effects from human activity on biodiversity: i) aggregation of pressures known to cause biodiversity degradation and loss across large spatial extents; and ii) aggregations of pressures known to affect species or habitats in specific locations.

There are several examples of metrics based on one-off large-scale aggregations of pressures at global level for the terrestrial (Venter et al. 2016; Theobald et al. 2025) and marine realms (Halpern and Fujita 2013), as well as rivers (Grill et al. 2019). The assumption is that the accumulation of multiple pressures will result in indirect and cumulative potential impacts degrading biodiversity. The metrics represent a proxy for this potential modification which can then be used to estimate other consequences or explore actions to reduce those pressures. For example, the Human Footprint (HFP) metric (Venter et al. 2016) has been used to evaluate functional connectivity among protected areas (Brennan et al. 2022) and to demonstrate that changes in HFP can predict changes in species' extinction risk across vertebrates (Di Marco et al. 2018). Engert et al. (2025) quantified large scale aggregation of pressures and their effects on biodiversity but focused only on effects of roads on forests. They developed a framework to determine impacts from primary roads (first cut roads into forest habitats) and secondary roads (derived from primary roads) in the Brazilian Amazon, the Congo Basin, and New Guinea. They used a combination of travel maps, Euclidean distance and land use data to estimate impacts. Impacts on forests from secondary roads were 31.5, 22.2, and 305.2 times respectively greater than those from primary roads.

Among assessments of multiple stressors for single species or habitats in specific locations, we find Griffiths et al. (2024). They used statistical models of fish abundance to quantify associations among threats and biophysical covariates to predict where cumulative impacts are likely to have the greatest impact on fish in marine habitats in North South Wales, Australia. They found that fishing had a more synergistic effect on populations than water quality. In Norway, Niebuhr et al. (2023) estimated cumulative impacts of tourist infrastructure on the habitat of wild Reindeer through empirical models representing pressures and also using also a decay function. They showed that while the impact of one isolated cabin was negligible, the cumulative impact of 'cabin villages' could be much larger than that of a single large tourist resort.

Other research has combined spatially explicit approaches with different types of knowledge to predict indirect and cumulative impacts. For example, Tulloch et al. (2019) combine spatial extent assessment with expert elicited magnitudes to determine impacts beyond direct footprint. In another study, a spatial future-focused model informed by local indigenous knowledge was used to assess regional cumulative effects of development on ecosystems across the land and sea (Tulloch et al. 2024). In both papers they found significantly more impact to be likely to materialise when indirect and cumulative effects are considered.

Our spatially explicit approach uses a distance decay function and 0-1 value ranges as in Venter et al. (2016) and Niebuhr (2023). However, our approach allows the inclusion of any spatial feature into the framework and analysis to assess differences between effects of features alone and the features combined. As in Engert et al. (2024) we estimate distance from source, but we did not use travel time to estimate effects from the source. Instead, rather we used the existing literature on the spatial extent of impacts on biodiversity from source to select different effect distances, and then ran a sensitivity analysis to inform which distance to apply in our model. Our analysis incorporates the effect of slope to determine the likelihood of an impact that has not been widely applied. More importantly, the parameters and input files in our framework can be changed in the GEE script and therefore can test different projects and their potential effects. Thus, while in this study we integrated the Human Modification Index into the framework as a measure of existing pressures, there is scope for using any similar metric. Similarly, while we investigated Development Corridors in our case study, any infrastructure project could be assessed by mapping its footprint and assigning an appropriate distance from the impact source.

We take a conservative approach in this analysis, assuming all projects have the potential to cause negative impacts, irrespective of their completion status. Although defining the status of each project can help inform project specific mitigation actions, given the inherent uncertainly and often changing nature of corridor and infrastructure development initiatives in general (Juffe Bignoli et al. 2024; Mahmoud et al. 2017; Engert et al. 2024), this analysis can be taken as a snapshot in time of a potential future if all planned and existing projects come together.

Regarding projects following existing roads, areas signalled for Development Corridors are, by definition, areas where human activity will increase over time. Again, this can inform this potential future of impact accumulation.

Our approach can give an indication of accumulation of risk in each pixel across the landscape and can help identify high risk areas. For example, risk hotspots, where there is more overlap of corridor projects (Figure 4.6), emerge mainly in sub–Saharan Africa, most alarmingly across the Albertine rift and southern Africa known to hold several global biodiversity hotspots. This approach shows the potential risk of large-scale projects crossing numerous countries, such as the Trans African Highway. It can also highlight risks to highly biodiverse countries such as the Democratic Republic of Congo, Kenya and Tanzania, which are crossed by more corridors and projects than any other. Similarly, a systematic review of the reported effects of roads and their underlying mechanisms inside and outside protected areas across in Sub Saharan Africa found the negative effects of roads on species reported at a similar frequency within and outside of protected areas (Perumal et al. 2021).

It is important to acknowledge that we did not assess the potential effects of development corridor projects on people´s livelihoods nor the role of the socio-economic context in how risks emerge. Development Corridors are complex initiatives that integrate a suite of highly interrelated economic, social and environmental objectives, and these should not be assessed in isolation (Juffe Bignoli et al. 2024; DCP 2022; Müller-Mahn 2020; Juffe-Bignoli et al. 2021). Nevertheless, our approach allows an understanding of one important part of the equation by quantifying the relative contribution of different kind of pressures in the natural landscape. This can support decisions about avoiding or mitigating potential negative environmental impacts, as well as facilitate exploration of mitigation actions to achieve better biodiversity outcomes, but this will have to also consider effects on people (Jones et al. 2019; Mancini et al. 2024; Biber-Freudenberger et al. 2025).

4.4.2. Actions towards improving impact assessment practice

The aim of impact assessment process such as Environmental Impact Assessments and Strategic Environmental Assessments is to inform decision-makers about the full spectrum of environmental and social costs and benefits associated with projects. Yet in practice, in the context of biodiversity impact avoidance and mitigation, many assessments remain superficial or proposed mitigation measures are not implemented at all (Kruger and Pohlo 2022; Cooper and Sheate 2002; Bigard et al. 2017; Simmonds, Reside, et al. 2020), particularly where capacity and enforcement mechanisms may be weak (Juffe Bignoli et al. 2024; DCP 2022). Our methodological framework can be adapted to any context and become a useful input to inform decisions on actions that could improve impact assessment outcomes. Below we explore this, distinguishing between policy level actions and on the ground actions.

Policy level actions are those that take place independently of project approval but that could have a strong influence in the approval processes (e.g. impact assessment regulations). To ensure the conservation of biodiversity, clear conservation objectives need to be defined alongside development objectives (Sayer et al. 2013; Reed et al. 2016). These should not only be site-level considerations, but landscape-scale goals to avoid disruption of wildlife corridors and ecological processes and loss of ecological connectivity (Keeley et al. 2019; Torres et al. 2022). This involves mapping all important conservation values and developing integrated landscape management strategies, as well as, when appropriate, delineating new and enhanced management of existing wildlife corridors or transboundary conservation areas (Kamath et al. 2023). Some policy level actions could include: i) a national planning approach that integrates development and conservation needs; ii) impact assessment policies, programmes and plans that are proactive and outcome oriented; and iii) allocating sufficient funding to support implementation of i and ii. Our methodological approach can inform i) by helping to identify areas were high Potential Impact Intensity values and conservation importance converge, and to set safeguards in the planning process to avoid those risks from the outset and facilitate the achievement of conservation and development goals.

On the ground actions are shaped by existing policies, plans and programmes and their implementation. They are more specific actions, taken at a site level but also across large spatial extents. For example, in a road development carefully selecting the best places for wildlife crossings in the planning phase, mitigation measures during construction, or restoration and compensation measures after construction. On the ground actions should focus on i) achieving the policy level defined outcomes through spatial planning and prioritising mitigation actions; and ii) designing those actions following the mitigation hierarchy at landscape level to avoid, minimise, restore and compensate for any unavoidable impacts, and iii) embrace adaptive management to change mitigation measures when there is evidence these are not working. Using Potential Impact Intensity and its associated metrics can help quantify direct, indirect and cumulative impacts for specific projects at high resolution and model the effects of avoidance, mitigation and compensation measures to support final decisions.

An approach that could help link policy action to on the ground actions is Systematic Conservation Planning (Margules and Pressey 2000; Pressey and Bottrill 2009), a widely used framework for designing a portfolio of solutions that meet a series of conservation targets. It is a goal-driven, data-based process for identifying, designing, and managing networks of places that conserve biodiversity and ecosystem services at a minimum cost. In the context of development and conservation it has already been used to incorporate conservation priorities when planning for developments (Kiesecker et al. 2020; Heiner et al. 2019a; Saenz et al. 2013) or to plan a landscape for conservation and people (Perschke et al. 2024). Potential Impact Intensity could be used as an input layer to these assessments or to identify areas of high risk that could be prioritised for restoration and protection.

4.4.3. Conclusion

To harmonise infrastructure development with biodiversity conservation anywhere in the world, impact assessment processes must be robustly completed and rigorously implemented. Central to this is adherence to the mitigation hierarchy, and consideration of direct, indirect, and cumulative impacts across the landscape, but the latter has historically been lacking. Here we take a step towards a more structured and systematic quantification of impacts that considers the contribution of indirect and cumulative effects and allows us to explore the relative differences between them, which in turn could help us to design more effective avoidance and mitigation measures.

5. Chapter 5 Towards more sustainable and inclusive Development Corridors in Africa

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Manuscript published as: Juffe Bignoli, Diego Juffe, Neil Burgess, Amayaa Wijesinghe, et al. 2024. 'Towards More Sustainable and Inclusive Development Corridors in Africa'. Environmental Research: Infrastructure and Sustainability 4 (3): 035012. https://doi.org/10.1088/2634-4505/ad7887.

Abstract

Development Corridors are linear programmes of infrastructure and agriculture aiming to facilitate rapid socio-economic development. In Africa, they are a major development activity, with 88 underway or planned corridors. Drawing from extensive literature and insights gleaned from a 4-year research programme, this review scrutinizes the impacts of Development Corridors on people, wildlife and ecosystems in Kenya and Tanzania, proposing solutions to achieve better outcomes. The overarching goal was to discern the principal challenges emerging from the practical execution of the prevailing corridor model. The holistic approach taken, assessing the Development Corridors paradigm through an integrated ecological, social, and economic lens, provides novel insights that have not been possible using more traditional—siloed—research approaches. Eight key challenge areas are identified: impact assessments processes; coherence across international, national and local planning; governance; inclusivity; equality; impacts on biodiversity and ecosystem services; incorporation of future climate risks; and integrated water resource management. Poorly planned and implemented corridors detrimentally impact livelihoods and ecosystems. They lack a sustainable development vision, detailed social, environmental or climate risk assessments, and develop incrementally in policy and corporate spaces. There is also often a disconnect between investors and recipient governments, with some investors funding what governments request without applying internationally recognised safeguards, and governments lacking capacity and resources to enforce regulations. We make recommendations for addressing these challenge areas. These aim to enhance impact assessment efficacy; integrate local perspectives into effective and inclusive corridor planning; overcome siloed project development and implementation; anticipate future development projections; and prioritise landscape preservation for enhanced ecosystem services and climate resilience.

5.1. Introduction

5.1.1. What are Development Corridors?

Development Corridors are large, linear, and often transnational geographical areas targeted for investment (Gannon 2022; Thorn et al. 2022; Sang et al. 2022; Nyumba et al. 2021; Lesutis 2020; Juffe-Bignoli et al. 2021). Conceptually, corridors evolve over time from transport corridors (the simplest manifestation) through to programmes aiming to achieve multiple social and economic objectives (The Development Corridor Partnership 2022). They frequently involve clustering of investments, logistics, and market integration and are formed with links to different national spatial development initiatives (Gannon et al. 2022; Healey 2004; World Bank 2009). Development Corridors are a global phenomenon spread in all continents across the globe (Juffe-Bignoli et al. 2021). A notable example of scaling Development Corridors to the global scale is the Belt and Road Initiative (BRI). Launched in 2013 and led by the Chinese Government, this initiative has connectivity of infrastructure as one of its five priority areas (Narain et al. 2020). Itcomprises six main economic corridors; China–Mongolia–Russia Economic Corridor, New Eurasian Land Bridge, China–Central Asia–West Asia Economic Corridor, China–Indochina Peninsula Economic Corridor, China–Pakistan Economic Corridor, Bangladesh–China–India–Myanmar Economic Corridor (OECD 2018). The BRI encompasses nearly 70 countries and international organisations, one third of global trade and GDP and impacts 60% of the world's population (Huang et al. 2020; Schulhof et al. 2022). However, as with other corridor initiatives, concerns about the BRI adequately addressing social and environmental impacts have been raised (Narain and Maron 2022).

Practically, corridors are implemented in a series of phases with variable duration, involving diverse actors depending on the context (Figure 5.1). In principle, these phases provide opportunities for corridor impacts to be assessed.

Several positive societal outcomes are envisaged through Development Corridors (Kirshner and Baptista 2023). However, limited evidence exists regarding the efficacy of Development Corridors in enhancing the lives of people in developing nations, especially those already in poverty or marginalised from mainstream development. There is some evidence that large-scale transport infrastructures associated with corridor development amplify preexisting social and economic disparities (Lesutis 2022c; 2022a; 2022b), while causing considerable ecological damage (Hughes 2019; Sloan, Alamgir, et al. 2019; Sloan, Campbell, et al. 2019; Ascensão 2018; Laurance et al. 2015a). Moreover, part of the failure of Development Corridors to fully realise their potential could stem from compartmentalised, siloed strategies or limited scopes of defining objectives and gauging measures of success (Gannon 2022; Gannon et al. 2022; Gannon 2023; Enns 2018).

Acknowledging the significance of these investments for national development and their capacity to deliver both favourable and adverse impacts, the United Nations adopted a key resolution on sustainable and resilient infrastructure at the 5th United Nations Environment Assembly in March 2022 (Box 5.1), now in the process of implementation.

Box 5.1 United Nations Environment Assembly resolution 5/9 on sustainable and resilient infrastructure adopted on 2 March 2022.

This resolution (United Nations Environment Assembly 2022) encourages Member States and other stakeholders to undertake key actions, with the most relevant for development corridors summarised below:

Consider integrating and implementing the 10 'International Good Practice Principles for Sustainable Infrastructure' (United Nations Environment Programme 2021) into national policies;

Implement existing tools, such as guidelines and best practices, including those developed under or endorsed by multilateral environmental agreements (MEAs);

Cooperate internationally to strengthen frameworks, including for financing, for sustainable and inclusive infrastructure that maintains and enhances ecological connectivity, avoids further fragmentation, and minimizes other potential impacts on ecosystems and livelihoods;

Conduct strategic and environmental impact assessments (EIAs) so that environmental considerations are integrated into decision-making at appropriate levels;

Promote investment in natural infrastructure and nature-based solutions for delivering essential services and improving ecosystem services, creating employment and accelerating the achievement of the Sustainable Development Goals (SDGs);

Promote investment in infrastructure that is environmentally, socially and economically sustainable, climate resilient, resource efficient, that prevents ecosystem fragmentation and contributes to sustainable production and consumption patterns;

Provide opportunities for the engagement of relevant stakeholders, including local communities, vulnerable people and indigenous peoples, in all stages of the process to identify, design, build and maintain infrastructure.

5.1.2. Development Corridors in Africa

African nations propose to implement at least 88 major Development Corridors over the coming decades (Thorn et al. 2022; Laurance et al. 2015a). These corridors typically aim to stimulate economic activity, involving the construction of various types of linear infrastructure projects, intertwined with agriculture and natural resource extraction (Sang et al. 2022; Juffe-Bignoli et al. 2021; Laurance et al. 2015a; Müller-Mahn 2020). The main transport investments for African Development Corridors are roads (34.8%), ports (20.7%), railways (17.9%) and airports (7.6%). Additionally, corridor investments commonly entail the development of resort towns, electricity transmission lines, dry ports, industrial parks, and water pipelines. These undertakings represent significant investment, ranging from USD 547 to 659 billion (Thorn et al. 2022). Exacerbated by protracted, long-term investment horizons and contractual repayment agreements, these projects have the potential to lock in development trajectories of African countries for decades, constraining the capacity of these countries to adapt to evolving circumstances.

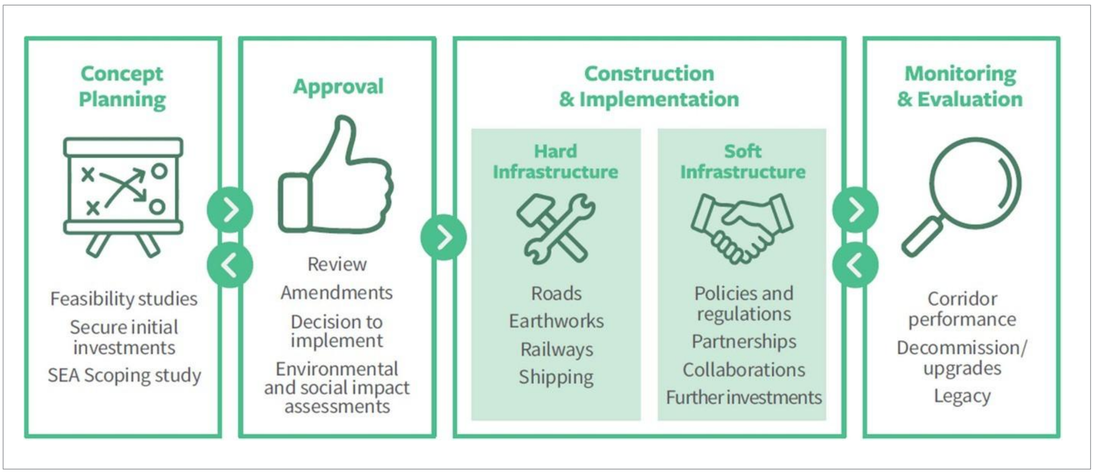

Figure 5.1 Phases of development corridors. Adapted from Juffe Bignoli et al. (2022).

Here, in a unique interdisciplinary study, four years of field-study and policy-synthesis undertaken through the Development Corridors Partnership (DCP) work in Africa (Box 5.2) are reviewed and synthesised into eight challenge areas concerning the implementation of corridors. This includes original works published by DCP, but also additional relevant literature not produced by the partnership. Available solutions to overcome these challenges are also explored, as well as final recommendations for more sustainable Development Corridors in Africa. Building from the results of the DCP project, the overarching goal of this paper is to summarise the main challenges emerging from the practical execution of the prevailing corridor model and explore potential remedies for those challenges.

Box 5.2 The Development Corridors Partnership (DCP) project.

The DCP project ran for four years from 2018 to early 2022 (Development Corridors Partnership 2023a), aiming to enhance the understanding of development corridors and their contribution to delivering the SDGs. This interdisciplinary project involved anthropologists, social scientists, ecologists, biologists, hydrologists, climatologists, and those with development expertise. The research scope was to study selected corridors in Kenya and Tanzania, map development corridors across Africa, and learn from similar interventions in China. The aim of the project was to develop an understanding of development corridor practice within these geographies and learn lessons that are applicable globally. Almost 150 outputs were produced by DCP, using insights gathered from thousands of people in Kenya and Tanzania—and technical experts from Europe and China—who are either benefiting or being affected by development corridors, have invested in them, are involved with planning, or are implementing them on the ground. All DCP resources are openly accessible online (supplementary information) (Development Corridors Partnership 2023b).

5.2. Methods

5.2.1. Overall approach

The Development Corridor´s (DCP) research methodology primarily employed an inductive approach, amalgamating qualitative and quantitative data collection techniques. This included extensive field work led by DCP, literature reviews, expert consultations, and national workshops. In total, excluding workshops, 149 publicly available outputs were produced, including 54 peer reviewed journal papers, 24 book chapters (The Development Corridors Partnership 2022), 11 policy briefs, 11 webinars, 10 reports, training materials, an e-learning course, and a series of workshops in China (n = 2), Tanzania (n = 13), Kenya (n = 13) and the UK (n = 3). These outputs are summarised in supplementary information for this chapter.

An holistic approach assessing the Development Corridors paradigm through an integrated ecological, social, and economic lens has not been done before. Here, DCP researchers delineate eight challenge areas, for which solutions to identified issues are scrutinized, culminating in final conclusions and recommendations. Where relevant, knowledge, resources and research not led by DCP are also included. Although the DCP concentrated its efforts in Kenya and Tanzania, it brought in insights from China and strived to extrapolate its findings to draw conclusions and solutions applicable to a global context.

5.2.2. Study sites

In Kenya, the research focused on the standard gauge railway (SGR) and associated road and infrastructure developments including the Lamu Port, South Sudan, and Ethiopia Transport corridor (LAPSSET) (Development Corridors in Kenya 2019);(Figure 5.2). The SGR stretches from Mombasa to Nairobi and is planned to extend to Uganda and further west. The aim is to increase the ease of travel between large cities, facilitate freight transport and establish local development hubs along its route. The SGR (Huang and Lesutis 2023) has reduced travel time between Mombasa and Nairobi from over ten hours to four. Between 2018 and 2020, annual passenger numbers surged from 1.6 to 4.7 million, while freight volumes increased from 258 000–1.1 million Twenty-foot container Equivalent Units (CAITEC 2021). However, the SGR traverses two National Parks, bisects wildlife migratory corridors (Nyumba and Waruingi 2022), which spurred local opposition and resulted in several litigations over the years (Lesutis 2022b; Huang and Lesutis 2023), and has affected the region’s hydrology and access to water for both people and wildlife (Sang et al. 2022). China has invested in the SGR, providing bilateral financial loans from the Exim Bank of China (Huang and Lesutis 2023) for infrastructure projects and construction and operation services (Strange et al. 2013; Vhumbunu 2016). Although, the SGR funding from China was discontinued without finalising the initially planned trajectory reaching Uganda (Huang and Lesutis 2023; CAITEC 2021), new efforts to moblise funds to finalise the project are underway (Ministry of Foreign Affairs of the Republic of Uganda 2024; Kitimo 2024).

In Tanzania, the focal corridor of research was the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). This agricultural development corridor runs from Dar es Salaam across a large swathe of central Tanzania (DCP Tanzania Development Corridors in Tanzania 2019) (Figure 5.2). Development efforts have concentrated on establishing agricultural clusters and improving infrastructure to facilitate the transportation of crops such as tomato, soybean, dairy, and potato, tea to market. By 2019, over 100 000 smallholder farmers had partnered with SAGCOT Centre-associated private companies, with 41 000 smallholders adopting improved technologies and investing over USD450 million in new businesses (Wellspring 2019). Since its inception in 2013, the corridor has established structures to promote active engagement from government, NGO and private sector partners. A multi-stakeholder 'Green Reference Group' (Southern Agricultural Growth Corridor of Tanzania (SAGCOT) 2023) and corresponding environmental and social 'feeder groups' have been established to provide guidance on issues related to inclusive green growth (Tam 2022).

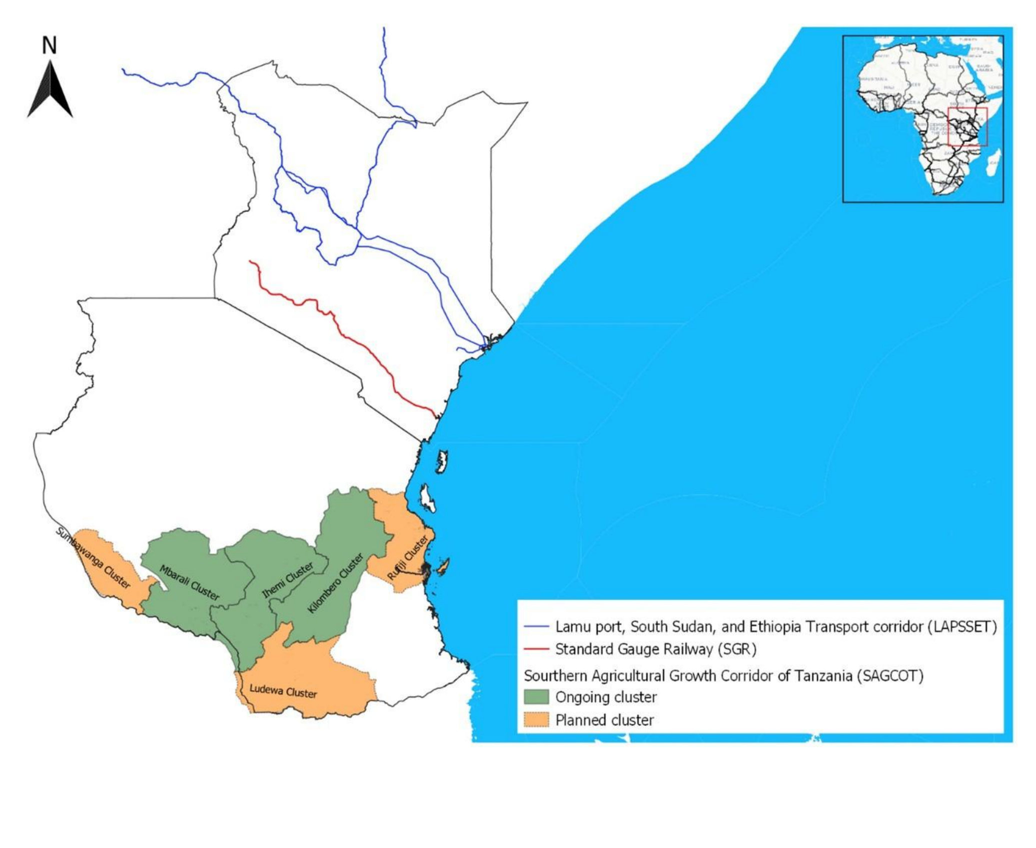

Figure 5.2 Location of development corridors in Kenya and Tanzania that formed the focus of this synthesis. SGR: standard gauge railway. LAPSSET: Lamu port, South Sudan, and Ethiopia Transport corridors. SAGCOT: Southern Agricultural Growth Corridor of Tanzania).

5.2.3. Data collection

Primary data were collected, combining quantitative and qualitative methods, through numerous field work programmes between 2018 and 2021 in Kenya and Tanzania. Qualitative data collection included semi-structured and structured interviews (e.g. (Huang and Lesutis 2023), participatory scenario workshops (e.g. Thorn et al. 2021), household surveys (e.g. Nyumba and Waruingi 2022), reviews (e.g. Juffe-Bignoli et al. 2021), Q-methodology (e.g. Gannon et al. 2022), climate vulnerability assessments (e.g. Siderius 2021) and ethnographic fieldwork (e.g. Lesutis 2022c). Quantitative data collection included land cover change analyses (e.g. Sang et al. 2022), spatial analysis of wildlife corridors (e.g. Taylor 2013), digitising implementing, ongoing and planned Development Corridors (e.g. Thorn et al. 2022, and hydrological modelling (e.g. Siderius 2021). This research was supported by secondary data retrieved from existing literature on the topic as well as from publicly available spatial databases on infrastructure projects, protected areas, land cover, biodiversity, and hydrology. A notable example of spatial analysis was gathering information on ongoing and planned corridors across Africa to create a spatial temporal database of Development Corridors in Africa. This consisted compiling road data from public websites and impact assessment reports and use these to, supported by satellite imagery, delineate, and validate 88 corridors projects in Africa (Thorn et al. 2022).

Complementary insights were obtained through several training courses, collaborative workshops, and extensive stakeholder consultations, as well as desk studies (see Box 5.1). The study topics ranged from social anthropology (Lesutis 2020; 2022c), biodiversity impacts (Nyumba et al. 2021; Juffe-Bignoli et al. 2021), land use change analysis and scenario building (Sang et al. 2022), hydrological modelling (Chilagane et al. 2021; Siderius et al. 2021), impact assessment (Thorn et al. 2022; The Development Corridors Partnership 2022), policy (Gannon et al. 2022; Conway D et al 2021), critical geography (Lesutis 2022c; 2022a; 2022b), among others.

5.3. Eight challenges in the current Development Corridors model

The research findings of DCP are summarised below into eight key challenges Development Corridors currently face. Each issue includes a heading, the issue summarised in one sentence, and a brief narrative with supporting evidence.

5.3.1. Impact assessment processes: poor application of existing best practice guidance in Development Corridors results in adverse outcomes for people and nature

Existing best-practices for designing, implementing, and monitoring the progress of large-scale development projects are not adequately applied by Eastern African and Chinese corridor development partners (Juffe-Bignoli et al. 2021; The Development Corridors Partnership 2022; Narain and Maron 2022). Strategic environmental assessments (SEAs) and environmental and social impact assessments are mandated by law in Kenya and Tanzania, but many do not follow international best practice (The Development Corridors Partnership 2022; Tam 2022; Makula et al. 2022). In Tanzania, despite a strong legal framework for EIAs, and the presence of relevant expertise and quality assurance mechanisms, weak coordination, and limited political will to implement best practice hinders EIAs from realising their full potential (Makula et al. 2022). Furthermore, safeguards commonly applied to grants and loans for large-scale schemes have not always been utilised in both Kenya and Tanzania (Narain et al. 2020; Narain and Maron 2022). This has resulted in environmental damage that could have been avoided, and in impacts on local communities creating in conflicts over land allocation (Enns 2019). Finally, not all large-scale developments have monitoring and evaluation systems in place to ensure current and future adverse outcomes are understood, measured, and addressed (Thorn and Wijesinghe 2021).

5.3.2. Planning coherence: poor integration across sectors and scales generates unintended cumulative impacts

Nationally, there is often inconsistency between corridor development and other government plans (Thorn et al. 2022; Thorn et al. 2021). Overlapping and often conflicting land use planning and ownership result in multiple claims being made to the same areas of land for different uses. For example, corridor plans intersect across Kenyan and Tanzanian national land use and development plans, often affecting implementation. In addition, governments have committed to various MEAs to develop plans to conserve habitats, species, reduce carbon emissions, protect areas of high carbon sequestration potential and safeguard water resources. These MEAs include the UN Framework Convention on

Climate Change (UNFCCC), the UN Convention to Combat Desertification (UNCCD), the Convention on Biological Diversity (CBD), the Convention on Migratory Species, the Ramsar convention on wetlands, the UNESCO World Heritage Convention, or the SDGs. However, corridor planners often lack the capacity to fully consider these commitments and/or are unaware of them or their responsibilities towards them. Moreover, corridor planning requires greater alignment with local government and village land use planning processes, yet this coordinated and integration with corridor design and implementation is often lacking (Thorn et al. 2021).

5.3.3. Effective governance: fragmented and non-inclusive governance hinders effective implementation

In the public sphere, corridors intersect with the institutional mandates of government departments seeking diverse public benefits. However, these are not always mutually reinforcing. Thus trade-offs between public and private benefits that develop incrementally can arise within a landscape (Gannon et al. 2022; Gannon 2023). To enhance governance and coordination, governments sometimes establish a single national focal point (e.g. LAPSSET Corridor Development Authority, SAGCOT Centre). However, their capacity to evaluate the delivery of development goals within their mandates remains limited, often due to the absence of policies that consider development trade-offs and impacts (Gannon et al. 2022; Gannon 2023). Governance systems for corridors need to involve policy makers, land officers, extension staff, protected area managers, and civil society working with communities at the village, local and national levels (Thorn and Wijesinghe 2021). Despite their power in the development discourse, corridors often remain rather nebulous and fragmented, lacking a coherent development plan or overarching oversight to manage development trade-offs and synergies. Better strategic governance to ensure oversight, planning, and coordination would enhance impact and catalyse sustainable development.

5.3.4. Consideration of inclusivity: historically marginalised communities are not meaningfully consulted about corridor development planning, implementation, and functioning

Even when national legal regulations on community inclusion exist, they are often not effectively implemented, and most consultations remain informative processes rather than meaningfully seeking community consent (Thorn et al. 2022; Lesutis 2022a; 2022b; Huang and Lesutis 2023). This undermines development initiatives, results in inequities in the distribution of benefits during construction and operation,and creates significant investment risks (Thorn and Mangieri 2021).

In Kenya, historically marginalised communities were not meaningfully consulted about corridor development. Even though national legal regulations on community engagement exist, in the best-case scenario communities are simply informed about the arrival of development initiatives, as shown by both the SGR and LAPSSET (Lesutis 2022c; 2022a; 2022b). This weakens long-term social inclusion at all stages of corridor implementation. For instance, in the Lamu Port in LAPSSET, there are impacts on local fishers, designated beach management units and rural communities through port development, loss of fishing rights (Lesutis 2022c) and reduced access to sacred forests (Thorn et al. 2021).

Small- and medium-entrepreneurs feel differential impacts. While new railways and roads between cities can lead to more employment (e.g. contractors, tourism businesses and food vendors around construction sites), such infrastructure can lead to job losses for truck drivers, taxi drivers, container freight warehousing businesses, loaders, mechanics, and roadside businesses like restaurants and hotels (Lesutis 2022a; Thorn et al. 2021). Newly constructed infrastructure often by-passes rural areas, and poor rural communities face reduced transport options (e.g. Emali, Athi River in Kenya) (Thorn et al. 2021). Indigenous and pastoralist communities with no land titles lose access to, or are relocated from, lands used for agriculture without consideration of indigenous cultural identity and social ties (Lesutis 2022b; Thorn et al. 2021; Thorn and Wijesinghe 2021; Thorn and Mangieri 2021).

5.3.5. Consideration of equality: Development Corridors tend to benefit already privileged socio-economic groups rather than helping improve the lives of more vulnerable groups

The modern development agenda and success indicators often overlook traditional livelihoods. For example, Lamu Port development has displaced over 4700 artisanal fishers in Lamu county. Although the port construction began in 2012 and the High Court ruled that displaced fishers are entitled to financial compensation, these fishers have not yet been compensated (Lesutis 2022c). Due to the Lamu Port development, the population of Lamu is expected to increase from 22 336 (2009) to slightly over 400 000 in 2030 (Okello et al. 2015). Factors like religion, migration, poverty and water scarcity are likely to exacerbate conflict (Maingey et al. 2021). The SGR has resulted in the physical division of villages, loss of land and non-financial assets, and increasing social conflict (Lesutis 2022a; 2022b). For instance, land compensation for the land acquired for the SGR primarily benefited landholders with secure land titles, while individuals with insecure (often communal) land titles lost access to the land they had cultivated (Lesutis 2022b). Inequalities arise concerning large-scale land acquisitions, which alter the distribution of resources and often detrimentally impact intercultural interactions. This is particularly evident when community groups that rely solely on one season of crops or one herd have limited options to diversify their livelihoods. Growing inequalities undermine subsistence self-sufficiency, changes family structures, alters traditional labour roles, and can lead to outmigration (Thorn et al. 2022).

Moreover, the Development Corridors narrative of 'opening up' access to underdeveloped regions and decentralising development, does not seem to have materialised in the case of the SGR (Gannon 2022). Governments often make commitments to deliver broader interventions to structure enabling business environments that support entrepreneurship within corridors. Yet because governance of Development Corridors is often weak and fragmented such interventions have been slow to materialise. As corridors have often been manifesting merely as 'transport corridors', with uneven development gains, local communities are also finding themselves on the frontline of trade-offs and impacts that come with corridor development (Gannon 2022). Development Corridors therefore often appear largely premised on a linear model of development, which assumes infrastructure universally brings development, creates jobs and supports entrepreneurship in areas such as agricultural value chains. In practice, inclusive development, the type of which national governments have committed to deliver through the SDGs, does not materialise from infrastructure development alone (Gannon 2022).

5.3.6. Impacts on biodiversity and ecosystem services: development corridor planning does not follow best practice to identify ecological or ecosystem service impacts or implement appropriate avoidance and mitigation measures

Poorly planned Development Corridors create problems when conservation areas are bisected by railways and roads. Upgraded (and faster) roads and railways in Kenya have led to an increase of road kills of wild and domestic animals (Nyumba et al. 2021; Nyumba and Waruingi 2022). The behaviour of animals in Nairobi National Park changed after the construction of the railway, with more species being found in the southern end of the park, avoiding areas of higher noise pollution and dust (Thorn et al. 2021). In Tanzania, local leaders observed that some animals (e.g. elephants), became more aggressive in the presence of traffic noise in SAGCOT (Cisneros-Araujo et al. 2021) and richness, diversity and abundance of insect pollinators are affected by habitat modifications (Southern Agricultural Growth Corridor of Tanzania (SAGCOT) 2023). Moreover, land conversion impacts other ecosystem services; for example, converting cropland results in loss of carbon, pollution, increased sediment loads and alternations in annual/seasonal water yields (Nyumba et al. 2021; Chilagane et al. 2021).

5.3.7. Incorporation of future climate risks: Development Corridors do not integrate climate or land use change risks and projections in their planning and implementation

Models of climate change in East Africa indicate that temperatures have increased and will continue to rise, while rainfall will become more variable (Amou et al. 2021; Trisos 2022), with higher frequency and intensity of extreme climatic events. Water-related risks, drought, heatwaves, extended dry seasons, flood risks are all expected to increase (Caretta 2022). This will lead to societal damages, significant financial burdens, and other negative impacts such as crop pest outbreaks, changes in species distribution (Trisos 2022).

Despite the known climate challenges, there is low integration of climate risk into infrastructure planning in Kenya and Tanzania (Siderius et al. 2021; Ruth et al. 2021; Siderius 2021). This is complex because different climate models project different patterns of rainfall, even for the same location. Hence, those planning Development Corridors need to account for a wide range of possible rainfall futures (Thorn and Wijesinghe 2021; Conway et al. 2019).

There remains a lack of understanding and practical examples on how to set climate change adaptation targets (e.g. nature-based solutions, climate smart agriculture) to address climate risks in different contexts (Xu et al. 2020; FAO and CAAS 2021), how to implement climate change adaptation actions in Development Corridors (Xu et al. 2020; Xu 2023), and how to promote desirable futures (Thorn and Wijesinghe 2021).

5.3.8. Integrated water resource management: Development Corridors fail to fully consider adverse impacts on water quality, quantity, supply and demand

Development Corridors frequently traverse water catchment areas, wetlands and water bodies—causing erosion and oil spills. The redirection of water into culverts often leads to gulley erosion, flash floods, and silt deposition. For instance, in the Rift Valley and Mbagathi Riverine Dispersal Corridor in Kenya, inappropriately located embankments and underpasses of the SGR obstruct water courses (Sang et al. 2022). Moreover, Development Corridors can diminish access to water, particularly during periods of drought (Sang et al. 2022; Nyumba et al. 2021). The inadequate planning for water can result in artificial water scarcity, which can be exacerbated or alleviated by climate change impacts (Thorn et al. 2021; Taylor 2013; Siderius et al. 2021; Makula et al. 2022; Cervigni et al. 2015; Kolusu 2019; Siderius et al. 2022).

5.4. Discussion

5.4.1. Exploring solutions to challenges

Development planners need to look beyond the development of corridor mega-infrastructure and towards a more interconnected set of policies, programmes, and plans (Gannon 2022; Gannon et al. 2022; Gannon 2023), that account for local complexities and prevent spillover of impacts (Sang et al. 2022; Nyumba et al. 2021; Lesutis 2022a; 2022b; Thorn and Wijesinghe 2021). Solutions that planners and implementers can use to address the eight issues outlined above are explored below.

Impact assessment processes: Systematically and consistently following impact assessment (i.e. EIA, SEA) regulations is the most direct way to start addressing social-ecological issues resulting from poor planning (Challenge 3.1.) (The Development Corridors Partnership 2022). However, best practice in impact assessment is generally not followed (Juffe-Bignoli et al. 2021) in some cases because of lack of capacity to effectively implement regulations and in other because projects are fast-tracked for political and economic reasons (Lesutis 2022a; 2022b; Huang and Lesutis 2023). Addressing challenges 3.2 (Planning coherence) and 3.3 (Effective Governance) is fundamental to improve these processes. Moreover, to be more effective, impact assessment tools need to be applied on the ground and follow the impact assessment project cycle (Juffe-Bignoli et al. 2021; The Development Corridors Partnership 2022).

Participatory planning approaches have been developed (Thorn and Wijesinghe 2021) and are particularly useful to bring differing agendas together, for example discussions between different Ministries in the same country (Challenge 3.3). To achieve this, user-friendly and participatory approaches are available to envision and monitor development trade-offs and synergies, for example, applying Q-Methodology (Gannon et al. 2022). This methodology supports a systems view of development interactions at various stages in Development Corridors evolution: from design and conception, to monitoring, decommissioning. It offers a participatory tool to explore possible outcomes and iterate strategies. Another tool developed for local scenario development and implementation (Capitani et al. 2016) has been used in the SGR and Kilombero Cluster of SAGCOT (Thorn et al. 2022). The 'KESHO' (meaning 'tomorrow' in Swahili) tool uilizes the 'lens of land use change' to chart the potential land use futures in 2030 and 2063, to resonate with the SDGs and African Union Agenda 2063. The potential land use futures and their impact on ecosystem services (Capitani 2019b) are ultimately driven by the views of local participants. 'KESHO' can also help to predict water and biodiversity futures, as well as agricultural expansion, which can then inform plans to manage potential changes (Capitani 2019b; Kariuki et al. 2022).

Coherence across international, national, and local planning: Development Corridors typically mobilise through a series of investments, programmes, projects and institutions that interact and develop incrementally within a corridor landscape. Experiences from Kenya reveal a gap between international donor commitments, national strategies and enforcement on the ground, which is sometimes misaligned with local needs. To ensure coherence across international agreements (Challenge 3.2.), corridor planners need to consider how their plans will assist or challenge commitments already made by the countries through for example, the SDGs, the UNFCCC, UNCCD, the CBD Kunming, more specifically the Montreal Global Biodiversity Framework and the 23 targets to be met by 2030, among others. Very often, these existing commitments are ignored when corridors are planned. At the same time, corridor planners also often ignore national development and conservation plans developed by other parts of government. Major actors with the power to make changes should take leadership and lead the efforts to meet these commitments. These are ministries and Office of the President of recipient countries and financiers from investor countries. The latter set, often very different environmental and social, standards, that contractors tend to only follow through work plans and timelines in contracts they do not have much power to influence. National and local level governments are important for ensuring that large-scale public or private investment is accountable to sustainable development agendas. They are also essential for providing services, like water and affordable housing, to marginalised communities. Cross-sectoral coordination is therefore needed, for example, between ministries and Office of the President.

Effective governance: To overcome currently fragmented and siloed corridor governance and management systems that limit holistic management of development trade-offs (challenges 3.3.), leadership needs to be championed at a high-level (i.e. Office of the President). Coordination should be accompanied by investments in institutional and policy environments (Pardoe et al. 2018; Averchenkova et al. 2019; Newell et al. 2019). For example, creating inter-ministerial and multi-stakeholder corridor fora to discuss key issues and share experiences, although these are likely to require enhancing and resourcing (Gannon 2022; Gannon et al. 2022; Gannon 2023; Gannon et al. 2021). Opportunities exist to enhance or embed multi-stakeholder partnership (MSP) processes, such as through regular meetings and working groups that operate in local languages to build decentralised cooperation, strengthen local negotiation capacities, build institutional memory and transfer knowledge internationally in the face of growing resource constraints. Meanwhile, the private sector can develop inclusive branding, promote reputation, and thus increase financial ratings (Thorn and Mangieri 2021).

Forging such partnerships will harness development synergies and address the barriers that prevent marginalised populations from participating in and benefitting from current corridor investments (Gannon 2022; Gannon et al. 2021).

Consideration of inclusivity and equality: Participatory planning is essential to ensure better consideration of inclusivity and equality (challenges 3.4 and 3.5). Participatory scenario planning, for example, brings together diverse stakeholders to develop a range of robust and flexible policies or investment strategies that will function in a variety of future contexts (Kok et al. 2007; Thorn et al. 2020; Vermeulen et al. 2013). Rather than forecasting the ‘most likely’ future or predicting a single or most probable outcome (Wilkinson and Eidinow 2008), scenario planning considers the potential effects of multiple future stressors (Thorn et al. 2020; McBride et al. 2017). Scenarios have been shown to bring an array of stakeholder voices together and help decision-makers adapt their strategic beliefs. They also help stakeholders to notice, assess and respond to change (Ament et al. 2023). For example, divergent scenarios of future land cover change were developed to explore potential futures of corridor developments in 2030 and 2063, to resonate with the SDGs and African Union Agenda (Thorn and Wijesinghe 2021). Scenarios were developed in the SAGCOT cluster of Kilombero in South West Tanzania, and along the SGR running from Mombasa up to Kisumu, in Southern Kenya. Additionally, trainer-of-trainer modules were developed, and workshops were conducted to teach practitioners to apply scenario planning tools in the UK, Tanzania and Kenya.

To address the issue of Development Corridors not facilitating inclusive and equal economic opportunities for all, development planners need to look beyond the development of corridor mega-infrastructure and towards a more interconnected set of policies, programmes and initiatives. These can harness development synergies and address the barriers that prevent marginalised populations from participating in and benefitting from current corridor investments. Strategic partnerships that coordinate public and private agricultural investments, develop soft as well as hard infrastructure, and overcome barriers to investment, could play a key role in upscaling the inclusion of small enterprises in corridors and these should be more actively integrated into corridor design. Research (Gannon et al. 2021) shows that MSPs can play in supporting small enterprises in Africa to grow and to adapt to climate change. MSPs are collaborative arrangements between public, private and civil society sectors, often built on the same philosophy as that underpinning the concept of the corridors: of mobilising the private sector in development action.

Impacts on biodiversity and ecosystem services: Regarding overlooked impacts on biodiversity (Challenge 3.6), best practice guidance for biodiversity mitigation planning is widely available (e.g. (The Development Corridors Partnership 2022; Ament et al. 2023; CSBI & TBC 2015) and should be applied across infrastructure corridors currently underway or being planned. This includes following long term established biodiversity mitigation frameworks (e.g. the mitigation hierarchy) (CSBI & TBC 2015) and adhering to international best practices in biodiversity mitigation (e.g. the International Finance Corporation Standard 6) (IFC 2012). Through DCP, we showed how planning for the maintenance of biodiversity values in Development Corridors can consider ecological connectivity (Cisneros-Araujo P et al. 2021), animal movements (Nyumba and Waruingi 2022) and biodiversity values (Juffe-Bignoli et al. 2021). Moreover, analyses have explored solutions to better understand risks and benefits in infrastructure projects in 137 countries (United Nations Environment Programme 2022) and in clusters within the SAGCOT. Climate risks should also be included in the project's appraisal process so that mitigation plans (e.g. meaningful local community engagements) can be developed (Thorn and Mangieri 2021).

Ecosystems and species provide ecosystem services for people, many of whom, especially in Africa, are dependent on nature for their livelihoods. In East Africa key ecosystems include mountain forests and wetlands for hydrological regulation, areas designated for wildlife for their tourism or hunting revenues, or natural woodlands for pollination, timber, firewood and charcoal production. Tools that integrate ecosystem services and biodiversity can inform both policy and land use decision-making (van Soesbergen et al. 2017; Capitani 2019a). For example, land use change modelling tools such as, CLUE-S (Verburg et al. 2002), biodiversity intactness models (Hill et al. 2018) and ecosystem service modelling tools SPHY (Terink et al. 2015) and InVEST (Natural Capital Project 2023) have been used to assess potential impacts of planned developments on ecosystem service delivery and biodiversity in the Kilombero and Ihemi clusters in the SAGCOT corridor. More importantly, in addition to detailed local analyses that the DCP project undertook, areas of global biodiversity importance are well mapped within countries and globally (e.g. Key Biodiversity Areas database (Birdlife International 2023), IUCN red list of threatened species (IUCN 2024), or biodiversity relevant data hosted at UN Biodiversity Lab (UN Biodiversity Lab 2023). These critical areas for conservation should be considered in development corridor plans to avoid unintended harm. Infrastructure development that integrates these values—framed in terms of nature-based infrastructure—can help deliver more SDGs targets than built infrastructure alone (Thorn et al. 2021).

Incorporation of future climate risks: Corridor planners need to consider climate change mitigation and adaptation strategies to manage these potential impacts (Challenge 3.7). For example, a climate risk assessment for the Rufiji River Basin that overlies much of the SACGOT development corridor (Siderius et al. 2021; Conway et al. 2021) was led by DCP. It involved developing an understanding of the basin and the key decisions being made across interdependent sectors such as water–energy–food. It also included identifying what is important for stakeholders and how they assess benefits, listing options that achieve enhanced and more sustainable development benefits (Conway et al 2021). Future climate projections for the Rufiji River basin show continued warming (0.8 ˚C–1.8 ˚C by the 2040s) and mixed patterns of change in future rainfall. Modelled changes in Rufiji stream flow range from approximately −30% to over +60%. Contingency plans for water management under stresses of climate change (addressing irrigation, hydropower and environmental needs) should include modified operating procedures for existing and planned hydropower infrastructure and water allocation under both drier and wetter conditions. This should occur alongside development of a multi-agency drought management plan for seasonal and interannual events. As impacts are cross-cutting, multi-agency coordination is going to be vital for both long-term planning and for shorter-term decisions, such as drought management. High level dialogue to this effect should be encouraged. Increases in the productivity of land and water via improved irrigation schemes and consideration of financial incentives for farmers are also fundamental. Especially water saving technologies, to adopt new measures should also be considered (Siderius et al. 2022).

Integrated water resource management: Finally, integrated water resource management should become a fundamental building block of all corridor plans (Challenge 8). Hydrological models have been developed for several river basins in East Africa. These include the Rufiji (Siderius et al. 2018; Conway et al. 2019; Geressu et al. 2020), and little Ruaha Basins in Tanzania (Chilagane et al. 2021) and the SGR region in Kenya (Sang et al. 2022). These hydrological models can be used to provide advice to those planning agricultural development, urban development, hydropower facilities, wildlife reserves and other water uses. Models show reduced water availability in the dry season in East Africa, a significant constraint for development planning at the basin scale. Careful planning of water uses and consideration of the impacts of climate change on water resources will be required across the whole region into the future, with guidance for the SAGCOT corridor in Tanzania already published (Conway et al. 2019).

5.4.2. Using available tools and guidance materials

Materials are already available to assist corridor planners, funders and implementers (e.g. (United Nations Environment Programme 2021; Sustainable Infrastructure Partnership 2023; Development Corridors Partnership 2022) to implement the solutions explored above. DCP has developed a source book on best practice and common failings in EIAs and SEAs as applied to Development Corridors (The Development Corridors Partnership 2022). This book contains 15 case studies across Asia, Africa and Latin America, with two chapters on lessons learnt. An e-learning course structured around the four stages of the creation of a development corridor has also been created to help development corridor practitioners available on the UNDP Learning for Nature website (Development Corridors Partnership 2023c)). This course outlines considerations for corridor planners (module 1), presents several existing tools that can help screen projects for biodiversity, carbon, ecosystem services and social risks (module 2) and the issues financiers need to consider (module 3). The modules show that existing tools, such as the Integrated Biodiversity Assessment Toolkit (IBAT 2023) and Exploring Natural Capital Opportunities, Risks and Exposure (UNEP-WCMC 2020), can be used for screening in the pre-proposal and planning stages of a development corridor.

In addition, a UNEP report (United Nations Environment Programme 2022) investigates the environmental risks and socio-economic benefits of planned road and rail transport infrastructure projects underway or planned in 137 countries. The report is accompanied by an online interactive viewer tool, the Global Infrastructure Impact Viewer (UNEP-WCMC 2022), which displays on a global map that attributes values to projects' risks and benefits. International Good Practice Principles for Sustainable Infrastructure (United Nations Environment Programme 2021) and a business brief on future-proofing infrastructure

(Thorn and Mangieri 2021) have been developed by UNEP for global use and can be applied to development corridor planning.

Guidance for businesses to report on and address risks and dependencies on nature are being produced by groups such as the Task Force for Nature Related Financial Disclosures (TNFD) (TNFD 2023) or the Science Based Targets Network. The TNFD framework, responds to a general increased pressure from global society on disclosing nature-related risks and opportunities in business operations. Understanding how these might affect project/investments and stakeholders, creates greater transparency and accountability. These kinds of guidance may facilitate systemic changes across business, which could leverage significant positive impacts.

5.5. Conclusions and recommendations

Four years of DCP findings in East Africa supported by other relevant research on Development Corridors have been summarised intro eight key challenges the current corridor paradigm is facing. Solutions to these challenges exist and generally involve applying international best practice on social and EIA, ensuring greater transparency, accountability, and coordination at subnational, national, and transnational levels and for all stakeholders involved in the process. Implementing the solutions entails meaningful consultation with local communities as early as possible in the project cycle, transparency in contract negotiations with recipients of funding, as well as full implementation and monitoring of mitigation measures agreed in the impact assessment process.

Table 5.1 presents a summary of how we might link the challenges with the solutions explored above to specific recommendations for key stakeholders. The stakeholder groups are primarily: (1) Impact assessment practitioners: technical experts who work on EIA and SEAs who need to use best available knowledge and guidance developed by UN agencies, NGOs, and business facing networks and initiatives (e.g. SBTN, TNFD); (2) Government: relevant agencies or parastatal entities need to coordinate work across Ministries, ensure that existing commitments and local regulations are followed and implemented, and that development that does not damage the environment or disadvantage groups; (3) Funders: those who finance Development Corridors need to ensure that their funds are supporting sustainable development and not harming nature or local people; and (4) Contractors: actors physically constructing the infrastructure need to ensure that the work they are doing is aligned with mitigation measures developed through the impact assessment process, working hand-in-hand with local government and communities.

By adopting these recommendations, the design, implementation and running of Development Corridors can better realise their development potential, maximise investment, and minimise unintended consequences for the greater good of African nations, its people, wildlife and ecosystems.

Table 5.1 Eight challenges in the current development corridor model and recommendations for key stakeholder groups

Description	Challenges and potential consequences	Recommendations for stakeholders
Impact assessment processes	Poor application of existing best practice guidance in development corridors results in poorer outcomes for people and nature.	Impact assessment practitioners to follow best practice guidance in impact assessment such as for example full consideration of the mitigation hierarchy or emerging frameworks such as the Science Based Targets for Nature guidance (SBTN). Government to create expert-led steering groups from a range of often siloed ministries, working together to deliver better outcomes. Government, funders, and contractors to use information about priority areas for conservation in the infrastructures contract negotiation processes and to ensure meaningful inclusion of local and indigenous peoples in the decision-making process. Funders, companies, and contractors to disclose impacts following emerging frameworks (e.g. TNFD).
Coherence across international, national, and local planning	Poorly-integrated planning across sectors and scales generates unintended cumulative impacts.	Impact assessment practitioners to undertake background research in partnership with government on international targets and national commitments to ensure that corridor plans and implementation aligns with national agreements for the UN Conventions on Biological Diversity, Climate, Wetlands, Wildlife Trade, Desertification, and the SDGs. Government and funders to integrate local needs and requirements when planning or designing and approving large-scale infrastructure investments. Government and funders to strengthen assessment of SDG co-benefits when designing infrastructure investments and seek to align with SDG standards across investors, donors and recipient countries. Governments to facilitate building partnerships between companies involved in implementing infrastructure investments and local stakeholders to help better understanding of best practices and sharing of experiences.
Effective governance	Fragmented and non-inclusive governance hinders effective implementation.	Governments to lead cross-sectoral coordination needs by championing it at a high level (i.e. Office of the President), investing in institutional and policy environments, and building decentralised cooperation and strengthen local negotiation capacities. Funders and contractors to develop inclusive branding, promote reputation and increase financial ratings.
Consideration of inclusivity	Historically marginalised communities are not meaningfully consulted about	Government and funders to ensure alignment of international donor commitments, national strategies, and implementation supporting with local needs. Impact assessment practitioners, governments, and funders to pursue greater integration of local needs is

	corridor development planning, implementation, and functioning.	required when planning or designing large scale infrastructure investments.
Consideration of equality	Development corridors tend to benefit already privileged socio-economic groups rather than helping improve the lives of more vulnerable groups.	Impact assessment practitioners, governments, and funders to carefully consider the potential outcomes of development corridors for people at all stages. All stakeholders to ensure that planning stages incorporate the needs of rural, poorer communities to align with national and SDG targets.
Impacts on biodiversity and ecosystem services	Corridor planning does not follow best practice to identify ecological or ecosystem service impacts or implement appropriate avoidance and mitigation measures.	All stakeholders to consider the existing values of the landscape for nature conservation and the delivery of ecosystem services to poor people. Impact assessment practitioners to use available tools and data to include the direct benefits of ecosystem services in corridor development plans. Government, funders, and contractors to ensure that ecosystem services provision to poor people is maintained or enhanced.
Incorporation of future climate risks	Corridors are not integrating climate or land use change risks and projections in their planning and implementation.	All stakeholders to consider the potential positive and negative future impacts of corridors on local populations, land use, and economic growth through collaborative scenario planning. Impact assessment practitioners to assess impacts of infrastructure development on habitat integrity, ecological processes, and ecological connectivity across the landscape and ensure these are reflected in implementation plans. All stakeholders to mitigate potential disasters that will negatively impact people and the infrastructure, such as floods and droughts created by the interaction of the new development with climate change.
Integrated water resource management	Projects associated with development corridors do not fully consider adverse impacts on water quality, water quantity as well as on water supply and demand.	Governments and impact assessment practitioners to develop contingency plans for water management under stresses of climate change (addressing irrigation, hydropower and environmental needs). Governments to promote high-level dialogues for the development of a multi-agency drought management plans for seasonal and interannual events.

6. Chapter 6 Discussion

Throughout this thesis, I have explored the proposed avoidance and mitigation of potential negative impacts on biodiversity, within biodiversity impact assessments. The main theme has been large-scale biodiversity impact assessment, assessing the effects of several projects sharing the same space and coexisting with multiple pressures. To do this, I have studied large-scale infrastructure development initiatives within Development Corridors. These are defined as *"extensive, often transnational and linear, geographical areas targeted for investment to help achieve sustainable development"* (Juffe Bignoli et al. 2021).

After my introductory chapter, Chapter 2 of the thesis starts with a global review of best practice in impact mitigation approaches in Development Corridors (Juffe Bignoli et al. 2021). In Chapter 3 I complete a compilation of Development Corridors projects in continental Africa, producing the first Africa Development Corridors database (Thorn et al. 2022). I then use this dataset to develop a new spatially oriented framework to account for direct, indirect and cummulative biodiversity impacts from large scale infrastructure initiatives (Chapter 4). Finally, in Chapter 5 I focus in on Kenya and Tanzania in East Africa, as a case study, to understand and illustrate the complexities of Development Corridors on the ground (Juffe Bignoli et al. 2024).

In this Discussion chapter, I focus on the three research areas that have driven this thesis overall: i) to gain a global understanding on what Development Corridors are, i.e., how they are conceived and evolve in space and time, and to what extend impacts on biodiversity are assessed following best practice; ii) to develop and test a more nuanced, spatially explicit method for assessing the potential impacts of Development Corridors on biodiversity; and iii) understanding Development Corridors from a multidisciplinary perspective. I then discuss some potential policy and practice applications of this work and finish by exploring further avenues of research that could emerge from this thesis.

6.1. Key research areas

6.1.1. Understanding biodiversity impact mitigation in Development Corridors

The main research question in Chapter 2 was: to what extent has best practice been followed in the literature assessing biodiversity impacts from Development Corridors? To explore this question, I carried out a global review published in Juffe Bignoli et al (2021), where I also provide a synthesis on the nature and key steps of the development corridor phenomenon. I find that Development Corridors are a global trend, and they are found across all continents (except for Antarctica). I show that the impact assessment literature does not fully consider comprehensive mitigation of biodiversity impacts (Juffe Bignoli et al. 2021). Comprehensive mitigation of biodiversity impacts means considering and quantifying not only direct impacts, but also indirect and cumulative impacts – and applying all steps of the mitigation hierarchy to mitigate its effects (see Table 2.1 in Chapter 2). In our review 62% of studies only assessed direct impacts, mostly using buffers to measure indirect impacts, and only 37% did this in the conception stage (i.e. when more impacts can feasibly be avoided). Our findings evidence the need to advance in the science of impact mitigation on indirect and cumulative impact assessment. Collinson et al. (2019) also found that most publications examined the direct impacts of roads only. Similarly, Cooper and Sheate (2002) in a review of UK environmental impact statements found 48% mentioned the term ‘cumulative effects/impacts’ and only 18% discussed these impacts. Aiming to fill in this gap recently (Narain et al. 2025) developed a framework for capturing indirect impacts in site level screening but leaves aside large linear infrastructure projects and cumulative impacts. More importantly, most biodiversity impacts research studies focus on frameworks at a project level which leaves out cases when several projects interact in the same landscape covering large spaces, as is the case of Development Corridors. Instead, our work, explores ways to quantify cumulative impacts covering large areas and distances.

To understand better the accumulation of large-scale infrastructure projects in Africa and instigated by the Development Corridors Partnership project, in Chapter 3 I study further Development Corridors in Africa. Over ten years ago, the extent and potential consequences of 33 Development Corridors in Africa were assessed by Laurance et al. (2015b). This followed other Africa-wide studies (Laurance et al. 2017) and case studies in Nigeria (Mahmoud et al. 2017) and Kenya (Nyumba et al. 2021), for example, showing emerging new projects and increasing concern on the potential negative impacts on biodiversity. I update and expand that research, by compiling and creating the first African database on Development Corridors (Thorn et al. 2022). I show that in 2022 there were 79 Development Corridors in Africa which comprised a total of 184 projects crossing the whole African continent, more than twice from what Laurance et al. found back in 2015.

Our research has therefore added new important insights into the Development Corridors literature. First clarifying development corridor terminology, the different phases of development of these initiatives in relation to biodiversity impacts and defining what best practice in biodiversity impact mitigation would look like (Juffe Bignoli et al. 2021). The outputs from this thesis are actively being used by other researchers already. In December 2025, Juffe Bignoli et al. (2021) registered over 11,000 views and downloads in the journal webpage and 21 citations Google Scholar (for example: Xu et al. 2024; Seki et al. 2022; Williams et al. 2022; Mtweve et al. 2025). The African development corridor database (Thorn et al. 2023) has also been used to inform research with 22 citations in Google Scholar (for example: Engert et al. 2025; Biber-Freudenberger et al. 2025; Simkins et al. 2023; Mudimu et al. 2025), 9,820 article accesses, and over 300 downloads in December 2025.

6.1.2. Improving quantification of indirect and cumulative impacts from infrastructure development

Chapter 2 and 3 led to the next research area: how to more robustly quantify indirect and cumulative impacts from infrastructure development across large areas considering the interaction of multiple planned projects and existing pressures?

In Chapter 4, I explore systematic assessment of indirect and cumulative impacts on biodiversity. There is extensive research exploring how to represent and quantify aggerated stressors on biodiversity and its potential consequences. Notable metrics in the terrestrial realm are the Human Footprint (Venter et al. 2016) and the Human Modification Index (Theobald et al. 2025). The Human footprint is a pressure-based index combining eight anthropogenic stressors and scale 0 to 50. It measures the degree of human pressure and follows a linear aggregation. The Human Modification is a cumulative ecological state index that uses 13 stressor categories represented in a continuous estimate of landscape modifications expressed as 0 (no modification) or 1 (fully modified). I develop a theoretical framework to estimate cumulative impacts of infrastructure projects when aggregated into corridors. I propose the Potential Impact Intensity metric that quantifies the intensity of impact in the landscape combining new with existing pressures. Potential Impact Intensity metric is calculated using each development project as the source of impact adjusted by distance and slope. I combine this with the Human Modification metric to account for existing pressures assuming more human modification can increase the intensity of impact. Our contribution to the literature here is twofold. First, I specifically focus on impact propagation and accumulation across the landscape of infrastructure projects, considering slope and a distance decay function supported by the evidence that impacts on biodiversity gradually from the impact source. Doing this allowed a first attempt at structured quantification of the potential effects of direct, indirect and cumulative impacts and interaction between numerous other new projects, which can support large scale infrastructure planning before projects are implemented. For example, during scenario exploration in Strategic Environmental Impact Assessment. This could involve calculating Potential Impact Intensity of several Development Corridor configurations to make decisions on which design can result in better outcomes for biodiversity. Second, I factor into our analyses the effects of existing stressors in the landscape through the degree of human modification in each pixel. This approach differs from others in that it combines potential new pressures from Development Corridors projects with existing pressures using published peer reviewed metrics. This allows exploring the contribution of existing stressors into the likelihood of impact when several linear infrastructure projects are planned as part of the same initiative. Our analysis therefore focuses on linear infrastructure and is not designed to provide a global metric, unless the global effects of a given infrastructure initiative is the aim of the assessment. In Chapter 4, I show that the accumulation of impacts dramatically changes the potential impacts in protected areas and Key Biodiversity Areas, show increases of up to 225% increase in potential impact intensity value.

These findings underline the urgency of developing practical applications to estimate impact accumulation between projects and across the landscape and not leave the indirect and cumulative impact assessment as a “nice to have” or unimplemented policy in impact assessment practice (Narain et al. 2025; Niebuhr et al. 2023; Cooper and Sheate 2002; Sinclair et al. 2017).

6.1.3. Development Corridors as Socio-Ecological Systems: A Multidisciplinary Assessment

This thesis has mostly focused on biodiversity impact assessment, but socio-economic considerations shape the outcomes of impact assessments on the ground. This is clear in the multiple case studies compiled in Hobbs and Juffe-Bignoli (2022) that illustrates the complexity of such multi-project and multi-stakeholder initiatives.

Chapter 5 takes a holistic view of Development Corridors and evaluates their impacts on people, wildlife and ecosystems in Kenya and Tanzania. Through a collaborative and multidisciplinary synthesis, I identified key challenges related to Development Corridors implementation in East Africa and grouped them in eight themes (Juffe Bignoli et al. 2024): impact assessments processes; coherence across international, national and local planning; governance; inclusivity; equality; impacts on biodiversity and ecosystem services; incorporation of future climate risks; and integrated water resource management. This is the first time that I am aware the Development Corridors paradigm has been assessed through an integrated ecological, social, and economic lens. This work provides a comprehensive insight into Development Corridors implementation and opens a number of potential research avenues on which I expand below.

6.2. Policy and practice applications

The research presented in this thesis shows that the existing biodiversity impact assessment processes need to be improved. I discussed above that our analytical approach to quantifying indirect and cumulative impacts could be used in Strategic Environmental Impact Assessment scenario exploration. This is key to focus on avoidance which is considered as the most effective way to reduce impacts on biodiversity (Phalan et al. 2018; Bull et al. 2022; Arlidge et al. 2018). Avoidance at the Strategic Environmental Impact Assessment phase is aimed to manage mitigation early in the impact assessment continuum, at the level of policies, plans and programmes (UNEP 2018). It is at this stage when a large-scale transboundary initiative, as is often that of Development Corridors, can be more effective if the mitigation plans are transferred into subsequent related project level Environmental Impacts Assessments (EIA) (Juffe Bignoli et al. 2021; Draper 2006; Environment 2005; Tulloch et al. 2019). This transference of information between impact assessments at a strategic and project level is what is called the impact assessment tiered approach, which is believed to improve the outcomes of the impact assessment process (González and Therivel 2022). Improving this transfer of information, could play an important role in mitigating impacts in Development Corridors project cycle that typically start with at the strategic level to then unfold into several projects (Juffe Bignoli et al. 2021) (Figure 6.1).

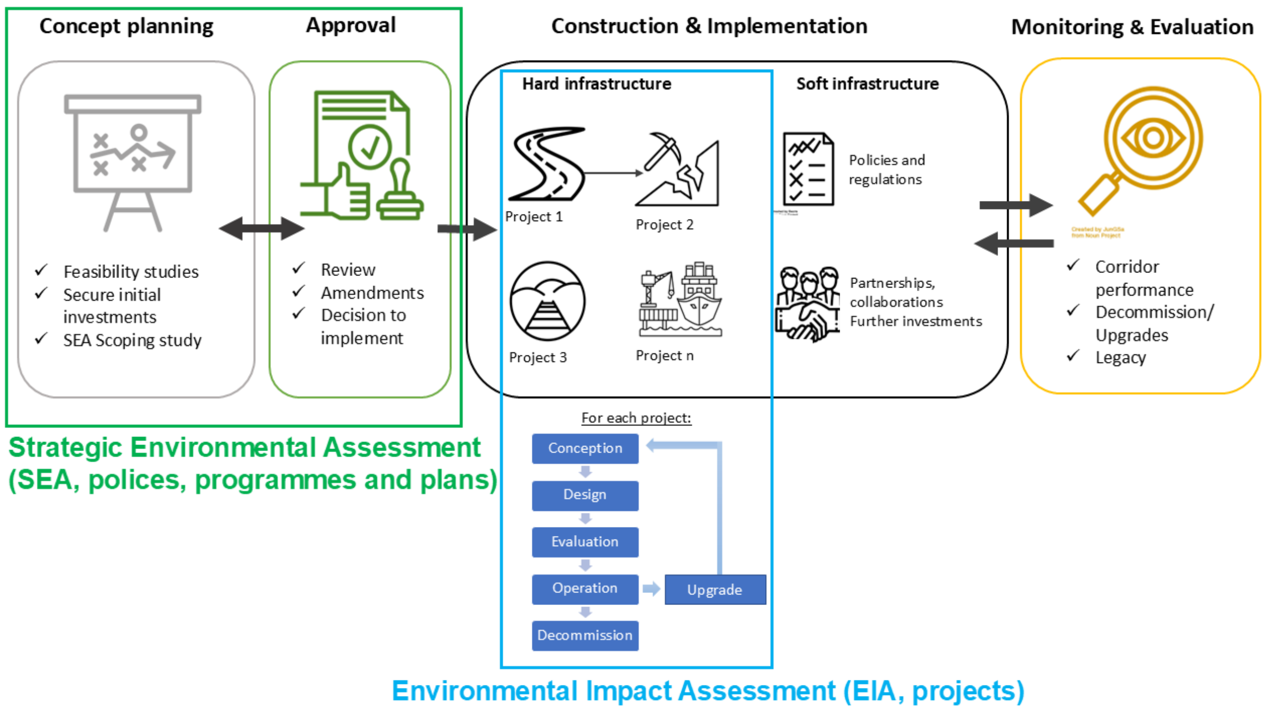

Figure 6.1 The role of Strategic Environmental Impact Assessment and Environmental Impact Assessment in the development corridor project cycle. Adapted from Juffe-Bignoli et al. (2021).

The databases such as the one developed in Chapter 3 and the methods explored in Chapter 4 of this thesis can support this process by identifying hotspots of potential biodiversity impacts at the strategic level. These impact hotspots would be places where potential impacts from development corridor projects would accumulate and where avoidance and mitigation are more important. The next step would be to apply biodiversity impact mitigation best practice at the strategic and project level such as the Mitigation Hierarchy (CSBI & TBC 2015) or go beyond reactive impact mitigation to proactive planning for development and biodiversity outcomes (Milner-Gulland et al. 2021; Heiner et al. 2019b). From a scientific perspective, through this work I shed light into how the development corridors phenomenon unfolds (Chapters 2 and 5) and developed a framework to assess whether best practice in biodiversity impact mitigation is being applied in the literature (Chapter 2). I have then highlighted the gaps in the literature regarding the exploration of the accumulation of impacts and developed a spatially explicit theoretical framework to better quantify these that can be replicated in any landscape (Chapter 4) which I tested by creating a database supported by data standard that can be used, expanded and improved over time following the protocols outlined in Chapter 3.

6.3. Future avenues of research

From this thesis new collaborations have emerged that have added further insights into the study of the potential impacts of large-scale infrastructure initiatives. Notable examples are co-leading on the compilation, editing and chapter writing of the book Impact Assessment for Corridors: From Infrastructure to Development Corridors (The Development Corridors Partnership 2022), co-authoring the European Commission led Lobito Corridor environmental assessment (Strona et al. 2025), and other academic collaborations (Engert et al. 2025; Maron et al. 2021; Milner-Gulland et al. 2021). Here I expand on two topics that I think constitute promising research avenues for the future.

6.3.1. Understanding the effectiveness of the impact assessment process on the ground

This thesis has mostly focused on biodiversity impact assessment, but socio-economic considerations shape the outcomes of impact assessments on the ground. This is clear in the multiple case studies compiled in DCP (2022) that illustrates the complexity of such multi-project and multi-stakeholder initiatives.

Chapter 5 synthesises the results of 4 years of multidisciplinary research through the Development Corridors Partnership of which this thesis was part of. Given the complexity of these issues raised, the synthesis only superficially discusses potential solutions and then summarises the findings in eight challenges and potential consequences for each of those challenges. Each of these could be used to propose multiple research questions for future research (Table 6.1).

Table 6.1 Potential questions for Development Corridor future research. Adapted from Juffe Bignoli et al. (2024).

Description	Challenges and potential consequences	Potential research questions
Impact assessment processes	Poor application of existing best practice guidance in Development Corridors results in poorer outcomes for people and nature.	Does application of best practice improve Development Corridor outcomes for people and nature?
Coherence across international, national, and local planning	Poorly integrated planning across sectors and scales generates unintended cumulative impacts.	Does greater cross-sectoral and multi-scale integration in corridor planning reduce cumulative biodiversity impacts? What institutional and planning gaps contribute to insufficient integration across sectors and scales in corridor development, and how do these gaps lead to unintended cumulative impacts?
Effective governance	Fragmented and non-inclusive governance hinders effective implementation.	What are the main governance related factors that affect impact assessment implementation? Which governance arrangements are likely to deliver better outcomes?

Consideration of inclusivity	Historically marginalised communities are not meaningfully consulted about corridor development planning, implementation, and functioning.	How, and to what extent, are historically marginalised communities meaningfully included in the planning, implementation, and governance of development corridors? How does the meaningful participation of historically marginalised communities shape governance processes and biodiversity outcomes in development corridor planning and implementation?
Consideration of equality	Development Corridors tend to benefit already privileged socio-economic groups rather than helping improve the lives of more vulnerable groups.	How are the socio-economic benefits and costs of development corridors distributed among different social groups, particularly historically marginalised and vulnerable populations?
Impacts on biodiversity and ecosystem services	Corridor planning does not follow best practice to identify ecological or ecosystem service impacts or implement appropriate avoidance and mitigation measures.	How effective are current corridor planning processes at avoiding, minimising, and mitigating impacts on biodiversity and ecosystem services? What institutional, technical, and governance factors explain variation in the application of best-practice ecological assessment and mitigation in development corridor planning?
Incorporation of future climate risks	Corridors are not integrating climate or land use change risks and projections in their planning and implementation.	What are the main obstacles to integrate climate and land use change into planning? How does not incorporating climate and land use change affect Development Corridors outcomes?
Integrated water resource management	Projects associated with Development Corridors do not fully consider adverse impacts on water quality, water quantity as well as on water supply and demand.	To what extent are Development Corridors the cause adverse impacts on water quality and quantity? What are other confounding factors involved?

6.3.2. Taking a deep dive into cumulative impact assessment for biodiversity

As discussed throughout this thesis, cumulative impact assessment is not widespread in impact assessment practice. Especially in the context of mitigating biodiversity impacts, there hasn't been sufficient technical development of approaches to cumulative assessment (but see Bigard et al. (2017); Whitehead et al. (2017); Cooper and Sheate (2002); and Noble (2010)). This thesis makes an important contribution in that direction through Chapter 4. Our ability to make future predictions on the nature and extent of cumulative impacts could make a major contribution to avoidance and minimisation strategies. However, this requires going further and, for example, incorporate land use change and climate change scenarios into the approach developed here, or using the systematic conservation planning approach to prioritise mitigation actions for several development projects while meeting a set of conservation targets and goals for the same landscape. Relevant examples of the latter lie in the Development by Design approach (Kiesecker et al. 2019; 2020; Heiner et al. 2019a; Saenz et al. 2013) which have been discussed in Chapter 2 but I have not found recent examples of these types of assessments. A promising approach is target based ecological compensation (Simmonds, Sonter, et al. 2020) that proposes propose a new framework for compensating for biodiversity losses from development in a way that is aligned explicitly with jurisdictional biodiversity targets. I am not aware of this approach being tested in practice. The novelty of this approach is that compensation is not determined project-by-project, but is explicitly designed to contribute to measurable, jurisdiction-level conservation targets, thereby linking impact mitigation with systematic conservation planning and improving the likelihood that compensation actions additional biodiversity gains at landscape scales.

6.4. Final conclusion: death by a dozen cuts

In the introduction of this thesis, I coined the term ‘Death by a dozen cuts’ in the context of biodiversity impact mitigation as opposed to the better well known ‘Death by a thousand cuts’. This is to illustrate that Development Corridors are likely to have important cumulative effects on biodiversity due to the large linear extent and often transnational nature of the infrastructure projects they propose. I believe that through the outputs of this thesis we make a valuable contribution towards understanding and avoiding death by a dozen cuts in the case of Development Corridors. I do this through reviews, new analyses, and datasets that are already being used by others to advance in this fascinating research area. Neither literature or practice has developed sufficiently robust approaches to treating cumulative and indirect biodiversity impact assessment for projects. This is particularly important for multiple overlapping projects, in development corridors and I think this area of research has major ramifications for the practice of Strategic Environmental Assessment and Environmental Impact Assessment.

Infrastructure development is fundamental to improve the quality of life of millions, but poorly planned infrastructure can have negative consequences for people and nature. If the whole suite of impacts discussed in this thesis are not assessed, it seems unlikely that infrastructure development proponents and assessors would be able to make informed decisions on the circumstances under which some projects should be developed, or even whether they should go ahead at all. More importantly, if plans go ahead, appropriate measurement of potential impacts is fundamental to re-design the proposed projects to avoid impacts or recommend suitable solutions to mitigate the impacts that cannot be avoided through minimisation, restoration or compensation. Consequently, the assessment of the accumulation of impacts seems a key step that drives all the subsequent decisions on impact mitigation.

My hope is that through this thesis I have contributed to a better understanding of how impacts accumulate and interact and opened the door to better quantification of this phenomenon to inform impact assessment. Finally, and as discussed in this thesis, another key part of the solution for avoiding death by a dozen cuts is to study how the impacts assessment processes outlined in paper are implemented on the ground. Well written policies and comprehensively developed impact assessments with proposed appropriate mitigation measures can fail if there is poor implementation on the ground. That is perhaps the largest challenge still to face, and involves combination of spatial, policy analyses, and field work that goes beyond this thesis and could well have been my "other" thesis in another life.

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Appendix 1 Co-authored publications

Through this thesis I was involved in many collaborations in the topic of development corridors. This appendix includes 6 publications co-authored in the context of this thesis but that do not qualify as thesis Chapters. In addition to this I also contributed as a reviewer to the UNEP International Good Practice Principles For Sustainable Infrastructure (United Nations Environment Programme 2021).

Maron, M., **Juffe-Bignoli, D.,** Krueger, L., Kiesecker, J., Kümpel, N.F., Ten Kate, K., Milner-Gulland, E.J., Arlidge, W.N.S., Booth, H., Bull, J.W., Starkey, M., Ekstrom, J.M., Strassburg, B., Verburg, P.H. and Watson, J.E.M. 2021. Setting robust biodiversity goals. Conservation Letters. 14(5). https://doi.org/10.1111/conl.12816

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Strona, G., **Juffe-Bignoli, D.**, Mandrici, A. et al. 2025. 'Large-Scale Biodiversity and Environmental Assessment of the Lobito Corridor'. JRC Publications Repository. https://doi.org/10.2760/9883428.

Appendix 2 Chapter 3 Supporting information

Supplementary Table 1. Sources of publications.

Some of the development authorities' names may change over time, or evolve to other regional bodies in the future, while the links were correct on 1 November 2022.

Category	Source	Link
	Programme for Infrastructure Development in Africa	https://www.au-pida.org/
	Global Infrastructure Hub	https://www.gihub.org/
	Global Infrastructure Connectivity Alliance	https://www.gica.global/maps
	NEPAD Africa Infrastructure Database	https://aid.nepad.org/index.php/auth/register
	The IUCN Water Knowledge Platform	http://www.waterandnature.org/
	Vital Signs	http://vitalsigns.org/
	OpenStreetMap	https://wiki.openstreetmap.org/wiki/Main_Page
	Vessels Tracker	https://www.vesseltracker.com/en
	Tripartite Transport and Transit Facilitation Programme	https://tttfp.org
	African Transport Policy Programme	https://www.ssatp.org
	PPP Knowledge Lab	https://library.pppknowledgelab.org/
	The Observatory of Economic Complex	https://oec.world/en
	World Port Source	http://www.worldportsource.com
	Southern African Research and Documentation Source	https://www.sardc.net/en/
	Early Warning System Database	https://ewsdata.rightsindevelopment.org
	FleetMon Maritime Vessels and Ports Database	https://www.fleetmon.com/
	Logistics Capacity Assessments	https://dlca.logcluster.org/display/public/DLCA/LCA+Homepage
Data portals and e-platforms	UK Foreign, Commonwealth and Development Office Dev Tracker Find a Port 4AllPorts	https://devtracker.fcdo.gov.uk/regions/298/ https://www.findaport.com/ http://www.4allports.com/
	Swiss Arab Entrepreneurs Platform	https://www.saentrepreneurs.ch/
	Maritime Services Directory	https://ports.co.za/directory_front.php
	Marine Traffic	https://www.marinetraffic.com/en
	SKYbrary Electronic Repository	https://www.skybrary.aero
	Seaports Information for The Maritime Community	https://seaport.homestead.com/
	Construction Review Online	https://constructionreviewonline.com
	Market Research	https://www.marketresearch.com
	Airport Technology	https://www.airport-technology.com
	Ship Technology	https://www.ship-technology.com
	Port Technology	https://www.porttechnology.org
	Railway Technology	https://www.railway-technology.com

	Hydrocarbons Technology	https://www.hydrocarbons-technology.com/projects/
	Road Traffic Technology	https://www.roadtraffic-technology.com/
	European African Infrastructure Trust Fund Information Centre	https://www.eu-africa-infrastructure-tf.net/infocentre/index.htm
	Railway Pro	https://www.railwaypro.com/wp/
	Dangerous Roads	https://www.dangerousroads.org/africa/
	CW Group Research	https://www.cwgrp.com/research/
	Cameroon Trade Hub	https://www.cameroontradehub.cm/documentation/bibliotheque/1/en
	Economic Community of West African States	https://www.ecowas.int
	East African Community	https://www.eac.int
Regional economic communities	African Union Development Agency NEPAD African Union European Commission	https://www.nepad.org/project https://au.int/en/resources/filter https://www.eeas.europa.eu/eeas/publications_en
	Union for the Mediterranean	https://ufmsecretariat.org/info-center/
	Southern African Development Community	https://www.sadc.int/documents-publications/

Multilateral development banks	African Development Bank Data Portal African Development Banks African Water Facility European Investment Bank World Bank Africa Infrastructure National Database World Bank International Finance Corporation World Bank Private Participation in Infrastructure Database Islamic Development Bank International Monetary Fund	https://projectsportal.afdb.org/dataportal/VProject/list https://www.africanwaterfacility.org/ https://www.eib.org/en/publications/index.htm https://databank.worldbank.org/source/africa-infrastructure:-national-data https://www.ifc.org/ https://ppi.worldbank.org/en/ppi https://www.isdb.org https://www.elibrary.imf.org
Corridor authorities	East African Crude Oil Pipeline Lamu Port Corridor Development Authority Maputo Corridor Logistics Initiative Trans African Concessions Cross Border Road Transport Agency Northern Corridor and Transport Coordination Authority North South Corridor Africa Tripoli Windhoek Trans African Highway Trans Africa Pipeline Central Corridor Transit Facilitation Agency Walvis Bay Corridor Group Standard Gauge Railway Uganda Southern Agricultural Growth Corridor of Tanzania	https://eacop.com https://www.lapsset.go.ke/ https://www.mcli.co.za/maputo-development-corridor/ https://tracn4.co.za/ https://www.cbrta.co.za/ http://www.ttcanc.org/page.php?id=26 http://en.reingex.com/North-South-Corridor-Africa.shtml http://en.reingex.com/Tripoli-Windhoek-Corridor.shtml https://transafricapipeline.org/ https://centralcorridor-ttfa.org http://www.wbcg.com.na/ https://www.sgr.go.ug/ https://sagcot.co.tz/
	Ghana Ports and Harbours Authority Beira Corridor	https://ghanaports.gov.gh https://beiracorridor.org/

National authorities	Berbera Port Authority Port Cotonou Togo Port Authority Abu Dhabi Ports Kenya Ports Authority Kenya Railways Corporation NamPort Authority Government of Malawi Roads Authority Cameroon Ministry of Economy, Planning and Regional Development Kenyan Ministry of Lands and Physical Planning South African Limpopo Economic Development Agency Tanzania Zambia Mafuta (TAZAMA) Pipelines Limited Tanzania Ports Authority City of Cape Town Invest Cape Town South Africa Parliamentary Monitoring Group Republic of Guinea Ministry of Mines and Geology	https://www.berberaseaport.net http://www.portcotonou.com https://www.togo-port.net/ https://www.adports.ae/ https://www.kpa.co.ke/ http://krc.co.ke/ https://www.namport.com.na/ https://www.ra.org.mw/ https://www.minepat.gov.cm/index.php?lang=en https://www.landportal.org/organization/ministry-lands-and-physical-planning https://www.lieda.co.za/Wordpress/ https://projectsportal.afdb.org/dataportal/VProject/show/P-ZM-DE0-001 https://www.ports.go.tz/ https://www.investcapetown.com/ https://pmg.org.za/ https://mines.gov.gn/en/priorities/infrastructure/
International organisations	Japanese International Cooperation Agency Japanese Embassy in Eritrea Japanese Ministry of Food and Agriculture United States Agency for International Development United States International Trade Administration United States Embassy and Consulate in Nigeria Chinese Embassy in Tanzania Netherlands Ministry of Foreign Affairs Agence Française de Développement German Cooperation Agency	https://openjicareport.jica.go.jp http://www.eritreaembassy-japan.org/ https://www.mofa.go.jp/region/africa/ https://www.usaid.gov/reports-and-data https://www.trade.gov/trade-data-analysis https://ng.usembassy.gov/ http://tz.china-embassy.org/eng/ https://www.rvo.nl/ https://www.afd.fr/en https://www.giz.de/en/html/index.html

	Organisation for Economic Commission for Development United Nations Conference on Trade and Development World Food Programme Geonode Global Airports	https://www.oecd.org/ https://unctad.org/publications https://geonode.wfp.org
Regional associations	Southern African Railways Association Africa Ports Trademark East Africa Centre for Aviation Macau Hub Science Promotion Nile Equatorial Lakes Subsidiary Action Program	https://sararail.org https://africaports.co.za https://www.trademarkea.com/publications/ https://centreforaviation.com/data https://macauhub.com.mo https://nelsap.nilebasin.org/index.php/en/
Journals	Geographical Review Economic Geography African Studies Quarterly International Journal of Applied Engineering Research	https://onlinelibrary.wiley.com/journal/19310846 https://academic.oup.com/joeg https://asq.africa.ufl.edu/ https://www.ripublication.com/ijaer.htm
Public private partnerships	Borderless Alliance West Africa EKN The Public Private Infrastructure Advisory Facility	https://www.borderlesswa.com https://www.ekn.se/en/ https://ppiaf.org/

Research groups	International Growth Centre Development Corridors Partnership Macleki Oxford Institute for Energy Studies	https://www.theigc.org https://developmentcorridors.org https://macleki.org https://www.oxfordenergy.org/library/
INGOs	Fahamu Networks for Social Justice Global Security Bank Track Trade Law Centre (tralec)	http://www.fahamu.org/about-us/ https://www.globalsecurity.org https://www.banktrack.org https://www.tralac.org/about.html
Private companies	Vallis Maputo Port Development Company INON Africa Bollore Transport and Logistics Saana Consulting COWI Artelia Passion and Solutions Inras Lackner Searates EGIS Engineering Services Group Proger company Limak Group of Companies Geoscience Ireland Nathan Incorporated Consulting AgDevCo Aurecon Group Novonor	https://vallis-group.com/research-2/ https://www.portmaputo.com https://www.inonafrica.com/ https://www.bollore-transport-logistics.com/en/ http://www.saana.com https://www.cowi.com/solutions/infrastructure/ https://www.arteliagroup.com/en/ https://www.inros-lackner.de/en/projects https://www.searates.com https://www.egis-group.com http://www.proger.it/en/we/ http://www.limak.com.tr/ https://www.geoscience.ie/ https://www.nathaninc.com/ https://www.agdevco.com https://www.aurecongroup.com/projects/ https://www.novonor.com.br/en/home
International media houses	The Economist Intelligence Unit Reuters Financial Times Rail Journal Railway Gazette International International Railway Journal Global Construction Review African Mining Market Business Daily Africa World Highways Infrastructure News	http://www.eiu.com/default.aspx https://www.reuters.com https://www.ft.com/ https://www.railjournal.com/africa/ https://www.railwaygazette.com/ https://www.railjournal.com/africa http://www.globalconstructionreview.com https://africanminingmarket.com/ https://www.businessdailyafrica.com/ https://www.worldhighways.com/ https://infrastructurenews.co.za/
	The New Humanitarian	https://www.thenewhumanitarian.org/
	ThinkGeoEnergy	https://www.thinkgeoenergy.com/
	The North African Post	https://northafricapost.com/
	How we made it Africa	https://www.howwemadeitinafrica.com/
	The Exchange: Africas Investment Gateway	https://theexchange.africa/
	All Africa	https://allafrica.com/
	Journal of Commerce Online	https://www.joc.com/
	Duta	https://indianexpress.com/about/duta/
	Reliefweb	https://reliefweb.int
	China Africa	http://www.chinafrica.cn
	Simple Flying	https://simpleflying.com/category/africa/
	Tefnanet News	https://tesfanews.net/
	Engineering news	https://www.engineeringnews.co.za
	Devex	https://www.devex.com/
	African Law and Business	https://iclg.com/alb
	Jeune Afrique BTP Infrastructures	https://www.jeuneafrique.com/rubriques/btp-infrastructures/

	Pana Press	https://www.panapress.com/actualite-lang2.html
	Daily Southern and East African Tourism Update	https://www.tourismupdate.co.za
	The Africa Report	https://www.theafricareport.com/
National media houses	Club of Mozambique	https://clubofmozambique.com/
	Daily Monitor Uganda	https://www.monitor.co.ug/
	The Independent Uganda	https://www.independent.co.ug/
	Construction Kenya	https://www.constructionkenya.com/
	Kenya Engineer	https://www.kenyaengineer.co.ke/
	The Star Kenya	https://www.the-star.co.ke
	IOL	https://www.iol.co.za/business-report/international
	Krugersdorp News	https://krugersdorpnews.co.za
	Cameroon Business	https://www.cameroonbusinesstoday.cm/
	CGTN	https://www.cgtn.com
	Xinhuanet News	https://www.borderlesswa.com
	The East African	https://www.theeastafrican.co.ke
	China Daily	http://global.chinadaily.com.cn
	Lusaka Times	https://www.lusakatimes.com
	Business in Cameroon	https://www.businessincameroon.com
	Cameroon Tribune	https://www.cameroon-tribune.cm
	The New Times Rwanda	http://www.newtimes.co.rw
	Tanzania Invest	https://www.tanzaniainvest.com/
	Brana Press Ethiopia	http://www.branapress.com
	Ethiopia Semoegna	https://semonegna.com/
	Agencia Angola Press	https://www.angop.ao
	Anadolu Agency	https://www.aa.com.tr/en/africa/
Other datasets	Laurance et al. (2015)	https://www.sciencedirect.com/science/article/pii/S0960982215013093

Supplementary Table 2. Data standard.

Field	Type	Description	Accepted values	Example
Project code	Code	The code comprises a combination of the corridor name, comprising three initials and four digits. Use consecutive numbers as new projects within the corridor are added.	letters for code numbers for project number	SGR0001
Project name	Text	Commonly used name to refer to a project within a development corridor. Roads and highways are used interchangeably by applying the term which was used most frequently in documentation.	Project name (100 characters)	Mombasa-Nairobi Standard Gauge Railway Project
Corridor name	Text	Specific name of the development corridor often formed by multiple projects. For some corridors which have the same name in two contexts, we added a contextual description (e.g., the North South Corridor in Southern and Eastern Africa, and the North South Corridor in Egypt). Where there was not consensus of the title of corridor, multiple names are given, or we use the main cities of origin and destination. If there was an alternative name for the corridor, this was included in the description.	Development corridor name (Max 100 characters)	Standard Gauge Railway
Infrastructure/development type	Text	Infrastructure types included roads, passenger and freight railways, oil and water pipelines, resort cities and industrial parks. We included electricity transmission lines when multiple counties have partnered to develop the infrastructure to enhance trade. Waterways included all forms of transport of goods and people including catamarans and large ships. Wet ports were included that cater for large shipping vessels, and dryland inland ports. International airports were included which are written into development strategic planning or policy documents, are international hubs which allow for the inflow and outflow of goods and services in the development corridors and improve trade and communications or are physically connected to development corridors in our database. We excluded dams, domestic electricity transmission lines, small ferry links, freshwater inland	Airport Dry port Electricity transmission Freight railway Industrial parks Passenger and freight railway Pipeline (oil) Pipeline (water) Port Resort city Road Waterway Other	Passenger and freight railway

		ports, local airport, agricultural corridors, bridges (unless part of roads in a development corridor), and other forms of infrastructure not connected to development corridors		
Status	Status	We assessed the five stages of corridor development. Planning included a new corridor that is still at the conceptual stages and yet to be implemented. In progress refers to a corridor that is being constructed. Operational means the main elements of the corridor are partially (c. 75%) or fully completed in a way that allows activity. Upgrading refers to an existing corridor whose infrastructure is being enhanced or significantly updated (e.g., expanding a road from single to a dual carriage). This only applied for major rehabilitations. On hold refers to a corridor that has stopped or temporarily stalled. Where sections of a project within a corridor had multiple stages, such as a road that was upgraded in one section, while it was operational in another section, we selected the status on the most advanced stage. We acknowledge this data would be highly temporally bound and users of the database should review the latest update of the database.	In progress On hold Operational Planned Upgrade No information (NI)	Operational
Country	Text	Country(s) where the project of the development corridor is located. Different values are separated by ";" and countries should be listed alphabetically.	Country name as per ISO 3166 standard (https://www.iso.org/iso-3166-country-codes.html) No information	Kenya; Tanzania
Region or province	Text	Region or province where the corridor is located. Different values are separated by ";". As we calculated this in ArcGIS 2.5.2, where there was no spatial information, or the project is planned, we state "NI".	Region of province name No information	Kajiado; Kwale; Machakos; Makueni; Mombasa; Nairobi; Taita Taveta

Description	Text	Short narrative of main objectives, functions, and features of the project or corridor.	A short summary of the project details (254 characters) No information (NI)	The Mombasa–Nairobi Standard Gauge Railway connects the port city of Mombasa to Kenya's capital city Nairobi.
Launch year	Year	Launch year refers to the completion and inauguration of the project. If there were multiple dates in terms of the upgrades of a project (e.g., a railway constructed in the 1900s and then upgraded in 2012), we used the original construction date. If the project experienced a significant upgrade, then the year of renovation was indicated, and the construction year (if available) was included in the comments. Where we included a future year, we acknowledge that this is the expected date recorded but there may be potential delays. If the status of a corridor was an upgrade, then the launch year refers to when the upgrade started. NI was used if no information could be found. NA was used when planned projects had not yet been launched.	Numeric value No information (NI) Not Applicable (NA)	2007
USD amount (million) Minimum	Number	Project budget (minimum) in USD	Numeric value No information (NI)	3000
USD amount (million) Maximum	Number	Project budget (maximum) in USD	Numeric value No information (NI)	2200
Amount description	Number	Description of what the minimum and maximum amount refer to. It could be the budget for a whole corridor, a corridor project, or a section of the project.	Cost of upgrade Partial project cost Total project cost	Partial project cost

Distance (km) Minimum	Number	Linear distance of corridor element in kilometres as reported in the sources reviewed (if applicable).	Numeric value No information (NI) Not Applicable (NA)	445
Distance (km) Maximum	Number	Linear distance of corridor element in kilometres as reported in the sources reviewed (if applicable).	Numeric value No information (NI) Not Applicable (NA)	550
GIS distance	Km	Linear distance calculated in ArcGIS.	Numerical value	1000
Area (km^2)	Text	Total area of corridor element in square kilometres as reported in the sources reviewed. This applies to all infrastructure except for ports and airports which are represented as points and polygons based on the available data.	Numeric value No information (NI)	220
Supplier or recipient of goods or services	Text	Specifies whether the project is a supplier or recipient of goods or services.	Predominantly net supplier Predominantly net recipient Both No information (NI)	Predominantly net supplier
Key beneficiaries	Text	Beneficiaries of the corridor. Values are separated by different values using ";".	Beneficiaries of the corridor No information	Farmers; private companies
Commodities traded or transported	Text	Key commodities traded by this project. Values are separated by different values using ";".	Commodities traded, exchanged, or transported within the corridor No information (NI)	Sugar, crude petroleum oil
Name of donors or financiers	Text	Name of entity or entities funding the amount specified in the amount field. Values for different donors are separated by “;".	Name of the bank	African Development Bank; World Bank
Amount funded (USD million) per donor type	USD	Funded amount for each donor in USD million. Values for different donors are separated by ";".	Numeric value No information (NI)	60%;40%

Type of major donors or financiers	Text	Type of entity or entities funding each amount. Separate by different values using “;". International development agencies are defined as international agencies that work to provide financial, technical, or other support to low- and middle-income countries. National development agencies are defined as national government agencies that work to provide for low- and middle-income countries. Multilateral banks are defined as financial institutions that are characterised by two or more countries working together to provide financial and technical assistance for development in low- and middle-income countries. Finance is allocated through low-interest concessional loans or grants. National governments are defined as institutions and leaders that represent a political authority with members from more than one political party that controls a nation. Private companies are defined as businesses that are a segment of a national economy that are owned, managed, and controlled by individuals and organisations seeking to generate profit. Public-private partnerships are defined as cooperative arrangements between two or more public and private sector actors that work together to complete a project and/or to provide services to the public. Regional Development Banks are defined as financial institutions composed of memberships from several countries in a specified region that provide financial and technical assistance for development in low- and middle-income countries. Regional Economic Communities are defined as regional groupings of African states, formed with the purpose to facilitate regional economic integration between members of the individual regions and through the African Economic Community.	International development agency Multilateral banks National development agency National government Private companies Public private partnership Regional development bank Regional economic community No information (NI)	Regional Development bank; Multilateral banks

Supplementary Table 3. List of the 79 development corridors included in the African Development Corridors Database.

No.	Project code	Corridor name	Infrastructure type	Status	Country
1	AAC0001	Assab-Addis Ababa Corridor	Road and port	Operational	Eritrea; Ethiopia
2	ABC0001	Abidjan-Bamako Corridor	Road	Upgrade	Côte d'Ivoire; Mali
3	ADC0001	Addis-Djibouti Corridor (or Ethiopia-Djibouti Corridor)	Passenger and freight railway; Port; Road; Airport	Upgrade; Operational	Djibouti; Ethiopia
4	ALC0001	Abidjan-Lagos Corridor	Road	In progress	Benin; Côte d'Ivoire; Ghana; Nigeria; Togo
5	AOC0001	Abidjan-Ouagadougou Corridor	Road; Passenger and freight railway	Operational; Upgrade	Burkina Faso; Côte d'Ivoire
6	BAA0001	Berbera-Addis Ababa Corridor (or Berbera Corridor)	Road; Port	Operational	Ethiopia; Somaliland
7	BCC0001	Bas Congo Corridor	Road	Operational	Democratic Republic of Congo
8	BLC0001	Beira Lobito Corridor (or Lobito Corridor)	Pipeline (oil); Port; Passenger and freight railway; Industrial parks; Airport	In progress; Operational	Angola; Democratic Republic of Congo; Mozambique; Zambia; Zimbabwe;
9	BSC0001	Bamako – San Pedro Corridor (or San Pedro-Bamako Corridor)	Road	Operational	Côte d'Ivoire; Mali
10	BVH0001	Beitbridge-Victoria Falls-Harare Corridor	Road	In progress	Zimbabwe

11	BYC0001	Brazzaville-Yaounde Corridor (Brazzaville-Douala Corridor)	Road, Port	In progress; Operational; Upgrade	Cameroon; Republic of the Congo
12	CCO0001	Chad-Cameroon Oil Corridor	Pipeline (oil)	Operational	Cameroon; Chad
13	CDC0001	Central Development Corridor	Road; Passenger and freight railway; Port	Operational; In progress	Burundi; Democratic Republic of Congo; Rwanda; Tanzania; Uganda
14	CDH0001	Cairo-Dakar Corridor	Port	Operational	Mauritania
15	CGC0001	Central Growth Corridor Guinea	Passenger and freight railway	In progress; Operational	Benin; Guinea; Niger
16	CNC0001	Cotonou-Niamey Corridor	Port; Road	Operational; UPgrade	Benin
17	DAC0001	Dakar – Abidjan Corridor	Road	Planned	Côte d'Ivoire; Gambia; Guinea; Guinea-Bissau; Liberia; Senegal
18	DBC0001	Douala-Bangui Corridor	Road	Operational	Cameroon; Central African Republic
19	DBO0001	Dakar-Bamako-Ouagadougou – Niamey-N'Djamena Corridor	Port; Freight railway	Operational; In progress	Mali; Senegal
20	DDC0001	Dar es Salaam Development Corridor (or Uhuru Development Corridor)	Road; Passenger and freight railway; Pipeline (oil); Airport	Operational; Planned	Tanzania; Uganda; Zambia
21	DLC0001	Dakar-Lagos Corridor	Port	Operational	Côte d'Ivoire; Ghana; Guinea; Sierra Leone

22	DNC0001	Douala-N'djamena Corridor	Road; Passenger and freight railway	Operational; Planned	Cameroon; Chad
23	KCB0001	Kribi-Campo-Bata Corridor	Road; Port	In progress	Cameroon; Equatorial Guinea
24	KGR0001	Kigoma-Gitega Corridor	Passenger and freight railway	In progress	Burundi; Tanzania
25	KJA0001	Kampala-Juba-Addis Ababa-Djibouti Corridor	Road	Planned	Djibouti; Ethiopia; South Sudan; Uganda
26	KMI0001	King Mswati III International Corridor	Port	Operational	Eswatini
27	KMN0001	Kribi-Mbalam-Nabeba Corridor	Freight railway	In progress	Cameroon; Republic of the Congo
28	LAP0001	Lamu Port South Sudan Ethiopia Transport Corridor (LAPSSET)	Port; Road; Pipeline (oil); Passenger and freight railway; Airport; Resort city; Road	In progress; Operational ; Planned	Ethiopia; Kenya; South Sudan
29	LBP0001	Libreville-Brazzaville-Pointe Noire Corridor (or Pointe Noire – Cabinda Corridor)	Road; Port	Upgrade; Operational	Gabon; Republic of the Congo
30	LCC0001	Cabinda Link	Road; Port	Operational	Angola; Democratic Republic of Congo
31	LIC0001	Lichinga Corridor	Road	Upgrade	Mozambique
32	LKJ0002	Lagos-Kano-Jibiya (LAKAJI) Agricultural Development Corridor	Road; Airport	Operational	Nigeria
33	LMP0001	Limpopo Corridor	Road	Planned	Mozambique

34	LOC0001	Lomé-Ouagadougou Corridor	Passenger and freight railway; Road; Port	In progress; Upgrade; Operational	Burkina Faso; Togo
35	LTT0001	Lake Tanganyika Transport Corridor	Waterway; Port	Operational	Burundi; Democratic Republic of Congo; Tanzania; Zambia
36	MAA0001	Massawa Corridor	Passenger and freight railway; Port	Planned; Operational	Eritrea; Ethiopia
37	MAC0001	Malange Corridor	Road	Operational	Angola; Democratic Republic of Congo
38	MDC0001	Maputo Development Corridor	Passenger and freight railway; Port; Road; Airport	Operational	Botswana; Eswatini; Mozambique; Namibia; South Africa
39	MDT0001	Maseru-Durban Transport Corridor	Road	Operational	Lesotho; South Africa
40	MDU0001	Manzini – Durban Corridor	Road	Operational	Eswatini; South Africa
41	MMC0001	South Madagascar Marine Corridor	Waterway	In progress	Madagascar
42	MTC0001	Mtwara Development Corridor	Port; Road; Freight railway; Waterway	In progress	Malawi; Tanzania
43	NAC0001	Nacala Corridor	Road; Passenger and freight railway; Port; Airport; Waterway	Operational; Planned; Operational	Malawi; Mozambique; Zambia
44	NBC0001	Namibe Corridor	Road	Operational	Angola
45	NEL0001	Nile Equatorial Lakes Subsidiary Action Program (NELSAP) Electricity Line	Electricity transmission	In progress	Burundi; Kenya; Tanzania; Democratic Republic of Congo; Rwanda; Uganda
46	NGC0001	Northern Growth Corridor Guinea	Freight railway; Port	Upgrade; Operational	Guinea
47	NIB0001	The Nimba-Buchanan Corridor	Freight railway	Operational	Guinea
48	NRC0001	Northern Corridor (or Trans Congo Corridor)	Road; Port; Freight railway; Airport; Dry port; Road	Operational; In progress	Burundi; Central Africa Republic; Democratic Republic of Congo; Kenya; Rwanda; South Sudan; Uganda

49	NSC0001	North-South Corridor	Passenger and freight railway; Pipeline (water); Electricity transmission; Airport; Port; Road; Passenger and freight railway	Planned	Botswana; Burundi; Democratic Republic of Congo; Egypt; Ethiopia; Kenya; Malawi; Mozambique; Rwanda; Sudan; South Africa; South Sudan; Tanzania; Zambia; Zimbabwe
50	OBN0001	Ouesso-Bangui-N'djamena Corridor	Road	In progress	Central African Republic; Chad; Republic of the Congo
51	PDA0001	Praia-Dakar-Abidjan Corridor	Waterway	Operational	Cabo Verde; Senegal
52	PNC0001	Pointe Noire – Cabinda Corridor (or Libreville-Brazzaville-Pointe Noire Corridor)	Road; Passenger and freight railway; Port; Airport	Operational	Angola; Republic of the Congo
53	POM0001	Port of Mogadishu	Port	Operational	Somalia
54	POT0001	Port of Toamasina	Port	Operational	Madagascar
55	POV0001	Port of Victoria	Port	Operational	Seychelles
56	PSC0001	Port Sudan Corridor	Port; Road	Operational	Sudan; South Sudan

57	SGC000 1	Southern Growth Corridor Guinea	Freight railway	In progress, Planned	Guinea
58	SGR000 1	Standard Gauge Railway Corridor	Passenger and freight railway; Dry port; Industrial parks	Operational ; On hold; Planned	Kenya; Uganda; Rwanda; South Sudan
59	SNC000 1	Sirari North – South Corridor	Road	Upgrade	Kenya
60	TAH00 01	Trans-African Highway 1 (or Cairo-Dakar Corridor; or Trans-Magreb Highway)	Road	In progress	Egypt; Libya; Tunisia; Algeria; Morocco; Mauritania; Senegal
61	TAH00 02	Trans-African Highway 2 (or Trans-Sahara Highway Corridor)	Road	In progress	Algeria; Tunisia; Mali; Niger; Chad; Nigeria
62	TAH00 03	Trans-African Highway 3	Road	Operational	Libya; Chad; Niger; Cameroon; Central African Republic; Republic of Congo; Democratic Republic of Congo; Angola; Namibia; South Africa
63	TAH00 04	Trans-African Highway 4	Road	Operational	Egypt; Kenya; Sudan; Ethiopia; Zimbabwe; Botswana
64	TAH00 05	Trans-African Highway 5 (or Dakar-Bamako-Ouagadougou – Niamey-N'Djamena Corridor)	Road	Operational	Mali; Senegal; Niger; Burkina Faso; Chad
65	TAH00 06	Trans-African Highway 6 (Djibouti-N'Djamena Corridor)	Road	In progress	Djibouti; Ethiopia; Sudan; Chad
66	TAH00 07	Trans-African Highway 7 (or Dakar Lagos Highway or Trans Coastal West African Highway)	Road	Operational	Nigeria; Benin; Togo; Ghana; Côte d'Ivoire; Liberia; Sierra Leone; Guinea; Guinea-Bissau; Senegal; The Gambia
67	TAH00 08	Trans-African Highway 8	Road	Operational	Nigeria; Cameroon; Central African Republic; Democratic Republic of the

					Congo; Uganda; Kenya
68	TAH0009	Trans-African Highway 9 (or Beira Lobito Corridor; Lobito Corridor)	Road	Upgrade	Mozambique; Zimbabwe; Zambia; Malawi; Democratic Republic of Congo
69	TAP0001	Trans African Pipeline Project	Pipeline (water)	Planned	Mauritania; Senegal; Eritrea; Ethiopia; Burkina Faso; Niger; Chad; Sudan; Djibouti; Nigeria; Mali
70	TCC0001	Trans-Caprivi Corridor (TCC) (or Walvis Bay-Ndola-Lumbumbashi Development Corridor (WBNLDC))	Road; Passenger and freight railway; Port	Operational	Democratic Republic of the Congo; Namibia; Zambia; Zimbabwe
71	TCU0001	Trans-Cunene Corridor (TCuC)	Road	Operational	Namibia; Angola
72	TDC0001	Tanga Development Corridor	Passenger and freight railway; Port; Road; Airport	Operational	Tanzania
73	TGC0001	Trans-Gambia Corridor	Road	Upgrade	Gambia
74	TKC0001	Trans-Kalahari Corridor (TKC)	Road; Passenger and freight railway	Operational; Planned	Namibia; Botswana; South Africa
75	TMC0001	Trans-Maghreb Corridor	Passenger and freight railway; Road	In progress; Operational	Morocco; Algeria; Tunisia; Libya
76	TOC0001	Trans-Oranje Corridor	Road; Passenger and freight railway; Port	Operational; Upgrade	Namibia; South Africa
77	TUC0001	Tema-Ouagadougou Corridor	Road; Passenger and freight railway	Operational	Burkina Faso; Ghana; Mali; Niger
78	WAT0001	West Africa Power Transmission Corridor	Electricity transmission	Operational	Ghana; Guinea; Guinea Bissau; Gambia; Sierra Leone; Liberia; Côte d'Ivoire
79	ZMR0001	Zambia-Malawi-Mozambique Railway Corridor	Passenger and freight railway	Operational	Zambia; Malawi

Appendix 3 Chapter 4 Supporting information

1. Modelling infrastructure impacts in relation to distance and slope

1.1. Distance

Understanding the spatial extent or area of influence of the potential impacts from development corridor projects is a fundamental piece to estimate the reach of those impacts across the landscapes. Classic "road-effect zone" work around major highways documents multi-process footprints on the order of several hundred meters (Forman and Deblinger 2000; Forman and Alexander 1998), and Europe-based field studies show traffic-dependent disturbance distances for breeding birds ranging from tens of meters to ~1.7 km (Reijnen et al. 1996). Later, a global meta-analysis found that mean bird and mammal abundances are depressed up to ~1 km and ~5 km from infrastructure, respectively (Benítez-López et al. 2010). At larger planning scales, corridor assessments often adopt broader analysis windows: for example, (Laurance et al. 2015b) mapped environmental values within a 50-km-wide band around each of 33 African development corridors to screen potential intersections with high-value areas; this band is a planning envelope rather than an assumed ecological impact distance. In the Belt and Road context, (Ng et al. 2020) explicitly evaluated potential impacts at multiple distance thresholds (1, 5, 25, and 50 km), again treating the larger distances as assessment extents for cumulative exposure, not as single-mechanism effect radii. (Hughes 2019) likewise used a 50 km buffered region around proposed routes to quantify forest loss, showing that 32% of all deforestation inside the 50 km corridor zone occurred within 14 km of roads. Therefore, we conclude ecological impacts associated with linear infrastructure decline with distance from the asset, but reported distances vary with taxon, mechanism, habitat, landscape context, and purpose of the analysis.

Here, we use an exponential decay function to mathematically represent that impacts from infrastructure are most intense in proximity to the infrastructure and decline with increasing distance. The Human Footprint metric (Venter et al. 2016) which is a globally standardized measure of the cumulative human footprint on the terrestrial environment uses a similar function and considers the maximum distance 15 kilometres . Building from this, we tested parameters for the decay function at difference distances from the sources and rates of decay to determine which of these parameters were more appropriate for our analyses. Based on the results, we set a maximum influence distance of 15 km and parameterized an exponential decay such that influence falls to ~1% at this limit. This is consistent with reported influence ranges for road-related impacts on biodiversity in previous literature. It ensures that the model envelope spans the upper tail of distances reported for many taxa (≤ ~5 km for mammals; ≤ ~1–3.5 km for many birds), while remaining well within the broader 50-km planning extents used in corridor-level screening studies. The exponential transform allocates most influence on the zone near the source and rapidly decreases contributions at larger distances.

Decay Function and Parameters

Here we evaluate exponential decay functions to select an appropriate parameterization that approximates to real-world ecological responses to impacts.

The general form of an exponential decay function is:

$$I(d) = \exp(-k * d)$$

where I(d) is the relative impact at distance d, and k is the decay constant. Parametrisation of k is critical, as it defines the rate of decline and the maximum effective influence distance.

The decay function applied here is a scaled exponential decay expressed as:

$$f(d) = [\exp(-k * d) - \exp(-k * D)] / [1 - \exp(-k * D)]$$

Where:

- d: Distance from the source (in meters)

- D: Maximum distance of influence (cutoff)

- k: Decay constant, derived from a specified impact value at D (ε)

- ε: Impact strength at distance D

This function ensures a value of 1 or maximum impact at source up to a negligible impact or minimum residual impact at distance D and cut off values of ε.

Values for K are calculated as:

k=−ln(ε)/Dk

Evaluation of decay scenarios

To evaluate how different decay configurations reflect ecological intuition and literature-reported ranges, we modelled decay curves using Maximum distances (D): 15 km, 25 km, and 50 km, and cut off values (ε): 0.1, 0.01, 0.001 (Figure 1).

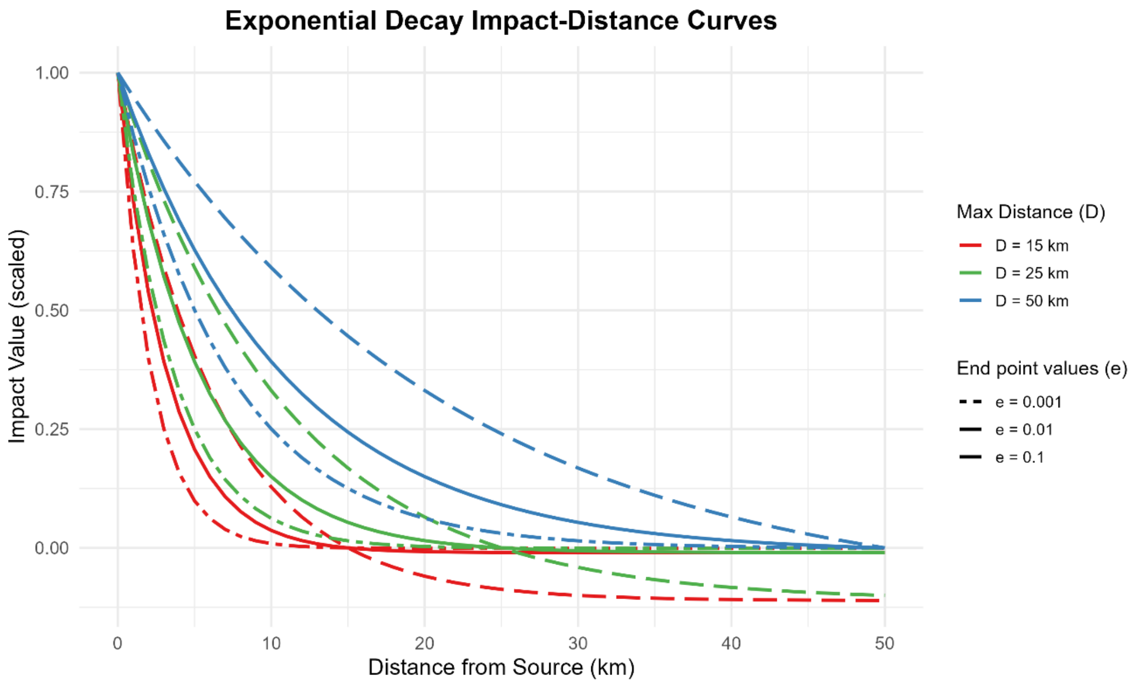

Figure 1 Result of modelling distance decay scenarios

Key observations after running the scenarios include:

- Smaller ε values (e.g., 0.001) lead to steeper declines, concentrating effects close to the source.
- An ε = 0.01 produces ~90% impact reduction within 25 km, which matches observed ecological response ranges from species abundance, forest fragmentation, and edge effect studies.
- 50 km cutoffs show widespread and minimal gradient; while valid in some contexts (e.g., large mammal movement or hunting reach), they are less commonly used in published studies.

Conclusions

We select different ε values to obtain a balanced representation of near-field steep impact and reduced long-range influence and test D = 15 km, 25 km, and 50 km (Table 1) to evaluate sensitivity and align with varied empirical ranges (e.g., 5–20 km in tropical forests; up to 30–50 km for species avoidance or deforestation spillover zones).

Table 1 Basic sensitivity analyses parameters

Distance (D)	**ε value**	**K value**
15,000 metres	0.01	0.000307011345732539
25,000 metres	0.01	0.000184206807439523
50,000 metres	0.001	0.000138155105579642

This modelling approach offers a reproducible and transparent method to estimate spatial infrastructure influence. Using a scaled exponential decay that: i) Captures intensity-distance trade-off documented in empirical studies, ii) allows control via ε and D to match observed biodiversity response curves, iii) Supports scenario testing, and cumulative impact analysis.

1.2. Slope

Potential impacts from infrastructure will not depend on distance to source solely. Slope, for example, is a key factor that influences the probability of impact. Slope increases travel and construction costs, and limits human access. To take this into account we modelled least slope-adjusted cost distance paths from the source to a chosen maximum distance and applied the decay function to the result.

We consider slopes >20° as prohibitive for development corridors and masked them out as obstacles for development in our cost distance function. The latter is a modelling assumption—not a universal threshold—but is consistent with evidence that road construction and human activities are greatly limited at slopes steeper than 16 degrees (Chen and Xu 2023; Wu et al. 2023; Weiss et al. 2018).

Moreover, the 87 projects across Africa go through mean slopes between 4.29 and 0.33, with a median of 2.94-0.28 and SD of 3.76-0.23. As a result, development corridor projects predominantly traverse areas with gentle slopes with some variations but typically well below the 20-degree threshold we have established.

2.Scripts

The scripts developed in this thesis were conceptualised and written by the author but debugged through Artificial Intelligence tools. Specifically, I used ChatGPT (Open AI) 5.2 and earlier 2025 versions (OpenAI 2025) to review the scripts, learn better coding, find mistakes, and more efficient ways of obtaining the results. All scripts used in Chapter 4 are publicly available in my GitHub repository here:

https://github.com/DiegoJuBi/Diego_Juffe_thesis2025

Parameterisation and Functions used

Parameterisation choices include:

- Maximum influence distance = 15 km.
- Slope threshold: 20° for masking impassable terrain.
- Decay constant k: Derived from the requirement that influence falls to 1% at max distance.
- Spatial resolution: 250 m in Africa-appropriate equal-area projection.

Google Earth Engine functions used include:

- `ee.Terrain.slope` for slope derivation.
- `cumulativeCost` for least-cost distance computation. Used to measure extent and intensity of potential impacts due to development corridor projects. The cumulative cost mapping function computes a cost map where every pixel contains the total cost of the lowest cost path to the nearest source location. We parametrised this function to measure extent and intensity of potential impacts from a proposed infrastructure. First, we set the source location as a corridor project line. We use slope as the cost surface assuming the more slope the more difficult for an impact to happen. Also, based on our assumptions, we mask out all raster cells that have a slope larger than 20 degrees where human development is unlikely to happen. Finally, we select 50 kilometres as the maximum distance to where the impact might spread. The cumulative cost function output is raster file output which cell values are dimensionless and range from 0 to the maximum cost from the source of impact. In our analysis, low-cost values correspond to areas near to the source and gentle slopes. Higher cost values will be obtained in places with higher slope and larger distance to the source.
- Map algebra operations for exponential decay transformation probabilistic combinations to obtain PII from ACD and EPs.
- `reduceRegions` for zonal statistics.

3. Sensitivity Analysis

To test the sensitivity of our approach, we explored how outputs change when key input parameters change. We ran the same script for different maximum propagation distances (including the associated parameter K, see SM1), different obstacle slopes, and different resolutions for LAP corridor only to assess the differences values obtained. However, we did not perform tests on the mathematical structure of the approach. Table 2 shows the results concluding our metric remains stable to parameter changes.

Table 2 Parametrisations to run sensitivity analysis

Run	Tag (suggested)	k_mode	maxDist_m	tail_e	slope_deg	work_scale_m	Purpose
1	baseline	tail_fixed	15000	0.01	20	250	Reference scenario
2	dist_25k	tail_fixed	25000	0.01	20	250	Distance effect (+)
3	dist_50k	tail_fixed	50000	0.01	20	250	Distance effect (++)
4	slope_10	tail_fixed	15000	0.01	10	250	Obstacle threshold looser
5	slope_30	tail_fixed	15000	0.01	30	250	Obstacle threshold stricter
6	res_100m	tail_fixed	15000	0.01	20	100	Resolution finer
7	res_500m	tail_fixed	15000	0.01	20	500	Resolution coarser

Results

Our results (Table 1) showed that national-level PII means are stable across a wide range of parameter settings. Changes in corridor reach (15–50 km) produced only small downward shifts in averages, while slope thresholds affected results mainly in steep countries (e.g. Rwanda, Lesotho, Burundi) and had negligible influence elsewhere. Resolution changes (150–500 m) altered values only marginally, with the 250 m baseline capturing a balance between local detail and computational efficiency. For most countries, variation across all scenarios was $<\pm 0.02$ around the baseline, confirming that the main spatial patterns are robust and not an artefact of specific parameter choices.

Table 3 Sensitivity Analyses results

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Geometric mean	Standard deviation	Median
Country	ACD_HM mean	ACD_HM mean	ACD_HM mean	ACD_HM mean	ACD_HM mean	ACD_HM mean	ACD_HM mean			
Algeria	0.44	0.43	0.42	0.45	0.44	0.44	0.45	0.44	0.01	0.44
Angola	0.36	0.36	0.37	0.37	0.36	0.36	0.36	0.37	0	0.36
Benin	0.44	0.42	0.41	0.44	0.44	0.44	0.44	0.44	0.01	0.44
Botswana	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0	0.36
Burkina Faso	0.45	0.46	0.46	0.45	0.45	0.45	0.45	0.46	0	0.45
Burundi	0.52	0.52	0.54	0.56	0.52	0.52	0.52	0.53	0.02	0.52
Cameroon	0.44	0.44	0.44	0.44	0.44	0.52	0.44	0.44	0	0.44
Central African Rep	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0	0.34
Chad	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0	0.34
Cote d'Ivoire	0.44	0.44	0.46	0.44	0.44	0.44	0.44	0.45	0.01	0.44

Dem Rep of the Congo	0.43	0.42	0.42	0.43	0.43	0.43	0.43	0.42	0	0.43
Djibouti	0.4	0.44	0.45	0.41	0.4	0.39	0.4	0.41	0.02	0.41
Egypt	0.46	0.48	0.46	0.46	0.46	0.46	0.46	0.46	0.01	0.46
Equatorial Guinea	0.38	0.4	0.36	0.38	0.38	0.38	0.38	0.38	0.01	0.38
Eritrea	0.33	0.34	0.33	0.33	0.33	0.33	0.33	0.33	0	0.33
Ethiopia	0.45	0.46	0.47	0.47	0.45	0.45	0.45	0.46	0.01	0.46
Gabon	0.36	0.35	0.33	0.36	0.36	0.36	0.36	0.35	0.01	0.36
Gambia, The	0.63	0.59	0.44	0.63	0.63	0.63	0.63	0.59	0.07	0.63
Ghana	0.49	0.49	0.5	0.5	0.49	0.49	0.49	0.49	0	0.49
Guinea	0.41	0.43	0.46	0.42	0.42	0.42	0.42	0.42	0.01	0.42
Guinea-Bissau	0.46	0.44	0.44	0.46	0.46	0.46	0.46	0.45	0.01	0.46
Kenya	0.46	0.47	0.49	0.46	0.46	0.46	0.46	0.46	0.01	0.46
Lesotho	0.55	0.51	0.45	0.57	0.55	0.55	0.55	0.53	0.04	0.55
Liberia	0.42	0.43	0.45	0.42	0.42	0.42	0.42	0.43	0.01	0.42

Libya	0.42	0.41	0.4	0.42	0.42	0.42	0.42	0.41	0.01	0.42
Malawi	0.51	0.51	0.53	0.52	0.51	0.51	0.51	0.51	0.01	0.51
Mali	0.39	0.39	0.4	0.4	0.39	0.39	0.4	0.39	0	0.39
Mauritania	0.35	0.35	0.34	0.35	0.35	0.35	0.35	0.35	0	0.35
Morocco	0.49	0.48	0.47	0.5	0.49	0.49	0.49	0.49	0.01	0.49
Mozambique	0.4	0.39	0.38	0.4	0.4	0.4	0.4	0.39	0.01	0.4
Namibia	0.42	0.42	0.44	0.42	0.42	0.42	0.42	0.42	0.01	0.42
Niger	0.36	0.35	0.36	0.36	0.36	0.36	0.36	0.35	0	0.36
Nigeria	0.49	0.48	0.47	0.49	0.49	0.49	0.49	0.49	0.01	0.49
Rep of the Congo	0.41	0.42	0.43	0.41	0.41	0.41	0.41	0.42	0.01	0.41
Rwanda	0.58	0.56	0.55	0.62	0.58	0.58	0.58	0.58	0.02	0.58
Senegal	0.51	0.52	0.53	0.51	0.51	0.51	0.51	0.51	0.01	0.51
Sierra Leone	0.44	0.44	0.45	0.44	0.44	0.44	0.44	0.44	0	0.44
Somalia	0.35	0.33	0.29	0.35	0.35	0.35	0.35	0.33	0.02	0.35

South Africa	0.42	0.42	0.43	0.43	0.42	0.42	0.42	0.42	0	0.42
South Sudan	0.3	0.29	0.29	0.3	0.3	0.3	0.3	0.3	0	0.3
Sudan	0.39	0.39	0.38	0.39	0.39	0.39	0.39	0.39	0	0.39
Swaziland	0.42	0.39	0.37	0.44	0.42	0.42	0.42	0.41	0.02	0.42
Tanzania	0.44	0.44	0.46	0.45	0.44	0.44	0.44	0.45	0.01	0.44
Togo	0.44	0.42	0.44	0.45	0.44	0.44	0.44	0.44	0.01	0.44
Tunisia	0.54	0.54	0.55	0.55	0.54	0.54	0.54	0.54	0	0.54
Uganda	0.52	0.53	0.57	0.52	0.52	0.52	0.52	0.53	0.02	0.52
Western Sahara	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0	0.37
Zambia	0.48	0.49	0.49	0.48	0.48	0.48	0.48	0.48	0.01	0.48
Zimbabwe	0.37	0.37	0.4	0.37	0.37	0.37	0.37	0.37	0.01	0.37

4. Full results

All results for Chapter 4 are available online in my GitHub repository: https://github.com/DiegoJuBi/Diego_Juffe_thesis2025

This includes the following files:

- **CH4_All_Africa_results:** All results from running the GEE script (see Section 2 in this Appendix).
- **CH4_LAPPSET_case_study:** The raw results used for the LAPPSSET case study presented in Chapter 4.
- **CH4_Sensitivity_Analysis:** all results from the sensitivity analysis (See Section 3 in this Appendix).

Appendix 4 Chapter 5 Supporting information

The supporting information for "Towards more sustainable and inclusive development corridors in Africa" (Juffe Bignoli et al. 2024) is available at: https://iopscience.iop.org/article/10.1088/2634-4505/ad7887#supplDataLink. All outputs are open access and can be found at the project´s resource hub at: https://developmentcorridors.org/outputs-new/